What can the EU learn from non-EU countries on its path to climate neutrality?

Deliverable 3.4

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Abstract

While the EU has set itself ambitious targets, there is a large implementation gap in many areas. Studying the successful implementation of climate policies in other countries may inform and improve EU policy-making and help address these implementation gaps. This assessment investigates several case studies from different countries and regions, spread across eight archetypes: electricity markets, innovation, phase-out of fossil fuels, electricity storage, railways development, passenger road transport, and efficiency in buildings.

The case studies and arguments around these archetypes are linked accordingly to one of four thematic areas: investment, innovation, integration, and infrastructure, which represent key challenges that the EU will need to address on its pathway to a net zero emissions target. The assessment shows that the diversity of experience faced by countries offers valuable insights into how policy developments have been successful and what the EU can learn from them.

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Abbreviations

AB	Assembly Bill
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
AFIF	Alternative Fuel Infrastructure Facility
AFPM	American Fuels and Petrochemicals Manufacturers
API	Application Programming Interface
ARENA	Australian Renewable Energy Agency
ATVM	Advanced Technology Vehicle Manufacturing
BC	British Columbia
BCCATC	BC Climate Action Tax Credit
BESS	Battery Energy Storage System
BEV	Battery electric vehicle
BIF	Bahn Infrastruktor Fonds (Railway infrastructure funds)
BMS	Battery management system
BTM	Behind the Meter
BV	Bundesverfassung (Federal Constitution)
C-PACE	Commercial Property Assessed Clean Energy
C&I	Commercial and Industrial
CA-GREET	California Greenhouse gases, Regulated Emissions, and Energy use in Transportation model
CACM	Capacity Allocation and Congestion Management
CAFC	Corporate Average Fuel Consumption
CAISO	California Independent System Operator
CARB	California Air Resources Board

CARBOB	California reformulated petrol blendstock
CCA	Community Choice Aggregate
CCM	Credit Clearance Market
CEAP	Climate Emergency Action Plan
CEC	California Energy Commission
CEF	Connect Europe Facility
CESA	California Energy Storage Alliance
CF	Cohesion Fund
CHAdeMO	Charge de Move, DC fast charging
CHF	Swiss Francs
CI	Carbon intensity
CIWB	California Integrated Waste Board
CMTA	California Manufacturers and Technology Association
CNG	Compressed natural gas
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide equivalent
COAG	Council of Australian Governments
COGATI	Coordination of Generation and Transmission Infrastructure
CPUC	California Public Utilities Commission
DCP	Dual Credit Policy
DER	Distributed Energy Resource
DETEC	Eidgenössische Departement für Umwelt, Verkehr, Energie und Kommunikation (Federal Department of Environment, Transport, Energy, and Communications)
DH	District Heating
DNSP	Distribution Network Service Provider
DoD	Department of Defense

DoE	Department of Energy
DSO	Distribution system operator
DuoS	Distribution Use of Service
EASE	European Association for Storage of Energy
ECV	Electrically Chargeable Vehicle
EDU	Electric distribution utility
EEA	European Economic Area
EED	Energy Efficiency Directive
EER-TLE	Energy Efficiency Retrofitting and Thermal Load Electrification Program
EMS	Energy management system
EPA	Environmental Protection Agency
EPBD	Energy Performance of Buildings Directive
ERA	European Railway Agency
ERTMS	European Rail Traffic Management System
ESP	Electric Service Provider
ESS	Energy Storage System
EU	European Union
EU ETS	EU Emissions Trading System
EUR	Euro
EV	Electric Vehicle
FABI	Finanzierung und Ausbau der Eisenbahninfrastruktur (Financing and expansion of railway infrastructure)
FCAS	Frequency Control Ancillary Service
FCV	Fuel cell vehicle
FERC	Federal Energy Regulatory Commission
FFB	Federal Financing Bank
FHA	Federal Housing Association

FinöV	Der Fonds zur Finanzierung des öffentlichen Verkehrs (the fund for financing public transport)
FIT	Feed-in Tariff
FOT	Swiss Federal office of Transportation
FRE	Fuel Reporting Entity
FY	Fiscal Year
FYP	Five-Year Plan
gCO_2e/MJ	Grams carbon dioxide equivalent per mega joule
GGE	Gallons gasoline equivalent
GHG	Greenhouse Gas
GND	Green New Deal
GSP	Gross State Product
HEV	Hybrid electric vehicle
HHS	Department of Health and Human Services
HSR	High-Speed Rail
HUD	Department of Housing and Urban Development
HVAC	Heating, Ventilation, and Air Conditioning
IA	Impact Assessment
ICE	Internal combustion engine (vehicle)
ICEV	Internal Combustion Engine Vehicle
IECS	Ithaca Energy Code Supplement
IGND	Ithaca Green New Deal
IIJA	Infrastructure Investment and Jobs Act
IOU	Investor-owned utility
IRA	Inflation Reduction Act
ISP	Integrated System Plan
JNR	Japan National Railway

JNRSC	Japan National Railway Settlement Corporation
JRTT	Japan Railway Construction, Transport, and Technology Agency
K-ESS	Korea Energy Storage Technology Development and Industrialization Strategy
KEA	Korean Energy Agency
kWh	kilowatt-hour
LCFS	Low-Carbon Fuel Standard
LCOE	Levelised cost of energy
LED	Light-Emitting Diode
LEV	Light electric vehicle
LiB	Lithium-ion battery
LLC	Limited Liability Company
LMI	Low and Moderate-Income
LNG	Liquified natural gas
LPG	Liquefied petroleum gas
LPO	Loan Programs Office
LSVA	Leistungsabhängige Schwerverkehrsabgabe (performance-related heavy-duty vehicle fee)
LUC	Land-use change
LuoS	Local Use of Service
LVA	Landverkehrsabkommen (Land Transport Agreement)
MASS	Market Ancillary Services Specification
MIIT	Ministry of Industry and Information Technology
MOTIE	Ministry of Trade, Industry, and Energy
MSF	Management Stabilisation Fund
NASA	National Aeronautics and Space Administration
NEA	Norwegian Environment Agency

NEM	National Electricity Market
NEV	New energy vehicle
NEVA	Norwegian Electric Vehicle Association
NGO	Non-governmental organisation
NIBA	Sustainability Indicators for Rail Infrastructure Projects
NIH	National Institutes of Health
NOK	Norwegian krone
NOVAP	Norwegian Heat Pump Association
NRLA	New Railway Link Through the Alps
NSF	National Science Foundation
NSW	New South Wales
NYGB	New York Green Bank
NYSERDA	New York State Energy Research and Development Authority
OTA	Overland Transport Agreement
PACE	Property Assessed Clean Energy
PCS	Power conditioning system
PD	Policy Directive
PDS	Peak Demand Saver
PG&E	Pacific Gas and Electric
PHEV	Plug-in hybrid electric vehicle
PI	Principal Investigator
PPA	Power purchase agreement
PV	Photovoltaics
PV	Solar Photovoltaic
R-PACE	Residential Property Assessed Clean Energy
R&D	Research and Development

REC	Renewable Energy Certificate
RED	Renewable Energy Directive
RES	Renewable Energy Source
REZ	Renewable Energy Zone
RI	Research Institution
RoI	Registration of Interest
RPS	Renewable Energy Portfolio Standard
RRF	Recovery and Resilience Fund
SB	Senate Bill
SBA	Small Business Administration
SBB	Schweizerische Bundesbahnen (Swiss Federal Railways)
SBC	Small Business Concern
SBIR	Small Business Innovation Research programme
SCE	Southern California Edison
SDG&E	San Diego Gas and Electric
SGIP	Self-Generation Incentive Program
SME	Small and medium-sized enterprise
STEP	Ausbauschritt 2025 de Strategischen Entwicklungsprogramms Bahninfrastruktur (Strategic Development Programme for Rail Infrastructure)
STTR	Small Business Technology Transfer programme
SWIS	South West Integrated System
TELGP	Tribal Energy Loan Guarantee Programme
TFC	Total Final Consumption
ToU	Time of Use
TPA	Trade Promotion Authority
TSO	Transmission system operator

TUOS	Transmission use of system (charges)
VPP	Virtual Power Plant
VRE	Variable Renewable Energy
WA	Western Australia
WEM	Wholesale Energy Market
ZEB	Zukünftige Entwicklung der Bahninfrastruktur (Future Development of Rail Infrastructure Plan)
ZEB	Zero Emissions Building
ZEV	Zero-emission vehicle

Executive Summary

With the adoption of the European Green Deal and the European Climate Law, the European Union set targets to reduce emissions by at least 55% below 1990 levels by 2030, and to achieve climate neutrality by 2050.

When adapting its policy framework to meet these targets, the EU can draw from experiences from non-EU countries, both in terms of their successes as well as their failures. There is no blueprint or historical precedent for this transformation; thus, the EU can learn from other countries that have already taken steps towards transformative change in the energy, transport, and building sectors. While many experiences cannot be directly transferred to the EU circumstances, it is possible to understand the mechanisms that have worked in other countries and regions, and the enabling conditions that have allowed them to function.

The EU will need to address not only direct challenges to specific sectors, but also indirect challenges which require a holistic and interdisciplinary approach to improve. For this reason, the approach taken in this report was based around four cross-cutting core challenges identified in the 4-I TRACTION project as key for the transition to climate neutrality in the EU: (1) fostering breakthrough *innovation*; (2) shifting *investment* and finance; (3) rolling out the *infrastructure* for a climate-neutral and resilient economy, and (4) *integration* of solutions across sectors.

This report summarises the results of 18 case studies in non-EU countries, which have been grouped into eight archetypes. Each archetype provides lessons that address a gap in the EU's policy framework. The following subsections briefly explain the gaps and describe the lessons that the EU can learn from the experiences of other countries about how these gaps can be closed.

Empowering local communities and prosumers to contribute to grid stability

The electricity market design in most EU member states is restricted, and charging schemes are too complicated to allow for smart electrification of the transport and building sectors, especially using electricity generated and stored by prosumers or local communities (Lynch et al., 2021; PvC, 2019). Taxation systems in many EU countries make peer-to-peer electricity trading difficult. A lack of suitable electricity tariffs and the slow roll-out of smart meters mean that individual flexibility in electricity consumption remains unrewarded.

The Virtual Power Plants (VPPs) and Community Batteries projects adopted in Australia provide examples of how reducing the barriers to electricity exchange between prosumers can decrease the challenges resulting from the high shares of variable renewable energy sources.

VPPs work by aggregating several distributed energy resources (DERs), such as solar and batteries, over a dispersed network to enhance capacity, efficiency, and operability of the incoming renewable energy into the grid system. Australia introduced regulatory reform for VPPs by establishing the Frequency Control Ancillary Services, in which owners of DERs were able to register connections, enabling prosumers to trade in the market. By mid-2022, the combined capacity of VPPs in Australia amounted to 300 MW, providing grid stabilisation services, with an increasing share of electricity coming from renewables.

The main purpose of the Community Battery is to reduce the number of times that electricity generation for solar PV in some parts of Australia has to be curtailed in order to avoid spikes in voltage levels that damage the system (Yildiz et al., 2021). Community batteries constitute shared neighbourhood battery systems that improve grid reliability in a local area and promote a higher uptake of household solar PV systems. The main advantage of a community battery for the consumer is that, in exchange for a monthly fee, it requires no upfront costs and is around 30% cheaper over the course of the battery's lifespan. Participants in this model benefit from the local use of service (LUoS) tariff for electricity exchanged between different prosumers. Sharing a battery at a local level decreases the costs and contributes to grid stabilisation.

Energy communities are already well established in many parts of the EU. The EU can build on this potential. However, their non-commercial nature limits their roles to facilitating electricity exchange between their participants, and in this way lowering their electricity bills. Their roles in increasing the flexibility of the electricity grid to increase the uptake of variable renewable energy sources has not been widely recognized.

With VPPs and Community Batteries, Australia has demonstrated the financial viability of such business models, that not only create savings but may also open up additional revenue streams. Key to this was allowing communities to participate in the electricity market. While in the EU some pilot projects, based on a temporary exception from certain fees, do already exist, they are not common. What is missing is a feasible business model that would reward smaller actors for offering storage and flexibility with a minimum of administrative effort, as is the case in Australia. Creating such a possibility for energy communities in the EU would be a win-win situation for both the participants and the electricity grid, as it would allow for more flexibility to develop higher shares of variable renewables.

Developing storage by electricity utilities

Apart from empowering energy communities and prosumers to help stabilise the electricity grid and reap associated benefits, electricity utilities should also contribute to solving the challenge of energy storage. In California, the three major electricity utilities were instructed to procure over 1.3 GW of energy storage by 2020, with installations to be completed no later than the end of 2024. The other electricity providers were expected to procure an equivalent of 1% of their 2020 annual peak load from energy storage projects, with these projects to be installed no later than 2024. The goal was significantly overachieved: as of May 2022, the three major electricity utilities have procured over 7.2 GW (California Energy Storage Alliance, 2022b).

In South Korea, storage development was engrained in its certificate system, targeting the development of renewables. The certificate system required electricity utilities to generate a certain share of their electricity from renewables. If they cannot meet this goal themselves, they can purchase certificates from utilities that overachieve their goals. Renewable energy projects equipped with storage benefitted from a multiplier that allowed them to receive many more certificates than in the case of projects without storage. In this way, the South Korean government reduced the initial risks faced from high upfront costs, ultimately making investment in storage attractive for investors.

The EU and most of its member states lag behind California and South Korea in terms of storage development. With a population 11 times that of California, the EU has a combined battery storage of only 10 GW, which is only a third more than California (Taylor, 2022). While the European Commission expects this to increase to around 57 GW by 2030, other estimates see a need for up to 200 GW storage capacity, to accommodate the rapidly growing renewables shares and electrified end uses (European Commission, 2022; Moore, 2022).

One of the major barriers to storage uptake in the EU is that it is not properly valued. The variety of benefits that storage brings to the grid, including flexibility, load shifting, and adjusting power frequency, must be valued and compensated adequately, in order to allow storage to compete in the market and to attract investors. In the US, the updating of federal-level regulations allowed storage to access multiple revenue streams. The message from California's storage boom is that well-crafted policy will unlock the array of benefits that storage brings to the grid while translating these benefits into financial rewards for investors.

Key takeaways for the EU are to consider setting binding targets for energy storage for utility companies, offering flexibility for the technologies to be used, and rewarding utilities for additional services provided by storage. Furthermore, the streamlining and simplification of planning and application processes are strongly encouraged. Increasing storage capacity could allow EU member states to not only reduce the role of fossil gas as a balancing source of electricity, but also help to ensure that the temporary ramp-up of coal-fired power plants is only for the short-term.

Enabling deployment of more renewables

The expansion of renewable energy developments in the EU faces two significant barriers: (1) long, laborious permitting procedures, and (2) spatial integration planning, adapted to the infrastructure limitation of the electricity grid. Despite the EU's Renewable Energy Directive setting a 24-month permitting limit, member states were unable to comply (ranging from 30 to 120 months across member states). Permitting issues are linked to spatial planning and compliance requirements, and administrative procedures.

Norway's experience with a centralised permitting system holds important lessons for EU policy-makers. First, while permitting systems must be streamlined, this cannot come at the cost of procedural justice. Norway's experience demonstrates that permitting systems must ensure long-term social acceptance, especially among local communities. This is especially relevant with regards to the Commission's latest proposal for 'Renewables Go-To Areas'. Secondly, local communities must benefit from the hosting of wind power projects, either by becoming a shareholder or by devising financial compensation schemes. Lastly, in order to handle the higher application load without compromising on community involvement and the assessment of environmental and socio-economic impacts, EU member states must invest in administrative capacity. Permitting systems that are efficient and generate social acceptance require sufficient and adequately trained staff, as well as a digital infrastructure that enables a simple and fast application process.

The Renewable Energy Zones (REZs) adopted in Australia help to deal with the second challenge, of lacking interconnection, capacity, and congestion. REZs are designated geographical areas for the concentration of renewable energy development, with simplified permitting procedures. They may also include renewables that complement each other, e.g., wind and solar energy, and balancing options, such as storage systems. This could reduce the costs of grid development leading outside of the Renewable Energy Zone. A key takeaway for the EU is that designating areas for renewable energy developments, with simplified permitting and connecting procedures for renewable energy projects, could facilitate implementation and reduce costs.

Decarbonising passenger transport

Against the overall trend of economy-wide emissions reductions, transport emissions across the EU have continued to rise. However, there are positive signs: in recent years, the number of electric vehicles (EVs) purchased increased significantly. In the first half of 2022, almost 19% of all new passenger cars sold in the EU were electrically chargeable, which is an increase from 10% in 2020, and 3% in 2019 (ACEA, 2022). This increase was largely driven by significant financial incentives set by public policies. While such incentives may be justified to develop new industries, this level of support is not financially sustainable in the long run. A key challenge faced in the EU is the lack of harmonised rules, market incentives, and fiscal tools, which make the conditions for EV adoption highly variable across the EU.

However, there are examples of policies that support the expansion of electric vehicles at significantly lower cost to the public budget, such as the Low Carbon Fuel Standard (LCFS) adopted in California, and the Dual Credit Policy adopted in China. The main aim of the LCFS is to reduce greenhouse gas (GHG) emissions by reducing the carbon intensity of the transportation fuel, taking into consideration the fuel's full life cycle GHG emissions. Fuel producers are obliged to fulfil increasingly stringent carbon intensity requirements by either increasing the role of low-carbon fuels in the portfolio or purchasing credits from other entities. Such credits can be generated in numerous ways, e.g., the sale of electric vehicles, installation of charging stations, or development of e-fuels for heavy-duty transport.

The Dual-Credit Policy, introduced in China in 2017, includes two elements: the Corporate Average Fuel Consumption, focusing on fuel consumption, and the New Energy Vehicles mandate, requiring car manufacturers and importers to achieve a certain share of low-carbon vehicles in the total number of vehicles sold. The main benefit of these mechanisms is that they send clear signals to car manufacturers and consumers, effectively reducing the risk of delayed action.

Furthermore, by making it possible to generate certificates by developing different elements of infrastructure for the zero-emissions transport sector, the LCFS offers an opportunity to include various actors in the framework of one policy instrument. At the moment, this especially applies to the installers of electric charging stations who, under the existing framework, operate under different rules and incentives in every member state. Rewarding charging station installations with credits that could later be sold to the fuel manufacturers would allow for a more harmonised approach. The instruments could be extended to other technologies or to different modes of transport.

Contrary to the existing system of promoting electric vehicles in different EU member states, in the LCFS scheme the fuels producers' proceeds provide the funding for the development of low-carbon alternatives.

Shifting to railways

The EU is not utilising the full potential of its railways, and yet, increasing the usage of railways is crucial for the decarbonisation of the EU's transport sector (Witlox et al., 2022). Presently, the system is heavily fragmented and suffers from a lack of coordination and interoperability of rail operators and track systems. Decisions on infrastructure, funding, and operations are left to member states, rather than being taken by a pan-European body.

Consequently, potential passengers are discouraged from long-distance rail travel due to the lack of a coordinated, pan-EU booking system.

The EU can learn lessons for promoting increased railway transport by looking to Japan, where railways exhibit remarkable performance levels by international standards, in terms of profitability, punctuality, track capacity usage, and customer-orientation. The main driver of this situation — in addition to significant funding for the railways' infrastructure and research — is a top-down governance approach, introduced after the privatisation of the railways, in 1987. The model facilitates a strong cooperation between rail companies and the national and regional governments in planning infrastructure and opening new lines. This governance structure is complemented by the vertically integrated nature of the market, that allows faster connections via through-train services across regional boundaries.

For its part, Swiss rail policy has succeeded in shifting more of its overall transportation from roads onto railways since the 1990s and thereby reduced emissions. The ample funding of rail operations has contributed to such successes; Switzerland spends five times more per capita on its railway than its neighbour, Germany, for example (Wüpper, 2021). Funding has been directed towards both small and large infrastructure investments, as well as research and development. The Swiss government provides a framework to ensure that there is enough investment in the infrastructure to support a country-wide modal shift from road to rail.

The case studies indicate that further Europeanisation of the railways' governance would have a positive impact on the role of this mode of transport and help to accelerate the decarbonisation of the EU's transport sector, especially in eastern European countries. One way to achieve this would be a significant expansion of the competences of the European Railway Agency, currently playing a mostly technical role. Alternatively, it could be incorporated into a new European Railways Research, Investments, and Information Agency. Its competences could include: (1) coordination of planning of railway infrastructure, (2) co-funding development of transboundary connections, (3) facilitating research that would allow faster decarbonisation of the railways' stock, (4) development of rapid trains, (5) ensuring better coordination between timetables for intercity connections across the EU, and (6) the development of a pan-EU booking system that would allow seamless train booking across the EU.

Furthermore, funding for this mode of transport should increase significantly. To meet the EU's climate neutrality goal, a massive modal shift from aviation and road transport towards rail is needed. This requires significant investments in infrastructure, as the current infrastructure is hardly adequate to meet current needs, let alone the future demand for mobility services (Witlox et al., 2022). Such investments need to be covered, to a large degree, from consistent public resources. In Switzerland, some of the railway infrastructure funding comes from the taxation of road freight transport. At the EU-level, such an approach could also include fees on aviation.

Decarbonising the building sector

Currently, the building sector accounts for 40% of energy used in the EU. By 2030, the sector must cut emissions by 60%, and reach carbon neutrality by 2050 (Ipsos Belgium & Navigant, 2019). As of 2022, the EU is not on track to reach these goals. Currently, renovation rates range between 0.4% and 1.2% across member states (European Climate Foundation, 2022).

Major barriers in the decarbonisation of this sector include its complexity, diversity, and the number of actors involved. The high, upfront investment cost of renovations is another key challenge. Homeowners often lack the necessary resources, or they are not willing to take the risk without being sure about the reduction of the energy costs.

The Property Assessed Clean Energy (PACE) programme, introduced in 2008 in Berkeley, California, USA, allowed homeowners to invest in energy efficiency, renewable energy improvements, and water savings without an upfront payment. It targets the renovation of both residential (R-PACE), and commercial (C-PACE) buildings.

In the programme, a special tax assessment is made on the estate owner's property tax bill in lieu of traditional mortgage or debt repayment schemes. In this way, the owners can make investments without the need to produce the high initial capital required for purchases. Importantly, the responsibilities remain linked to the *property* where the improvements were made, and not to the *owner*. Investments are to be repaid through the energy savings generated by the building upgrades, usually over a 10 to 20-year period. One of the main advantages of the PACE scheme is its recognizability; in the US states in which it has been implemented, property owners mostly know what to expect and how to apply to the programme.

In the EU, bureaucratic efforts by property owners and construction companies could be reduced through a support scheme for home renovation that could function according to similar criteria as the PACE programme. This could include a similar application process, but with some differences regarding the balance between the grants and the loans. However, such a pan-EU programme would require clear criteria about which elements are harmonized and which can differ between different participating countries and regions.

Phase-out of fossil fuels for heating and transport

While focusing efforts on expanding zero-emission technology in different sectors, equally important will be phasing out old, fossil-intensive technologies. Norway has been a global pioneer in this regard. As early as 2020, it was the first country to end the use of oil for heating in existing buildings. The city of Vancouver, Canada, has introduced policies to implement the phase-out both oil and gas boilers from new buildings after 2022. Redistributing revenues from carbon taxation, combined with zero-interest rates, helped to mitigate the negative consequences of this policy for those who would not have been able to afford low-carbon alternatives and energy efficiency measures otherwise.

Experiences from Norway and Vancouver reveal that to gather sufficient support for such a policy-driven phase-out, adopting alternative, younger technology must become economically attractive. Norway and Vancouver both used a mix of taxation incentives and subsidies to penalise fossil-based technologies and to incentivise cleaner alternatives (i.e., heat pumps and thermal retrofitting). In the EU context, this approach raises the importance of aligning energy taxation and carbon prices with EU climate goals, while highlighting that that penalties alone will only partially achieve these goals, and they need to be accompanied by incentives, i.e., subsidies to accelerate the deployment of alternatives.

Supporting innovation

Innovation is essential for reaching the EU's goal of climate neutrality by 2050. However, the EU should also find ways to develop and deploy low-carbon innovation that will have an impact in the short term.

The U.S. Department of Energy Loan Program covers up to 80% to 90% of eligible costs of innovative large-scale projects, with fixed interest rates. The Department of Energy Loan Program Office's team of experts, which can strongly influence the content of the projects and accompany their implementation, conducts in-depth reviews of the submitted proposals. This opens the door to venture capital, willing to invest in projects receiving strong financial and expert support from the government.

For large-scale innovation, the DoE Loan Program offers several useful lessons for the EU. Firstly, the existing support for innovation could be complemented by a stream of support, focusing on more risky proposals that may not qualify to receive funding from the Innovation Fund. Secondly, the EU should significantly increase funding for large-scale innovative projects. This is illustrated by the significant oversubscription in the first call for proposals for the Innovation Fund (European Commission, 2022a), indicating that the potential for innovation is there, but much more funding, e.g., as loans, is needed to fund transformative innovation. Finally, the role of experts assessing the proposals should move from being mere evaluators to that of being co-creators. This task is partly carried out by the Project Development Assistance, provided by the European Investment Bank, for *selected* projects (European Commission, 2022c). This practice should be expanded and mainstreamed. A permanent group of experts should not only review the submitted proposals, but also actively engage in their development.

The EU should also facilitate the development and implementation of small-scale innovation. The small-scale Small Business Innovation and Research (SBIR) and the Small Business Technology Transfer (STTR) programmes adopted in the United States support cooperation between small and medium enterprises and research institutes to drive not only innovation development but also its commercialisation.

An EU version of the programme should focus on driving innovation, especially in areas where there is a clear research gap, identified by commercial actors or different public actors, to deploy low-carbon technologies, with the managing agency, e.g., CINEA, playing only a controlling function. As a result, calls for proposals should target the needs of the small businesses, to either reduce their energy costs and emissions, or to create products that will facilitate decarbonization by their consumers.

1. Methodological basis

1.1 Introduction and background

The project '4i-TRACTION' aims to identify transformational practices to advance the transition to net-zero emissions in the EU. In this context, 'transformational' means addressing the challenge of aligning the European Union in its entirety with the goal of climate neutrality — "across all sectors, with regard to its technological, economic, political, and social implications, and across the different phases of the process" (Goerlach et al. 2022, p.7).

This requires thinking back from the goal of net zero in 2050, overcoming path-dependencies, developing transformational institutions, and fostering sectoral and technical integration. For this reason, the project focuses on four challenges — the '4i's' — that are central for transformation: fostering breakthrough **innovation**, shifting **investment** and finance, rolling out the **infrastructure** for a climate-neutral and resilient economy, and **integration** of solutions across sectors (see **Table 1.1**).

Table 1.1: Overview of the 4-Is.

Challenge	Aspects pursued in 4i-TRACTION
Innovation	• Focus on technological and business model innovation as sources of solutions for climate neutrality — as well as policy and governance innovation for new governance solutions. • Within technological innovation, focus on innovations at higher levels of technological readiness, for which there is a higher chance that they can be scaled up sufficiently towards commercialisation within the timeframes considered. This also includes market creation for new technologies, products, processes, and services. • Adopt a system-wide perspective, including the policy context, to understand how actors active in the field shape innovation outcomes, as well as the role of specific RD&D policies and the broader political framework conditions.
Infrastructure	• Assess which new infrastructure is needed for climate neutrality, which needs to be upgraded, which can be converted, and which becomes obsolete. • Develop and assess policy instruments and governance to develop an EU infrastructure compatible with climate neutrality: support the co-evolution of infrastructure and technologies, incorporate uncertainties, and handle the time lags involved.

	• Analyse the interplay of physical infrastructure with regulations and markets. • Include the role of digitisation of the energy system and (smart) infrastructure.
Investment and Finance	• Adopt a more detailed and granular perspective, beyond the sectoral approaches currently pursued in financial regulation, and analyse the implications of such a granular perspective. • Identify specific instruments with a high transformative potential for mainstreaming climate issues in the financial sector. • Propose how the financial sector can contribute to the exnovation/phase-out of incumbent fossil technologies, and the implications of the resulting stranded assets. • Analyse the role of financial regulators and supervisors in the EU and propose steps to better incorporate climate issues in regulatory decisions. • Develop options to improve the internal procedures, incentives, and governance structures of financial institutions for integrating climate issues.
Integration across sectors	• Explore what an "all-of-government" approach to transformative climate policy would entail at EU level. • Ensure the coordination of parallel, interdependent processes in different policy areas. • Extend the established understanding of climate policy integration to include integration across economic sectors and technological trajectories. • Provide tools to respond to the governance challenges arising from the erosion of classical sector distinctions as a result of sector coupling. • Ensure coordination across parallel, interdependent processes of technological change

Source: (Goerlach et al., 2022)

Part of this analysis is a series of case studies that aim to outline good practice examples in eight selected areas, such as phasing out combustion engines and gas-fired boilers, expansion of railways, reform of permitting and licensing of renewable energy deployment or procurement mandates for electricity storage. In all these areas, the project looks at experiences outside of the EU in order to assess whether lessons learnt in other jurisdictions can enrich the policy options available for EU policy-makers.

This section provides an overview of the methodological considerations that have been used to guide the design of the case studies. It proceeds as follows: Section 1.2 discusses the necessity of adopting a harmonised conceptual framework to derive insights from country case studies, defines the concept of good practices and describes the archetype approach underlying the individual case studies. Section 1.3 explains the common structure that has been chosen as an analytical basis for all case studies. This harmonised structure makes the studies comparable and allows identifying common factors and important differences across cases. Section 1.4 considers how the insights from individual country case studies can be synthesised to derive generalised insights on the design and implementation of transformative policies. Section 1.5 discusses limitations of this analytical approach and presents some ideas how, given these constraints, policy-relevant lessons can be derived from this line of research.

1.2 General considerations

Case studies are a cornerstone of social science research. They serve a variety of purposes, such as testing hypotheses or improving the understanding of functional mechanisms. Case studies frequently combine multiple analytical methods, such as analysis of official documents, data, and stakeholder interviews. Case studies have emerged as a fundamental tool of policy analysis, due to the complexity of the political process, which is often beyond the scope of rigorous modelling or statistical analyses. For this reason, this project conducts case studies to identify good practices for the EU along a harmonised framework. This section explains the concept of best practices, elaborates the archetype approach for our analyses and discusses why it is necessary to rely on a harmonised framework.

1.2.1 Selecting good practices and identifying good practices

The aim of the case studies is to identify lessons that could be learnt for the EU by looking at examples of 'good practices' from other countries. We start by identifying a revealed policy gap in the EU, i.e., an outcome in which observed developments are not in line with what would be required to achieve net-zero emissions by 2050.

At a dedicated workshop, six such revealed policy gaps were identified:

- the renovation rate in the EU's building sector
- emissions from road transport
- low-carbon infrastructure development, especially railway networks and transmission grids
- electricity market design for smart electrification of the transport and building sector
- the speed of renewable energy deployment
- development and commercialisation of the new technologies

As a next step, we look at countries that show a better performance in this aspect and identify policies that are in place there as candidates for policies from which the EU can draw lessons to close the policy gap. The consortium had initially identified 42 possible candidate policies. This selection was narrowed down in a further workshop to the eight archetypes discussed in the next sub-section.

The way a certain policy has been implemented in the respective country does not necessarily constitute a best practice that can be directly transferred to the EU. Rather, for the purposes of our case studies, it is sufficient to find good practices in other countries. We understand good practices as policies that have been implemented elsewhere and have the potential to — at least partially — address a policy gap that has been identified for the EU. From the observed outcome for which the country in question has performed better than the EU — e.g., faster roll-out of renewables, or quicker phase-out of fossil energy — one can conclude that the respective policy or practice holds lessons that are relevant for the EU.

As these policies likely have favourable characteristics but also certain limitations, they cannot be considered *prima facie* 'best' practice. Gaining a close understanding of how a certain policy or practice has been implemented in another country and which effects it had is thus a necessary, but not a sufficient, condition for deriving a best practice for the EU. The research process may reveal short-comings or failures in policy design, implementation, or enforcement, which also hold important lessons that can inform EU policy-making.

To identify good practices for the EU, two further steps are hence necessary: first, it is necessary to address shortcomings of the policy under study and to discuss alternative design options. Second, one needs to specify how these insights can be transferred to the EU, taking into account constraints arising from the political, institutional, and economic setting.

1.2.2 The archetypes approach

Instead of focusing on single policies, the case studies assessed in the framework of this project adopt a broader perspective and focus on 'archetypes'. An archetype can be understood as an assembly of policies and practices that can be applied to close a revealed policy gap. Hence, each archetype may contain more than one case study of a good practice in a country outside of the EU. Due to this rather generalised approach, archetypes offer greater flexibility and can be regarded as toolkits that can serve to fill policy gaps in the EU.The eight archetypes considered in the scope of this project are summarised in **Table 1.2** below.

Table 1.2: The Archetypes.

Archetype	Case studies	Region	Relevant "I"
Decentralisation of the electricity sector	Virtual Power Plants	Australia	Integration
	Community Batteries	Australia	

Facilitating innovation	U.S. Department of Energy Loan Programme	United States	Innovation, Investment & Finance
	Small Business Innovation Research Programme	United States	
	Small Business Technology Transfer Programme	United States	
Facilitating fossil fuels phase out (exnovation)	Phasing Out Fossil Fuels in Heating	Norway	Innovation /Exnovation & Investment
	Phasing Out Fossil Fuels in Heating	Vancouver, Canada	
	Norway Internal Combustion Engine Vehicle Phase-out	Norway	
Electricity storage	Storage Procurement Mandate	California, US	Infrastructure, Investment & Finance
	Renewables Portfolio Standards	South Korea	
Facilitating railways development	Railways in Japan	Japan	Infrastructure
	Railways in Switzerland	Switzerland	
Permitting of renewables	Wind Power Permitting	Norway	Investment, Infrastructure
	Renewable Energy Zones	Australia	
Decarbonisation of passenger cars	Low Carbon Fuel Standards	California, US	Investment and Finance
	Dual Credit Policy	China	
Decarbonisation of the building sector	Property Assessed Clean Energy	United States	Investment
	Ithaca’s Green New Deal	Ithaca, US	

1.2.3 Conceptual frameworks

Despite the wealth of case studies on issues relevant for climate policy, it is often challenging to derive clear-cut, generalisable insights from this literature due to the different approaches applied in different studies (Jakob et al., 2020). For this reason, researchers have called for harmonised frameworks to guide case studies and allow comparability (Cherp et al., 2018; Sovacool & Hess, 2017). Recent advances in conducting meta-analyses of social science results have further emphasised the importance of comparability across studies and of ensuring ‘assessment-readiness’ of case studies already in their design phase (Minx et al., 2017).

A prominent example that clearly shows the advantages of a harmonised approach is the Institutional Analysis and Development framework developed by Ostrom (2005) to allow for a better understanding of why countries in relatively similar situations choose different policies. Another case in point is the varieties of capitalism approach (Hall & Soskice, 2001) that provides a guiding principle by which analyses of institutional configurations can be compared across settings.

This does not mean that all case studies need to adopt a common theory. Depending on the issue area and the country under study, different theoretical underpinnings and empirical strategies might be suitable, as suggested by Moore et al. (2021), who point out the diversity of approaches used to study transformations for climate change mitigation. Nevertheless, a common framework ensures that these studies have some common denominator. As Jakob et al. (2020) point out in their analysis of the political economy of climate policy, cases with very different settings can nevertheless be compared by clearly stating the relevant actors, their objectives, and the role of the country context in which policies are designed, implemented and enforced.

For the purpose of the good practice case studies, we do not rely on an existing conceptual framework. Rather, as described in Section 3, we establish a set of categories that each individual study should consider and that can be used for later comparison. These categories include structural as well as process factors in a similar spirit to the approach used by Karapin (2016) to compare climate policies across US states. The categories are deliberately wide to allow for flexibility as the individual case studies are very heterogeneous and look at different outcomes and phenomena.

1.3 Case study design

Each case study for a certain archetype contains three distinct elements, as shown in **Table 1.3**. First, authors explain which policy gap is addressed by the archetype under study and to which of the 4is it relates to. Second, they need to include several case studies of specific policies that are concrete expressions of an archetype, which clearly explain the policy design and how it has performed in closing the policy gap. Third, authors will be required to provide an account of lessons to be learnt for the EU.

Table 1.3: Case studies

Element	Focus
Context and background	• Policy gap addressed • Which of the 4is covered • Economic and political context • Research approach
Several case studies of specific policies	• Reason for introduction • Type of policy and design • Actors involved, public opinion • Lessons learnt: evaluation and potential improvements
Lessons for the EU	• Potential to close policy gap in EU member states • Design options: in general, or specific for selected member states • Implications for policies on supranational level • Conceivable political and institutional obstacles

1.3.1 Context and background

To start with, each of the eight case studies explains how the selection of the case study addresses the identified (implementation) gap in the European climate policy framework that hinders the EU from reaching the goal of climate neutrality by 2050 and to which of the 4is it relates to (which can be more than one). Furthermore, authors provide a clear account of the economic, social, political, and institutional context in which the measure has been introduced. This could include, for instance, a description of the country's economic structure, its potential to generate renewable energy, or and whether utilities are privately or state-owned. Relevant information on the political system might include, for instance, whether a country is a presidential or parliamentary democracy, and whether specific events, such as an upcoming election, have influenced the design of the policy and its adoption.

Authors also provide a short account about the general climate and energy policies prevailing in this country and situate the policy in question in this policy environment. In particular, previous experiences with similar measures can have a strong influence on implementation decisions, and it is important to consider which role the respective policy plays in the overall policy mix (Nemet et al., 2017).

Finally, if similar approaches were used for all case studies of specific policies, the respective section explain the research approach and how data were obtained. This includes theoretical considerations and references to the most recent literature, in particular studies that have analysed either the policy in question, or similar policies in other countries. References explaining the overall policy context are included whenever possible, and all official documents are clearly referenced. In some cases insights from stakeholder interviews were included selected based on their expertise in the respective areas.

1.3.2 Description of specific policies and their effects

Case studies of specific policies describe the design and implementation of policies and practices under study. A straightforward starting point for this discussion is the type of policy or practice under study (e.g., standards, taxes…), and in which sector(s) it has been adopted (e.g., residential, transport….). This overview has been complemented by a more in-depth account of policy design. For instance, this could include a description of how targets were determined, which agencies were responsible for enforcing the policy, and how they deal with non-compliance by regulated entities. Whenever possible, it was discussed whether and how the policy was monitored and if any ex-ante or ex-post measures existed to carry out adjustments in case the policy was projected to miss its initial targets.

A further important issue that has been addressed for the respective policies is the policy process. Whenever relevant for understanding the lessons learnt, the actors involved in the deliberations preceding the adoption of the policy are described. If available, information on public opinion before and after the introduction of the policy is provided. In some cases, this is enriched with an assessment of which key industry stakeholders supported or opposed the policy.

Gaining a closer understanding of the interests in support of, and opposition to, the policy helps to assess potential political barriers and ways to overcome them (Oye & Maxwell, 1994). In this regard, it is essential to broaden the focus to complementary measures that have been introduced to facilitate the introduction of the policy, very much in the spirit of policy sequencing (Meckling et al., 2015), or whether specific compensation schemes to ease political resistance have been applied. It is also crucial to take stock of any changes that have been made to the policy and investigate the underlying reasons for these changes.

The case study ends with an evaluation of the effects of the policy. This evaluation includes a 'positive' component, i.e., describing the effects that can be attributed to the policy, as well as 'normative' aspects, i.e., whether the policy has been judged to be successful. In particular, at this stage, lessons learnt on how the policy could have been designed in a better way from the outset, or how its introduction could have been facilitated, are spelled out.

1.3.3 Lessons for EU

Finally, the analysis discusses what can be learnt, for the EU to close the gap between the existing situation in a specific area and what needs to happen to reach the goal of climate neutrality. That is, it presents a clear idea of how to get from a 'good practice' in the country under study to a 'best practice' in the EU. This requires not only taking into account the potential improvements that could be made to the policy studied, but also considering how it could be adapted to the political and institutional situation of the EU.

Here, a particular challenge arises in relation to the multi-level governance nature of EU climate policies. Many of the potential measures to address policy gaps will concern policies that are adopted on the level of EU member states. Due to the large degree of variation, it is not helpful to think about a single 'best practice' design. Rather, two ways to proceed in this direction are conceivable: first, one might aim at identifying design features that are of relevance for a broad set of EU member states. Second, one might more specifically focus on the situation in those member states that display the largest gaps.

When applicable, this discussion also considers whether and how provisions on the supra-national level can facilitate progress on the level of individual member states. This could, for instance, take on the form of EU directives spelling out general principles while at the same time providing leeway for nationally appropriate implementation.

1.4 Synthesising case studies

Beyond lessons learnt within each individual archetype, this research provides a valuable basis on which to draw more wide-ranging general conclusions for the design and implementation of transformative policies. This exercise should best be considered as exploratory, to produce hypotheses and questions for future research that can provide more detailed insights.

To derive conclusions regarding the design of transformative policies, it is not sufficient to look at individual factors. Rather, their combinations need to be analysed to better understand the interaction between different factors. For instance, a certain policy design option might occur frequently in a certain economic situation. These considerations should best be backed up by theoretical and empirical insights from existing literature. In this process, it is important to take into account the possibility of selection bias. As only 'good practice' policies were selected for study, identifying common factors does not yield sufficient information on factors that differentiate them from other policies that were not successful. Hence, a comparison to cases that were not successful would be required in order to establish that a certain constellation of factors or design options actually matter for a 'good practice'. Comparative work could complement the research undertaken within 4i-TRACTION by adding insights from the available literature on policies that were not successful.

1.5 Limitations

The research approach described in this paper is subject to several limitations, which should be kept in mind when assessing the insights derived.

First, the policy gaps analysed are *revealed* policy gaps. That is, based on the observations that certain targets are not met in the EU, we assume that the underlying reason is a lack of policy. However, it is also conceivable that the target is too ambitious for the EU context. Even if other countries show better performance than the EU in a certain area (e.g., the roll-out of renewables or electric vehicles) this could be due to other underlying reasons, unrelated to policy, such as geography or economic structure. It hence seems be desirable to perform cross-checks with experts to ensure that the revealed policy gaps constitute actual policy gaps.

Second, the selection of good practices provides some leeway for researchers to prefer some cases over others without a clear, unambiguous justification for their choice. Even if the selected cases constitute good examples, one might also have chosen other good examples from different countries, which might have yielded different insights. These insights would probably not have contradicted the findings but might have shed some light at a different aspect of the policy gap and archetype. Therefore, it is important to keep in mind that case studies on specific policies can only provide a partial picture of best practices to close a policy gap.

Third, even if the highest scientific standards are adhered to, qualitative research always involves a certain degree of subjectivity, e.g., regarding the interpretation of stakeholder interviews. It is desirable, therefore, to cross-check insights from these studies with other methods, such as modelling, statistical analyses of empirical data, and stakeholder surveys.

For the above reasons, the insights from these case studies should best be regarded as exploratory ones, to generate ideas and hypotheses that can be examined by further research, rather than definite policy proposals.

2. Archetype 1: Decentralisation of the Electricity Sector

2.1 Introduction

The EU's electricity market is undergoing a significant change, resulting from the increasing role of distributed renewable sources of energy. The share of renewables from solar and wind in the EU was 22% in 2020 (EEA, 2022c). According to some 1.5°C-compatible scenarios, their share should increase to as much as 94% by 2050 (Climate Analytics, 2022a). Electrification of transport, industry, and the building sector will mean a much more significant growth in electricity generation from distributed renewable energy sources in absolute terms. All this must be accomplished while ensuring energy security, affordability, and sustainability in the short term in order to meet long-term decarbonisation. This ultimately adds pressure to Europe's ever evolving electricity grid, markets, and regulatory frameworks to deal with the inflexibilities of RE integration into such systems (Bernath et al., 2021).

An electricity market dominated by distributed renewable energy sources offers some challenges, but also numerous benefits. The variable character of wind and solar energy requires utilisation of different tools to ensure continued supply of electricity: starting from better grid interconnections, through energy storage, better utilisation of dispatchable renewables such as hydro and bioenergy, and ending on demand management. At the same time, as can be clearly seen in the case of reduced availability of nuclear energy in France in 2022, such a system is much more predictable and resilient. It can also be deployed much faster, which applies especially to solar energy. Finally, its distributed nature means that, in many cases, electricity can be consumed close to the point of generation, thus reducing network losses.

However, the way that the electricity market is currently organised in the EU has been developed with the centralised electricity system in mind, in which electricity consumers are on the receiving end of the system. To make matters worse, taxation of electricity and high levels of bureaucracy for small-scale electricity producers, who would like to store their electricity externally or share it with their neighbours, strongly discourage those actors, who could help integrate high shares of wind and solar energy.

This has led to calls, and the need, for market and regulatory reform in Europe that could increase the role of Distributed Energy Resources (DERs) (Schittekatte & Pototschnig, 2022). DERs constitute a decentralised network of small to medium-scale renewables, such as solar and batteries. Other than energy generation and small-scale behind-the-meter consumer-based batteries, DERs also include 'smart charging points' for EVs, 'power-to-heat' such as heat pumps, and 'demand response', a process to adjust energy consumption to assist the grid's needs individually or in aggregation (IRENA, 2019). DERs are expanding the number of options to integrate variable sources of electricity — which is a very important role, bearing in mind the dominant role to be played by wind and solar PV in the energy system of the future.

2.2 Why consider electricity market design and community batteries?

The challenges of integrating much higher shares of electricity from wind and solar are not unique to the EU. In fact, development of solar PV in some parts of Australia exceeded most expectations — a trend that is set to continue, given the excellent conditions for the utilisation of this source of energy.

To cope with the increasing shares of distributed, variable sources of energy, Australia is one of the leaders in taking advantage of the Virtual Power Plants (VPPs). Through this digitalisation tool, widely dispersed DERs can be aggregated, making system operations more dynamic, meaning less need for excessive financial investments in storage and generation capacity, and consequently optimising the whole system (IEA, 2021d).

Box 2.1 Why is decentralisation of electricity system important for integration?

Decarbonisation through electrification is the most feasible and appropriate means to move away from fossil fuels, especially for sectors such as transport and buildings. Integrating these sectors is key to ensuring successful decarbonisation, while also making the most of existing infrastructure, most of all by allowing all actors – from households to grid operators, to electricity market participants – to play a role in generating and storing electricity, as well as in load shifting.

While sectoral integration can happen at many levels, the level at which the energy services (e.g. in the form of electricity, warmth, cold, or mobility) are used is the most efficient. To avoid curtailment of excess solar or wind power production, residential batteries, virtual power plants, and electric vehicles can be used to store this excess power. Energy consumers may also decide to use their boilers and even households as "batteries" by heating water during the day and preheating or precooling their apartments when energy is cheap, and the buildings are well insulated – options that are not available on a large scale.

The main goal of a VPP is to digitally aggregate energy from a collection of independent, dispatchable DERs, usually solar panels and batteries installed in commercial and private buildings, to meet local and immediate needs of the grid. From its centralised digital management system, VPP software communicates across a large, distributed and connected network of independent, small-storage batteries and renewable power units to distribute large amounts of electricity to where it is needed (ARENA, 2022).

The two main roles of a VPP's energy aggregation capabilities are to (1) enhance the capacity, efficiency, and operability of the decentralised storage and generation from independent renewable energy sources, and (2) allow for the trading of electricity on the market. Through VPPs, any excess energy created from an independent prosumer becomes accessible to the main network when energy supply is needed (SolarPowerDirect, 2022). The key advantages of VPPs are their ability to reduce a grid's overall electricity demand, particularly during peak demand hours, and their ability to provide voltage support during conditions of over-voltage. To enable the creation of a VPP, the regulatory framework must be designed in such a way that allows consumers to dispatch power to the grid on demand and without incurring fees (SolarHub, 2022).

Another tool investigated in this report that could facilitate better and more efficient integration of high shares of wind and solar PV is the Community Battery. Such a battery is a way for residents with solar PV systems, but who do not own a battery, to be able to store the excess electrical energy produced by their solar unit. Due to the economies of scale, this is a much more cost and resource-effective way of storing excess electrical energy at the local level than using individual batteries. At the same time, by creating an additional buffer between the prosumers and the grid, the strain on the grid caused by an excess of power produced by rooftop solar PV systems during daytime hours is significantly reduced. Accessing this stored energy during the hours of peak demand helps to flatten the peaks in the grid demand, reducing both the strain on the grid, and the overall power costs. Similar to virtual power plants and grid-scale batteries, stored energy can, with sufficient numbers of community batteries, be released to accommodate variability in power supply due to the intermittency of grid-scale renewable energy, helping to facilitate higher levels of renewable energy penetration. Community battery trials are currently under way in Perth, Sydney, and Melbourne (Western Power, 2022b).

2.3 Case Study 1: Australia's Virtual Power Plant (VPP)

The first case study looks at Australia's experience in trialling Virtual Power Plant technology to accommodate the growing stock of distributed solar and battery technology in Australian communities. Section 2.3.1 introduces the reader to the current trends in DER uptake, and looks at how Australia's regulatory electricity market is set up and explores the existing policy gaps. Section 2.3.2 describes the policy development for the projects to test the feasibility of VPP. Section 2.3.3 evaluates the impact of the project and policy around the VPP trials, particularly looking into the effect on market participation, operational quality and issues, security, and consumer perception. Section 2.3.4 briefly outlines the future of VPP in Australia, and Section 2.3.5 concludes, with remarks on the suitability, strengths, and weaknesses of the technology, based on Australia's experience.

2.3.1 Context and background

Australia has vast renewable energy resources, including some of the highest levels of solar irradiance in the world (ESMAP, 2020). Together with Australia's high proportion of standalone homes (over 70% in 2021) with ample roof space and large numbers of owner-occupiers, this has led to a world-leading level of residential rooftop solar PV penetration of around 30%, or over 3 million installations, as of 31 January 2022 (AEMO, 2021b; Australian Bureau of Statistics, 2021). Such a high number of rooftop solar PV systems creates challenges for the management of the power grid. However, having an installed rooftop solar PV system is strong motivation for many to utilise the electricity generated by it more efficiently, by purchasing a home battery system. No country has a greater share of rooftops with solar PV systems than Australia, and consequentially, it is a world leader in home battery adoption, with over 30,000 residential units installed in 2021, totalling 333 MWh of capacity (Colthorpe, 2022a).

The increase in household and commercial battery installations presents an opportunity to begin utilising these DERs for grid stabilisation purposes. A key way to operationalise DERs to this end was the creation of virtual power plants (VPP); a collection of dispatchable DERs, most commonly batteries, centrally managed to meet local and immediate needs of the grid. In addition to the recent increase in home battery adoption, the current trend towards electric vehicle (EV) adoption, though still nascent in Australia compared to other regions of the world, is likely to play a significant role in the evolution of the VPP sector. The batteries in Evs are currently six to ten times larger than standard household batteries, giving them a far greater capacity to store power generated from rooftop solar and, therefore, to discharge to the grid (Kuiper, 2022). With projections of Evs reaching ubiquitousness in the coming decades, their potential impact on VPP markets is profound, likely improving the profitability of VPPs, given their far greater ability to load shift the 'solar peak', particularly if the average rooftop solar PV size continues to increase.

The strong recent and projected future demand for home batteries, and the looming shift in EV prevalence, created an incentive to understand their potential for grid management services, overall system cost reductions, and how best to amend or design regulation to encourage and safely integrate their potential through VPPs. The VPP market is booming in Australia, with over 300 MW in total capacity operating across Australia's national energy market (NEM) in 2022, more than double the capacity from just two years prior (AEMO, 2021b; Kuiper, 2022).

The Australian Energy Market Operator (AEMO), an organisation jointly owned and established by industry and Australia's state and federal governments to operate Australia's National Energy Market (NEM), initiated the **VPP Demonstrations** project in 2019 to trial and study the creation and operation of VPPs across the NEM. This chapter will describe the project and its genesis, and the lessons learnt from it.

2.3.2 Policy gap addressed

In 2018, during the development of the VPP Demonstrations project, several VPP portfolios were already operating across the NEM. The first of these in Australia was established in 2016, in the state of South Australia, a region that has proven itself in recent years to be a world leader in achieving very high levels of renewable power generation. In December 2021, generation from renewables in South Australia reached 100% almost every day, with wind and solar generation combined, averaging almost 80% over the entire month (OpenNEM, 2022). Generation from *rooftop* solar alone reached over 28%.

In 2016, there was a sufficient number of small-scale batteries installed for the major power retailer, AGL, to roll out the world's largest solar VPP demonstration, involving 1000 connected batteries (AGL, 2016). Providing 5 MW of peaking capacity and 7 MWh of storage, this project was a sign of things to come, particularly for South Australia. A further VPP in the state, led by Tesla, is to became the largest in the world at the time, with a total of 50,000 households connected (SA Department of Energy and Mining, 2018).

The projected growth in size and number of VPPs has created a strong impetus to better understand the potential of VPPs to impact the NEM, as well as what capabilities will be required to facilitate a secure and operable power system in the future, when there will be larger numbers of DERs (AEMO, 2021b).

Given the AEMO's remit over NEM regulation and its direct connection to state and federal governments, it was the obvious choice to develop and execute a trial to assess the various capabilities of VPPs and how their establishment might be catalysed. Given their nascency in

2018, there was, then, no federal effort to understand the regulatory framework best suited to both manage and incentivise their growth into a significant force in Australia's power system. The rapid pace of change of Australia's power system in recent years, beyond that of most developed countries, gave an urgency to this task (AEMO, 2019a).

In 2018, the South Australian government introduced an AUD 100 million home battery subsidy scheme, as part of its efforts to manage the world-leading penetration of renewable energy in its section of the NEM. This is a key reason why the majority of VPP portfolios in Australia around this time were in South Australia. The federal Labour Party, in opposition in 2018, committed to support the installation of 100,000 new home batteries with an AUD 200 million scheme if it were to win the 2019 federal election (Clean Energy Council, 2019). It was not elected to power in 2019, but this was further incentive for the establishment of a framework for better understanding, and pre-empting the looming wave of, home battery installations and the VPPs likely to follow.

Conversely, the conservative federal government in Australia, in power since 2013, had long expressed scepticism over the role of renewable energy in Australia's electricity system, and was not taking any policies to the 2019 election that encouraged either utility-scale or distributed renewable energy technologies. In either eventuality, there was an argument to be made for an intervention of the type proposed by AEMO with its VPP Demonstration project. In the case of the re-election of the conservative government, there was unlikely to be any federal regulatory engagement with the already booming DER sector. The latter scenario indeed came to pass, with little in the way of federal engagement with industry or regulatory bodies, such as the AEMO, on this issue.

The AEMO, formed specifically to manage the NEM and to lead the design of Australia's future energy system, was therefore the primary stakeholder in executing the necessary actions to prepare for the projected rise of DER (AEMO, 2022c). The VPP Demonstrations project was formulated to inform such necessary actions.

2.3.3 Description of the policy

Reason for introduction

The potential for small-scale batteries in Australia is great, with a 'step-change' scenario published in 2021 by Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO), showing 40 GWh of capacity in the NEM by 2050 (Graham, 2021). This represents more than a hundredfold increase on currently installed capacity, and would have a profound impact on Australia's electricity system. With residential demand for batteries already strong in 2018, an urgency arose to understand the implications of the rise of home batteries for the NEM, and of informing the necessary regulatory response.

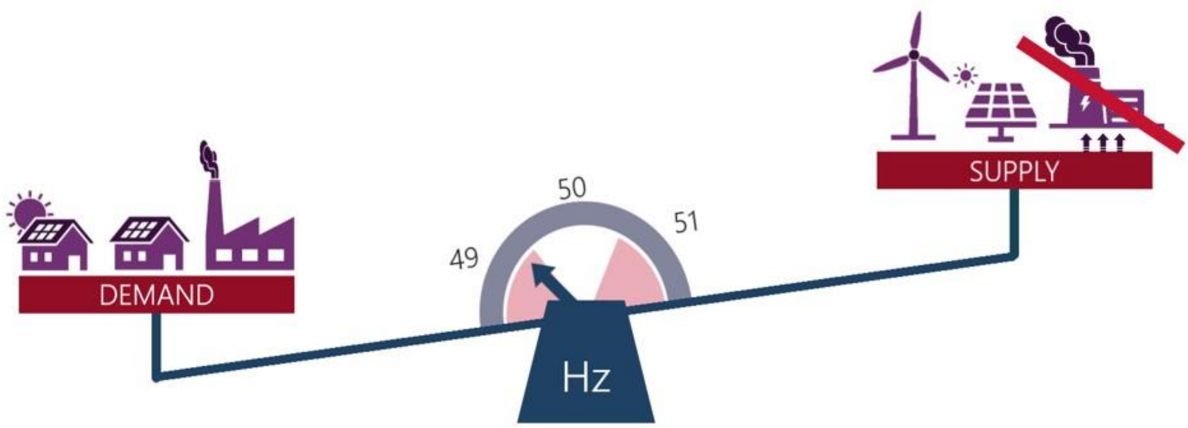
The AEMO proposed a two-year project that would provide sufficient data to illustrate these implications and to discern what the optimal regulatory response should be. To achieve optimal project design, the AEMO initiated an extensive consultation process with industry stakeholders to determine a set of key objectives, remaining flexible in order to incorporate new lines of enquiry over time as deemed necessary.

The five key objectives for the project that developed through this process were:

1. Understand whether VPPs can reliably control and coordinate a portfolio of resources to stack value streams relating to frequency control ancillary services (FCASs), energy, and possible network support services to distribution network service providers (DNSP).
2. Develop systems that provide AEMO with operational visibility of VPPs, to understand their impact on power system security, local power quality, and how they interact with the market.
3. Assess current regulatory arrangements affecting participation of VPPs in energy and FCAS markets, and inform new or amended arrangements where appropriate.
4. Provide insights on how to improve consumers' experience of VPPs in future.
5. Understand what cyber security measures VPPs currently implement, and whether VPP cyber security capabilities should be augmented in future (AEMO, 2021b).

Relating to the first objective, AEMO aimed to test a new FCAS specification that differed slightly from the existing specification covering participation in FCAS markets. FCASs help to maintain grid frequency at nominal levels, which is critical to maintaining grid stability, through a rapid injection or reduction in energy. At extreme levels, divergences in generation and load, that cause such variations in grid frequency, can lead to cascading failure and blackouts (see **Figure 2.1**). Traditionally provided by coal and gas generators, FCASs are now increasingly being provided by batteries, both grid and residential-scale, as well as wind power.

Figure 2.1: Depiction of a decline in generation lowering grid frequency, and consequently, stability.



Source: AEMO (2020).

In recognition of the importance of this work, the Australian Renewable Energy Agency (ARENA) contributed funding of AUD 3.46 million to the VPP Demonstrations project, roughly half of the total project cost, of AUD 7.07 million (ARENA, 2022). ARENA is an independent agency, though funded by the federal government, and is Australia's primary vehicle for funding an acceleration in the pace of pre-commercial innovation in the field of renewable energy.

2.3.4 Description of policy

The achievement of the AEMO's objectives required careful policy design, detailed in this section. It was determined by AEMO that to achieve the various objectives, the project duration should be a minimum of 12 months, with extension if necessary to allow gathering of sufficient operational data or until arrangements for ongoing market participation can be put in place (AEMO, 2019b).

To encourage participation from VPPs as intended, an interim amendment was made to the existing specification covering the provision of FCASs. The amended specification is called the VPP Demonstrations FCAS Specification. The amendment enabled a battery to be registered at its connection point as both a negative and positive load simultaneously. Previously, batteries at the connection point were required to be registered separately as a negative load, and again as a positive load. In addition, the previous measurement and monitoring specifications of FCASs were altered to make this process easier. Overall, these two changes aimed to lower the cost of participation in contingency FCAS markets (AEMO, 2019b).

To enable operational visibility, the AEMO developed a series of data submission interfaces that trial participants could use to submit the required data, as outlined by AEMO. These application programming interfaces (APIs) were broadly categorised into the following groups: enrolment data, FCAS response data, VPP operational data, and telemetry data. The technical specifications of these APIs were beyond the general scope of this policy analysis.

To ensure the saliency and comprehensiveness of the insights gained for the purpose of improving VPP customer experience, AEMO enlisted a consumer insights specialist to conduct social science research on three key questions:

- What are consumers' experiences of participating in Australia's early stage VPPs?
- Is VPP participation attractive enough for consumers to let VPP operators utilise their assets?
- How can consumers' experience of VPP participation be improved to make it more attractive for consumers to sign up in future?

The selected reviewers developed a multi-staged market research approach that yielded an interim and a final report that are now hosted on the AEMO website. To facilitate this research process, AEMO stipulated that participating VPPs must supply at least three quarters of their VPP consumers with information about participating in the study. Despite not being obliged to participate, 2400 consumer surveys were completed voluntarily, with an average response rate of 25%.

Each participating VPP was required to complete a cyber security questionnaire during the registration process, designed to determine the maturity of participating VPP organisations' security systems. A US-based cyber security firm engaged AEMO's cyber security team, seeking to examine the VPP use case from a cyber security risk perspective. The insights from this collaboration were published in the final knowledge sharing report.

2.3.5 Evaluation of policy and its effects

The VPP Demonstrations Project operated across the NEM for a period of two years, during which the VPP market expanded considerably, with the number and capacity of VPPs operating on the NEM growing rapidly (AEMO, 2021b). This increased the urgency of obtaining and utilising the insights sought by the project, to ensure an efficient and sustainable integration of these innovative actors within the energy system.

Broadly speaking, the VPP Demonstrations Project was a success; it achieved its core objectives, the details of which will be laid out in detail in the following subsections. The information collected by the AEMO will be invaluable in shaping the evolution of the Australian VPP market over the coming years and decades, with all relevant stakeholders (consumers, VPP companies, DNSPs, and the AEMO itself) ultimately benefitting from the insights gleaned over these two years of its operation.

VPP capability for market participation

Throughout the duration of the VPP Demonstrations Project the AEMO observed several instances of VPPs reliably and effectively providing contingency FCASs, including in response to major power system events (AEMO, 2021b). Several instances of successful provision of various types of FCASs over various regions of the NEM were also observed.[1] Conversely, there were three identified instances of under-delivery, that were all identified as preventable,[2] with processes and systems updated where necessary to ensure this would not happen again.

As there was no penalty imposed on participants for over-delivery, AEMO observed that VPPs typically had an over-delivery buffer, meaning VPP operators usually ensure they have more

[1] These included delivery of several variable/proportional and standard switch responses.

[2] Reasons for instances of under-delivery were: a needed firmware upgrade to ensure appropriate frequency support settings were enabled, an error in approach to value stacking that led to batteries discharging when they should not have, and incorrect drop rate setting (7% instead of 0.7%).

capacity available than what they are enabled for, to lower the risk of under-delivery (AEMO, 2021b).

Optimal operational arrangements for VPPs will differ, based on whether they are configured for the FCAS or energy market. Information gained on participation in FCAS markets has been fed into both the Market Ancillary Services Specification (MASS) consultation process, as well as the Integrating Energy Storage Systems rule change process, with the latter being changed to allow higher and lower contingency FCASs to be provided by VPPs.

Operational visibility

To ensure a power system maintains operational stability, three key factors must be accounted for by the system manager: visibility, predictability, and coordination. With VPPs being an emerging technology, though set to play an increasingly significant role in the future energy system, they must be assessed against these factors (AEMO, 2021b).

The AEMO requires visibility of any controllable resources in a VPP portfolio, including not only demand-side DER-like batteries, but also rooftop solar PV. For this purpose, gross data which include information on activity behind the meter (BTM) is preferable to net data, which can hide battery charging as low solar PV generation, for example.

Reliable forecasts of load or generation shifting is necessary for publication to the market or for generation scheduling. This includes both *operational* forecasts, which relate to the aggregated generation or load under control in each VPP portfolio, and *availability* forecasts, which show the available capacity of generation or load in each VPP portfolio, both in five-minute resolution. In addition, data are provided on the actual performance of the VPP portfolio, in terms of delivered aggregate generation or load, also in five-minute resolution.

Though the trial VPPs provided forecast schedule data to the AEMO throughout the trial, they were not bound by their forecasts, and often diverged from it. If this was to be improved, it was found that that VPPs would not necessarily need to participate in central dispatch,[3] at least not until the capacity of VPPs reaches certain thresholds that currently differ significantly state by state (AEMO, 2021b).

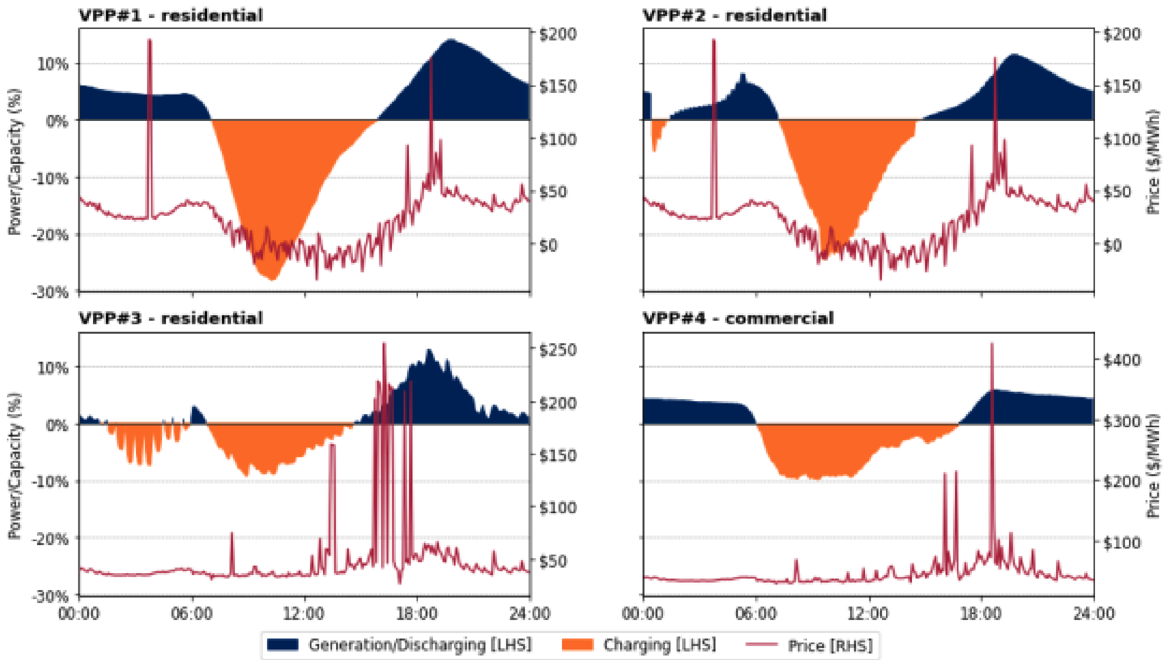
With regards to the data transfer framework established via four APIs, it was deemed that none of the four APIs was the suitable long-term solution for establishing real-time visibility. The reasons for this varied from a separate system that facilitated future enrolments, participant difficulty in API development, lack of necessity until greater VPP capacity exists for the mandated extent of forecasting data, or for the device-level telemetry data that were required under the VPP Demonstrations project.

[3] Central dispatch refers to the process where the transmission operator determines generation and consumption schedules, as well as dispatching generation and demand facilities.

Market dynamics and planning insights

Data received from the participating VPPs were analysed to understand the extent to which they responded to energy FCAS market price signals, with all eight participating VPPs displaying similar charging and discharging behaviour. This largely aligned with an optimisation of household self-consumption as opposed to responding to price signals (see **Figure 2.2**).

Figure 2.2: VPP average normalised daily operational profile and average daily price per region (1 December 2020 to 28 February 2021).



Note: Power/capacity ratio refers to average VPP power in MW divided by total VPP capacity.

Source: AEMO (2021b).

Even with extreme variation to price, there was limited response, with only three out of seven VPPs responding at times, and the most responsive of these responding less than two out of five times. This suggests that other factors, such as contract specifications between operators and customers and algorithms used to manage VPP charging and discharging, were much more impactful.

The customer type proved to be a significant factor affecting charging and discharging behaviour, with residential customers showing consistently high discharging during evening peak periods compared to considerably lower discharging during this time for commercial customers (see **Figure.2**). Commercial customers also showed a smaller daytime level of charging, with solar output prioritised for high daytime demand.

Battery size was also shown to affect charging/discharging patterns, with smaller batteries being used more to recharge in early morning hours after depletion during the previous evening peak demand period. The average daytime charge for smaller battery systems was generally lower than for larger systems.

A key insight garnered through the duration of the project is that if capacity was extrapolated out to a very large VPP sector, it could substantially contribute to peak demand management, and lessen the duration of negative spot prices (AEMO, 2021b).

With regards to FCASs, it was shown throughout the project that VPPs often bid at very low prices, often undercutting traditional providers, such as coal-fired power stations. With a sustained growth of VPPs, overall FCAS prices and costs could fall considerably if such low bids were to continue. Their share of the overall FCAS market grew rapidly over the duration of the project, from 0.6% to 3% over just the twelve months to April 2021.

Local power quality issues

Local power quality issues, particularly in areas with a high concentration of rooftop solar PV systems, have been shown to limit VPP performance (SA Power Networks, 2021). When local voltage is high due to high rooftop solar output, VPP capacity can be reduced due to the VPP battery inverters reducing the available power output. In addition, VPP discharging can also increase local system voltage to a level where solar and battery inverters in the area trip and self-curtail. These issues arise due to the VPP's lack of awareness of local network capacity.

It was also found that the five-minute telemetry data received from VPPs, in addition to helping understand VPP impacts on the overall network, could also help to build an understanding of the underlying performance of the low voltage network and identify issues unrelated to VPP operations. Two such examples of this potential were the use of data to identify several sites where VPP equipment had been installed incorrectly, and to detect potential shock hazards at some consumers' premises (SA Power Networks, 2021).

Consumer insights

Several key findings arose from the study commissioned by AEMO to provide insights on how to improve consumer experience. In general, the consumer experience of participating in the available VPPs was positive, particularly when consumers assessed their participation as creating value, whether financial, environmental, or to their community (CSBA, 2021). Enhancements to the consumer experience could be achieved with greater understanding of these three key value streams. The majority of consumers indicated that they would be willing to promote participation in a VPP to others.

The single greatest factor affecting sign-up and retention was that of financial savings, either potential or realised; those who either did not identify cost savings or who were unclear as to whether they would realise financial gains, become dissatisfied. The greater the tangible impact that consumers can see resulting from their relinquishing control of their asset, the more accepting of the loss of control they were likely to be.

Cyber security

A future electricity system characterised by a far greater level of decentralisation poses novel cyber security challenges. The aggregation of DER control into a VPP creates the potential for these aggregated devices to not respond to remote instructions or transmit telemetry in a timely fashion, or to respond incorrectly to a required instruction. This could be through tampering of the software, firmware, or settings, or from the manipulation of communications pathways of the DER ecosystem, or through denial of service attacks, whereby a system is flooded with illegitimate requests such that it is unable to respond effectively to a legitimate request (AEMO, 2021b).

Recently passed legislation that increased cyber security obligations on key actors, and expanded the types of actors covered, did not impose any specific requirements on VPP operators, meaning that mitigating cyber security risks remains at the discretion of consumers and businesses (Security Legislation Amendment (Critical Infrastructure) Bill 2021, 2021). As VPPs increase in size, and their impact on Australia's power system increases, the imperative to include VPP operators in the list of actors that is covered by such legislation will increase considerably.

2.3.6 Current and future trends

Recent developments

In June 2021, after the completion of the VPP Demonstrations Project, AEMO released a draft determination on prospective changes to the market ancillary service specification (MASS), which specifies how participants in the FCAS market must act. A critical outcome included in this report was that the relaxed rules of the VPP Demonstration FCAS specification, wherein metering was allowed at the device level, rather than at the connection point, was not continued (AEMO, 2019c). This means that some VPP operators currently in operation on the NEM, including Tesla, will not be able to utilise their current and preferred approach (Allston, 2021).

The overall flexibility in the system as to how VPP operators can supply a FCAS is reduced as a result of this reversion to the existing MASS, while greater resources will be needed to monitor the status of uncontrolled loads. Requiring measurement of generation and load at the connection point financially isolates a battery from the solar PV system, removing the battery's ability to provide solar storage, and significantly reducing the financial viability of joining a VPP (Allston, 2021). The final specification is yet to be released, as of July 2022, and submissions are being assessed in response to this draft specification, with changes to the final specification still possible at this point.

Since the completion of the project, several new VPP products have reached the market on the NEM, and, despite all participants but one failing to generate substantial revenue during the trial period, nearly all of them will continue to offer residential VPP products. This is a recognition of the potential for future opportunity given the lessons gained from trial participation and the likelihood of a steep increase in battery and EV uptake over the next few years.

Potential future developments

Despite the profit margins realised by VPPs currently being slim, the number of VPP operators on Australia's NEM has increased dramatically in just a few years. A likely reason for this is the clear future potential VPPs have to transform the power system and tap various income streams, providing an enticing prospect to establish early market prominence in a sector with very large growth potential.

While the current VPP market participants are limited in the services they can provide, the development of increasingly sophisticated algorithms and software will improve their ability to provide a range of FCASs, while household VPPs will likely be able to participate in the wholesale energy market, contribute to minimum system load requirements, and provide distribution network services (Kuiper, 2022).

2.3.7 Discussion

The lofty prediction by the AEMO of up to 700 MW of participating capacity in VPPs across the NEM by 2022 has failed to materialise, with an estimated total of 300 MW rolled out by the first half of 2022 (Kuiper, 2022). A key factor in this shortfall is likely to be the estimated slim margins for VPP operators and low profitability experienced by many customers that were part of the VPP Demonstrations Project. The average annual household saving from participation in a VPP for the duration of the project was roughly AUD 200, far less than the potential saving that could have been generated by storing and using BTM solar PV generation (Kuiper, 2022).

The VPP Demonstrations Project saw participation from VPPs with four distinct business models for residential customers, all in a nascent state and likely to evolve considerably with the rapidly shifting economics and potential revenue streams of VPPs (Kuiper, 2022). Noted future revenue streams that are likely to improve VPP commercial viability include provision of regulation and fast frequency response FCASs, household participation in wholesale demand response, and greater provision of distribution network services.

One key factor that has the potential to drastically change VPP economics is the projected proliferation of EVs, that can also be used as BTM storage, with battery capacities usually three to four times larger than standard household battery models (Graham & Havas, 2021; Purtill, 2021). These larger capacities have greater potential to shift the "solar peak" by absorbing more solar PV generation, to be released during peak demand hours when electricity prices are at their highest.

The looming retirements of thermal plants that currently provide the bulk of FCASs will create greater opportunity for VPPs to provide these services, further improving overall profitability. In addition, as total rooftop solar capacity continues to increase, exported generation will increasingly displace centrally generated power, eroding current retailer revenue streams. In this environment, retailers who are able to effectively aggregate these DERs and manage their exports are likely to establish a competitive advantage over those more reliant on traditional income streams. Under this future scenario, if a retailer does not have an established relationship with prosumers that enables access to these resources, it will find itself with few customers to sell to, implying a struggle to maintain profitability. Under the most optimistic scenario recently modelled for the AEMO, the share of households with solar PV reaches over 50% by 2050 on the NEM, and over two thirds on the South West Integrated System that includes Perth and the surrounding region (Green Energy Markets, 2021).

In early 2022, one of Australia's largest retailers, Origin Energy, announced that it would embark on a tenfold expansion of its 205 MW VPP over the next four years. In justifying this much greater focus on expanding its VPP, Origin noted that it "Creates lower churn, deeper engagement and seeks to fulfil customers' expectations for lower costs, decarbonisation and energy autonomy" (Calabria & Tremaine, 2022). Furthermore, the upfront costs to establish or expand a VPP are very low compared to large-scale generation assets.

Currently, the large majority of VPP participants in Australia are households, so incorporating commercial and industrial (C&I) customers into VPPs or creating exclusively C&I VPPs in the future has great potential. Many such companies have large premises with ample rooftop spaces that are ideal for larger solar PV systems and therefore larger batteries, helping VPP aggregators to reach the scale necessary to provide certain grid services much more easily. In addition, the hardware requirements and contractual overheads that arise when engaging and managing hundreds or thousands of customers are far greater than for a handful of C&I customers that constitute the same total capacity (Dufresne Research, 2022).

There are other, more technical reasons why larger C&I customers are beneficial to a VPP, including: more complimentary battery value stacks with less contest for battery control from different value streams, the tendency for residential VPPs to be derated due to greater export during daytime hours, lower marginal cost of enablement for C&I VPPs, and the ability for a

C&I battery to access the wholesale market without needing to link a battery or VPP investment to a specific retailer (Dufresne Research, 2022).

As of 2022, there was one retailer with a C&I VPP in Australia, with the majority of its capacity participating in the FCAS markets. Much of this capacity is demand response, rather than rooftop solar with batteries but, given the rapidly increasing number of commercial-scale solar PV system installations in Australia, this is likely to change with future market entrants (CER, 2020; Enel X, 2022).

Over the course of the project, VPP responses to price signals varied considerably. This was in part due to the variation in contract structure, whereby some retailers imposed more stringent restrictions on the use of systems by customers (AEMO, 2021b). This variation made forecasting VPP behaviour difficult, and demonstrates that without achieving greater consistency, network operational forecasting will prove challenging as VPPs begin to scale.

In general, it was found that VPP batteries showed a smaller and less predictable response than anticipated. This was in part due to the nascency of the established VPPs, as several participating companies noted in a post-trial survey that they would seek to better consider wholesale prices in their dispatch algorithms in future (AEMO, 2021b). Such algorithms were shown to improve over the course of the trial, with charging and discharging periods becoming more optimised to respond to evening peak demand periods.

As VPP responses to energy spot prices improve over time, their ability to improve the overall efficiency of network operation will increase markedly, providing that energy market rules and procedures enable their effective operation. This implies that early and consistent engagement with network regulatory bodies is crucial to enable a smooth scaling up of VPPs and their positive impacts on network operation. Ensuring sufficient and accurate data collection and processing in the nascent stages of VPP proliferation is crucial for informing such discussions.

Although the VPP Demonstrations Project did not cover the delivery of local network services, some clear lessons for establishing and optimising relationships between VPPs and DNSPs were evident. Two VPP operators noted that local power quality issues in areas with high penetration of solar PV systems led to lower VPP performance and ability to deliver market services (AEMO, 2021b).

Ensuring VPP operators are able to receive real-time localised network conditions and respond accordingly will optimise both network and VPP performance. Greater flexibility in export limits, for example, that allow VPP participants to increase exports when local grid conditions can accommodate them, could maximise participant earnings, while ensuring the greatest possible contribution to managing periods of peak demand. Conversely, limiting exports during periods of grid congestion can help to minimise localised power quality issues.

Optimising export levels from participants can also act to incentivise the purchase of larger solar PV systems, that provide VPP operators with greater flexibility to respond to price signals.

One DNSP received operational telemetry data during the project that served to improve its understanding of the underlying performance of the low voltage network and the VPP's overall impact on the network and helped to identify other issues unrelated to VPP operations.

2.4 Case study 2: Community batteries

This section will delve into Australia's experience with establishing community batteries. Section 2.4.1 opens the case study with the existing solar power capacity and how problems integrating such power from DERs has been addressed through energy storage systems, giving perspectives from the customers' experiences. Section 2.4.2 goes into more detail with the outcomes of the community battery project at Alkimos Beach, the PowerBank trials, and other trials developed across Australia. Sections 2.4.3 and 2.4.4 discuss the changes to the regulatory framework and the political support surrounding their adoption, detailing the profitability, affordability, and required network changes. Section 2.4.5 discusses the assessment of the policy. Lastly, Section 2.4.6 concludes by discussing the suitability of this approach.

2.4.1 Context and background

The widespread adoption of household solar PV, especially in Southern Australia — as described in previous sections — has brought myriad benefits, but also challenges. The grid has struggled to keep up with the greater-than-expected uptake of solar PV and has been placed under increased strain during peak demand (AEMO, 2021c). Periods of oversupply, when weather conditions favour solar energy, can also be challenging as they may lead to spikes in voltage levels that damage the system. Solar curtailment is used to counter this, whereby household solar systems stop exporting to the grid, or even shut down, to prevent excessively high voltage levels (Yildiz et al., 2021). This leads to energy being wasted, and although the average home loses less than 1% of its power production to curtailment, some households lose as much as 20% due to factors such as location and local electricity network equipment (ibid).

Installation of household batteries is the most popular way of mitigating this issue. However, a larger battery serving a number of households, known as a community battery, is a more efficient way of dealing with this challenge. Community batteries are shared neighbourhood battery systems that improve grid reliability in a local area and promote a higher uptake of household solar PV systems (Western Power, 2022a). They tend to be of greatest use in neighbourhoods where there are a lot of homes with rooftop solar PV, sending large amounts of electricity into the grid (Mountain & Burns, 2021). As use of the storage is virtual, rather than purely geographically bound, there is greater flexibility for all stakeholders.

Additionally, customers stand to gain directly from community batteries through reduced electricity costs. This would involve a corresponding financial mechanism, such as through a credit system. In this case, customers who generate excess electricity with their household PV systems are granted a credit for the net energy created. They can then draw the credit down at a later point, e.g., in the evening when rates are highest. This allows customers to reduce the amount of electricity they pay for, especially at peak rates (Synergy, 2021).

Although it is possible to install storage at the household level, community batteries require no upfront costs and are around 30% cheaper over the course of the battery's lifespan (Western Power, 2022a). Ultimately, benefits at both the grid and customer level help to ease the clean energy transition and support a greater uptake of household PV systems, which is a critical aspect in meeting Australia's Paris Agreement obligations.

2.4.2 Leading the way: trialling community batteries

The Alkimos Beach trial

The potential of storage to take stress off the grid, avoid heavy upfront investments, and offer lower prices for customers makes a community battery a useful solution for the issues facing the Australian electricity grid. Several trials have been undertaken to assess how community batteries work in practice.

The first of these began in April 2016 at Alkimos Beach in the state of Western Australia (WA). Alkimos Beach, located in Perth's northern suburbs, has been a trailblazer in terms of addressing environmental concerns. It is Australia's first six-star 'Green Star' community, meaning it leads the world across a range of environmental and social indicators (World Green Building Council, 2018). The community's openness to emerging sustainable technologies made it an attractive location to trial the country's first community battery.

The project was conducted by Synergy and Western Power, two state-owned companies. Synergy is a retailer, while Western Power manages the network. The intention of the trial was to gather information about how to deploy community batteries at a larger scale in the near future. There was a mandatory requirement for all homes in the suburb to install a solar PV system and an efficient hot water system, adding to the community's suitability for the trial, as high solar PV penetration was then guaranteed (Synergy, 2021). Once the site was selected, a 1.1 MWh lithium-ion battery was stored in a shipping container, as shown in **Figure 2.3** below.

Figure 2.3: The site of the first community battery storage trial in Alkimos Beach.

Source: Lendlease Communities (2018).

All participants in the trial, of which there were 119 residential households (Purtill, 2022), paid a simple time of use (ToU) tariff called the Peak Demand Saver plan (PDS). The plan had two rates across three-time bands: off-peak day, off-peak evening, and peak daily, as outlined in **Table 2.1** below. The peak period charged almost twice the rate of the off-peak periods, with the aim of taking pressure off the grid during peak demand by incentivising energy use during off-peak periods.

This fluctuation in price was greater than rates outside of the trial, with the off-peak prices lower than those on standard rates, while the peak prices were higher (Lendlease Communities, 2017). Alongside the ToU tariff was a monthly subscription fee of AUD 11, which was heavily subsidised by the companies (Synergy, 2021).

Table 2.1: PDS time bands and their associated rates.

PDS time band pricing	
Time bands	**Rate**
Off-peak day (midnight - 4pm)	26.8145 c/kWh
Off-peak evening (8pm - midnight)	26.8145 c/kWh
Peak daily (4pm - 8pm)	51.1995 c/kWh

Source: Synergy (2021).

It is common in Australia for households with PV systems to sell excess energy back to the grid. During the Alkimos Beach trial, participants instead received credits which would then offset energy consumption during the day's two latter time bands, i.e., peak daily and off-peak evening. If, at the end of a billing period, a participant generated more solar credits than they used in the latter two time bands, they could then receive Solar Sell Back credits at the end of the billing period (ibid).

The ToU tariff was aimed to shift energy use to off-peak times, which was indicative of another aspect of the trial — that of energy efficiency incentives. Alongside community-scale storage infrastructure, the effect of energy efficiency incentives on reducing household energy costs and reducing pressure on the grid was central to the trial. All homes in the Alkimos Beach community received an AUD 4150 Energy Smart Home Package. This included rebates for solar PV systems, heat pumps, and energy-efficient air conditioning systems (Lendlease Communities, 2022). Synergy, in cooperation with its community partners, organised eco-coaching programmes to assist residents with reducing their electricity consumption and installed smart meters to develop understanding of consumption behaviour (Synergy, 2021).

After five years, the trial concluded in May 2021. In its assessment of the trial, Synergy noted numerous lessons for the future deployment of community storage. Regarding the engagement of stakeholders, it was found that engaging the community in the early stages contributed to the acceptance and success of the project. Equal importance was given to regularly updating participants on the progress of the trial (Synergy, 2021). Yet it was also found that there was more trust among participants towards community partners, as some residents suspected Synergy of exaggerating potential savings (ibid). Despite workshops being held to explain the pricing system, there was still confusion among participants as to whether they would save money (Purtill, 2022).

The same could be said of stakeholders in the planning process. By engaging with them early and continuously updating them of developments, obstacles were pre-empted and rectified. For example, the aesthetics of the CESS was important to the local council, so a visual animation of the site was helpful in receiving approval from local authorities in this regard (Synergy, 2021).

The timing of the trial's launch coincided with, what was at the time, Perth's coldest winter in more than twenty years (Farcic, 2017). This proved to be problematic, as energy bills were higher than normal. Several trial participants dropped out (Synergy, 2021), indicating a portion of the blame was directed at the storage trial. To this end, launching in spring or summer could have avoided bad first impressions and retained some of the participants who dropped out early.

Despite the early complications, the trial was successful in reducing electricity costs for participating households (see **Table 2.2**) Around 83% of participants benefitted financially, with the average household saving AUD 683.80 over the course of the trial. This translated to AUD 35.83 per bill (ibid). Naturally, the extent of savings varied depending on household characteristics, such as the number of people in the home. However, the AUD 11 subscription fee was highly subsidised and not commercially viable. Although the low fee meant customers got a good deal, it also prevented the trial in its current form from being brought to market.

Table 2.2: Savings received by PDS participants over the course of the Alkimos Beach trial.

Measure	Total
Participants	119
Bill issued	2.271
All participants total savings	$81,376.00
Average participant saving	$683.80
Average participant saving per bill	$35.83
Peak consumption offset	85%

Source: Synergy (2021).[4]

From a grid perspective, participants on the PDS tariff reduced their network electricity consumption during peak periods in comparison to the control group. This was due exclusively to their electricity use being supplemented by the battery, as their peak consumption remained the same (ibid). This reduction of peak network consumption was one of the project's primary concerns. Multiple benefits from reduced pressure on the grid during peak periods can thus be realised through community batteries, including a decreased threat of blackouts and less wear and tear on the transmission and distribution lines. However, the high costs of the Alkimos Beach trial meant there was not a sufficient business case for the trial to be expanded at scale. Yet the trial did show that the deployment of storage technologies at the community level could be achieved. A more sustainable tariff structure would therefore be crucial to the widespread deployment of community batteries.

The Alkimos Beach community battery did not receive a discount on network tariffs. This partly explains the challenge in making the trial economically feasible. Efforts to solve this issue, such as a discount for use of system charges when the battery draws electricity from the grid, could be an important step towards increasing the profitability of community batteries. Discounted network tariffs may involve changing some of the battery's operating parameters or sometimes using it for network purposes (Mountain & Burns, 2021).

PowerBank trials

In 2018, midway through the Alkimos Beach trial, Synergy and Western Power partnered on another set of trials in WA known as the PowerBank trials. The PowerBank is a form of community battery which integrates bulk solar energy into the grid while providing virtual storage to customers for their excess solar energy (Western Power, 2022b). The PowerBank model allows customers to virtually store up to 6 kWh or 8 kWh of excess solar power.

[4] The savings were calculated by comparing the costs incurred by all participants during the trial with the costs they would have incurred on the standard residential government regulated Home Plan (A1) while they were participating in the ABEST.

Depending on each household's existing energy use, Western Power recommends whether the 6 kWh or 8 kWh option is more suitable (ibid).

As was the case in the Alkimos Beach trial, customers do not pay upfront investment or maintenance costs for the battery. However, the ownership model is different. The Alkimos Beach trial was a retailer-led project as the battery was owned by Synergy. In the case of the PowerBank trials, Western Power owns the equipment while Synergy delivers the customer-side product (Energy Transformation Taskforce, 2019b). In other words, the battery is network-owned rather than retailer-owned.

The trial was launched as a solution to pressure on the network due to high rooftop solar PV penetration. There have been several stages, with the first iteration taking place in Meadow Springs, a suburb of Mandurah. Meadow Springs was deemed a suitable site for the initial trial as the suburb has one of the highest rates of rooftop solar PV in Australia (Energy Transformation Taskforce, 2019a). This was the first time in Australia that a utility-scale battery was integrated into an already established metropolitan network and made accessible to individual customers (Maisch, 2018).

Some of the trial's central objectives were to gather performance insights, test the physical capabilities and needs of the infrastructure, and explore potential profitability (Energy Transformation Taskforce, 2019a; Western Power, 2022b). After proving to be efficient, Western Power expanded the trial to the communities of Falcon and Ellenbrook. There were also significant savings for customers (although, like at Alkimos Beach, the trial was highly subsidised in order to test which kinds of households suit battery storage the most). In the first year alone, participants saved AUD 228, with this collectively amounting to AUD 11,000 among the 52 households (Carroll, 2021a).

There are caveats to the amount customers save, depending on their energy use patterns. Many customers had power remaining in the battery at midnight when the virtual product resets and the remaining energy is bought back. This meant that consumption between midnight and dawn was not drawn from the virtual battery, whereas customers who own a behind-the-meter battery would have been able to access this energy (Energy Transformation Taskforce, 2019a). Batteries can be extremely useful for customers who consume high amounts of energy during the evening peak period. For customers who use their energy throughout the day efficiently, battery storage is not as effective. Western Power supplied advanced meters to each participating household to allow customers to keep track of their energy use (Western Power, 2022b).

The most recent phase of the trial has expanded to nine other locations in WA, bringing the total number of sites to 12. With 600 households participating in this phase, it represents a substantial scaling up compared to earlier stages. The 18-month PowerBank 3 trial commenced in 2021 and is ongoing, meaning that results are yet to be released.

Other trials throughout the country

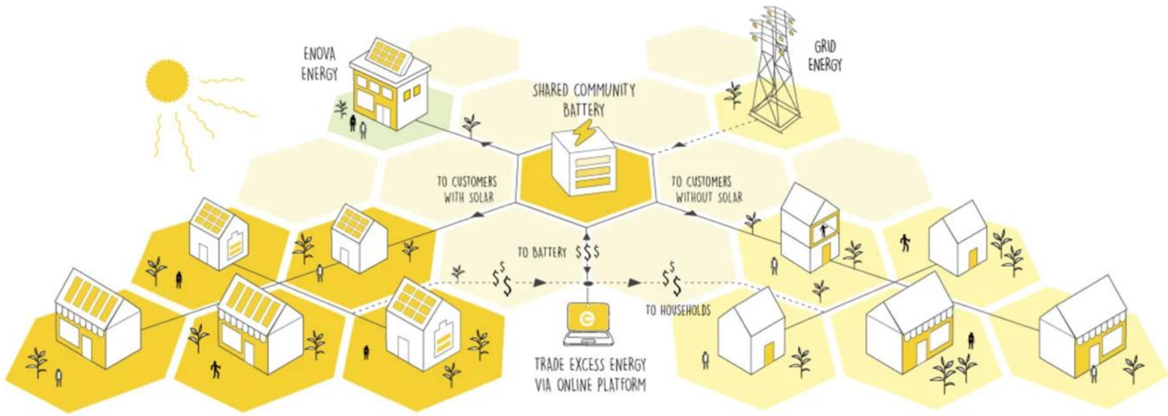
Numerous other trials of community batteries are taking place across Australia, with other states following the lead set by WA. In New South Wales (NSW), network provider Ausgrid launched a two-year trial in Beacon Hill, a suburb of Sydney, beginning in February 2021. 250 households will be serviced by the 150 kW / 267 kWh battery, and each household can store up to 10 kWh of excess solar energy per day (Cohen, 2021). The energy stored by each household is credited against the amount of energy they used on that day. Credits are paid each quarter as a direct cheque rather than as a credit on the household energy bill. Excess energy is then used to smooth demand and help cut costs for the wider community (HIP V. HYPE Sustainability, 2021).

The Beehive Project, also in NSW, is a first-of-its-kind shared community battery[5] trial in Australia. The trial includes 500 participants, of which half have rooftop solar systems and half do not. The 1.07 MW / 2.14 MWh battery is not designed to discharge power exclusively to the homes that feed it energy throughout the day. Instead, the energy circulates throughout a community of participants by customers sharing and trading it on an app (Enova Energy, 2021; HIP V. HYPE Sustainability, 2021). Energy usage from households with solar is matched with non-solar households and participants can then conduct transactions with each other as well as with the battery itself. This peer-to-peer trading allows participants to access more renewable energy at a price they can decide on (Carroll, 2021b). The flexibility afforded by this model lets renters participate in the project and allows people to move homes and continue their involvement in the trial (HIP V. HYPE Sustainability, 2021). The NSW Government is a major funder, providing AUD 1 million to support battery costs, the upkeep of the app, and university-led research into how the project functions (Enova Energy, 2022).

The "beehive" serves as a useful metaphor for understanding how the project functions. The bees are the households producing and consuming the energy, which constitutes the honey. The trading platform represents the honeycomb, while the battery is the queen bee. This concept is shown in **Figure 2.4.**

[5] It is called a "shared community battery" because the stored energy is distributed to households that are not geographically close to the battery (Enova Energy, 2021).

Figure 2.4: A visual representation of how the Beehive Project works.



Source: Enova Energy (2021).

In Victoria, the Fitzroy North community battery is Australia's first inner-urban community battery (Yarra Energy Foundation, 2022a). The initiative is led by the Yarra Energy Foundation (YEF), a not-for-profit focused on clean energy, that is connected to the city council. The project benefitted from funding from the state government's AUD 11 million Neighbourhood Battery Initiative (ibid). The 110 kW / 284 kWh battery provides power to everyone connected to that part of the sub-network, regardless of the energy retailer they use, whether they have solar panels installed, or whether they own their house (Murray-Atfield & Asher, 2022). Core aims of the project include investigating how to make community battery a financially sustainable business model at scale and how to deploy the batteries within existing regulatory and planning guidelines (Yarra Energy Foundation, 2022a). Part of the YEF community battery initiative's aim is to provide data sharing to the public. **Figure 2.5** provides an example of the electricity transmission by the community battery.

Figure 2.5: A snapshot of the daily charge/discharge ratio of the Fitzroy North community battery.

Note: Live statistics regarding the battery are provided by the YEF. *Source*: Yarra Energy Foundation (2022b).

Also in Victoria, is the 'Electric Avenue' project. The trial is spread across a range of suburbs near Melbourne rather than in one street or interconnected streets. In this case, a fleet of 40 batteries (30 kW / 66 kWh each) is installed on power poles to manage pressure on the local infrastructure (United Energy, 2021b). Unlike other trials, delivering savings to customers is not a central aim of the project. The project is instead designed to improve electricity reliability and enable greater solar PV exports in local areas where there is already considerable pressure on the low voltage distribution network (United Energy, 2021a). At a cost of AUD 11 million[6], the trial is expensive compared to other community battery projects. However, it is still significantly cheaper than traditional network investments (United Energy, 2021b).

Although customers are unlikely to see reductions in their energy bills as a direct result of the Electric Avenue trial, they stand to gain in other ways. During peak demand, the network struggles to physically move enough electricity to meet customer needs and there is a threat of outages. The Electric Avenue project thus improves reliability while increasing access to renewable energy. At the same time, customers save on network charges that would otherwise be higher if traditional network upgrades were required (United Energy, 2021b).

2.4.3 Recent updates to the regulatory environment

Since the adoption of the first community batteries, there have been updates to the regulatory environment, with the intention of removing barriers to entry for emerging technologies such

[6] AUD 4 million is provided by the Australian Renewable Energy Agency (ARENA) while United Energy, the network that owns the batteries, will fund the remainder (Colthorpe, 2021).

as storage in the WEM. In 2017, the Australian Energy Market Operator (AEMO) announced a change to rules surrounding the settlement period for the electricity spot price. The change came into effect in October 2021 and reduced the settlement period from 30 minutes to 5 minutes (AEMO, 2021a). Under previous rules, imbalances existed between operational dispatch and financial settlement. Although there were already five-minute dispatch markets, the price associated from one window to the next was averaged out over 30 minutes. If a battery asset dispatched energy when prices were high, but prices dropped afterwards, the battery received a lower payment for the power than what it was worth when dispatched (AEMC, 2017; Colthorpe, 2021). This impeded the introduction of batteries, which are extremely fast in responding to grid and market signals. The new rules allow for this service to be more accurately valued, thus removing a key barrier to market penetration.

In December 2021, the Australian Energy Market Commission (AEMC) established a rule making it easier for batteries to enter the market. A single category, known as the Integrated Resource Provider (IRP), was established which allows storage to register and participate in the National Electricity Market (NEM) in a more efficient way (AEMC, 2021a). The rule enables community batteries to participate in providing FCASs. The AEMO specifies in its ruling that, for community batteries to compete in contestable markets (providing energy and FCASs), they must be operated by a market participant (e.g., a retailer) and not distributed network service providers (DNSPs). However, no changes were made to network charges. Although the AEMO recognised the calls from stakeholders to exempt storage from network charges, as the energy market transitions to a more price responsive load and more dynamic environment, major changes are yet to be announced. However, it noted that it anticipates a rule change request from interested participants which will allow the Commission to consider such a rule change in more depth (AEMC, 2021a, 2021b).

Recent rule changes have eased the ability of network companies to provide community batteries (National Energy Retail Amendment Rule 2022 (SA), 2022; National Electricity Amendment Rule 2022 (SA), 2022). Networks, or DNSPs, have been impeded from providing community batteries to promote competition in the market. The process has since been streamlined, whereby projects are evaluated based on their risks to market competition versus the benefits to customers and the grid. As WA is not part of Australia's main NEM[7], the involvement of networks in providing community batteries had already been ongoing. The new changes therefore bring the rest of the country more in line with WA. The rule changes also assist the establishment of stand-alone power systems (SAPS). These can be particularly useful to remote communities out of reach of existing power lines as well as for communities who lose access to the network due to natural disasters (ibid; AEMC, 2022).

[7] The Northern Territory is also excluded from the NEM.

2.4.4 Political support at the national level

Community batteries have seen a big political push from the Australian Labour Party's endorsement of them during the 2022 federal election. It is part of Labour's Powering Australia plan, which aims to promote economic growth, reduce emissions, and cut household energy bills through a suite of energy initiatives. Regarding community batteries, Labour has promised to invest AUD 200 million to install 400 community batteries across Australia, something which can impact up to 100,000 households (Labor, 2021). This will be combined with Labour's Australian Made Battery plan, which intends to develop a 'National Battery Strategy' and support the domestic battery manufacturing industry (Labor, 2022). Since winning the election, Labour's plan is now government policy. If the promised investments are realised, Labour's election will mark a significant shift for Australia's storage industry.

2.4.5 Policy Assessment

A common thread across many of Australia's trials is how to design a model that is financially sustainable for all parties. Many of the trials, as indicated by the Alkimos Beach and PowerBank projects, are highly subsidised. While this, effectively, guarantees savings for customers, it is not economically sustainable for networks and retailers. It is imperative then to develop a tariff system that benefits all stakeholders. Recent updates to the regulatory environment are positive steps in making market participation easier but more needs to be done. Updating the rules around network charges has significant potential to increase the profitability of community batteries.

During the Alkimos Beach trial, there were no explicit regulations relating to how battery storage would participate in the Wholesale Energy Market (WEM) (Synergy, 2021). Network charges are a significant barrier to the deployment of community batteries. In Australia, energy flows between customers and the battery are billed twice: once when the battery imports energy, and again when it exports energy to customers (Shaw, 2020).

Due to the flows between customers with rooftop solar PV and a community battery only using a small segment of the network, network costs are correspondingly lower. The ability of batteries to reduce pressure during peak demand, and to increase demand at times when solar output may otherwise need to be curtailed, help to reduce network costs. However, network tariffs do not adequately reward batteries for their benefits to the system. This is because current tariffs charge customers based on how much energy they use, which is not the main driver of a network's costs. Additionally, the same price is applied to all customers in a particular tariff class regardless of where they are located, even though local demand has a bigger impact on network costs than system-wide demand (Harris & Hoch, 2022).

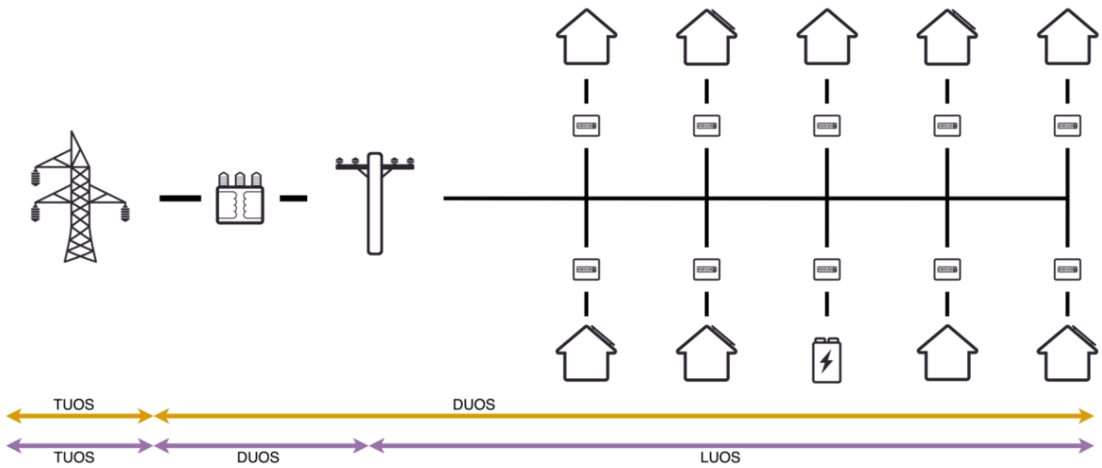
Two complementary changes to network tariffs can be used to rectify issues with valuing community batteries, as illustrated in **Figure 2.6**. Firstly, a local use of service (LUoS) tariff can be applied to reduce costs. Given that the flows between households and a community battery only use a small section of the network, their prices should in turn reflect the lower costs. An appropriately discounted LUoS has significant potential to direct community batteries to service local customers effectively as well as to improve the hosting capacity of the network (Shaw, Sturmberg, et al., 2020). Alongside this can be the application of two-way tariffs. This refers to charging LUoS and distribution use of service (DUoS) on both exports and imports. As this disincentivises batteries from exporting upstream, the network's hosting capacity is thus improved (Harris & Hoch, 2022; Shaw, Sturmberg, et al., 2020).

The Australian National University (2020) has analysed different ownership models[8] and how they can distribute revenue to stakeholders in the energy system. Regardless of the ownership type, a reduced LUoS is needed to make a financial case for community batteries. Although a network-owned for-profit battery has potential to be financially viable under current market conditions, a considerable share of the battery would need to be leased for market participation. Such a model is currently being trialled for a grid-scale battery in Dalrymple, South Australia (ElectraNet, 2019).

Revenue is more difficult to achieve for network-owned community batteries as networks are locked out of the energy and Frequency Control Ancillary Service (FCAS) markets.[9] Ultimately, community batteries owned by a third party have the greatest potential to be financially viable under current regulations while also providing value to the widest range of stakeholders (Shaw, Ransan-Cooper, et al., 2020).

[8] These ownership models are: (1) third-party owned community battery; (2) third-party owned for-profit model; (3) network-owned community battery, and (4) network-owned for-profit battery.
[9] This is done with the aim of preventing monopolies.

Figure 2.6: Different network tariffs in Australia



Note: The orange arrows indicate the current TUoS/DUoS (transmission/distribution) dichotomy. The purple arrows indicate a potential trichotomy with LUoS tariffs *Source:* Shaw, Ransan-Cooper, et al. (2020).

The main finding of ANU's (2020b) report is that community-scale batteries are already achievable without major changes to current regulations. However, for these projects to be financially viable, a discounted LUoS is necessary. The authors recommend that an LUoS should apply when a battery withdraws from the grid. Similarly, an LUoS is recommended for when customers consume electricity previously stored in a battery (ibid). Without a community battery, a discounted LUoS would lead to economic losses for the network. The presence of a community battery counteracts that because the increased number of transactions from the charging/discharging of the battery allows the network to receive the same amount of revenue. Any network charges incurred by the battery owner can then be offset by savings from energy arbitrage (i.e., the purchase of electricity during off-peak hours when it is cheap and selling it during peak hours when rates are highest) (Wilson et al., 2021).

Despite the high proliferation of solar PV in Australia, the community batteries system is not guaranteed to be beneficial for all neighbourhoods. One of the main benefits of the system is shifting consumer demand from peak to off-peak periods. For the scheme to work, a combination of solar PV systems of an appropriate size, a ToU tariff in which prices are higher during peak periods, and a smart meter are all required. Despite the fact that the Alkimos Beach trial took place in a community in which all homeowners had solar PV installed, several households were disqualified from participation in the trial as it was deemed that their solar PV systems were insufficiently large to benefit from the ToU tariff that the trial implemented, as the price signals would not instigate a change in electricity consumption behaviour (Synergy, 2021).

Additionally, while the community battery format is touted as an alternative to at-home battery systems due to lower, or no, costs to participating households, it nevertheless necessitates upfront capital expenses, from the installation of rooftop solar and a smart meter. The Alkimos Beach trial participants each received a rebate of up to AUD 4150 for the installation of solar PV, energy monitoring devices, and heat pumps, among others (ibid). The solar panels alone, however, cost an average of AUD 4000 for 3kW of capacity, increasing to an average of AUD 9610 for 10kW (Wrigley, 2022). The popularity of solar PV in Australia can largely be attributed to the preponderance of government support schemes for rooftop solar. But even without such schemes in place, the savings from the community battery are insufficient to compensate for the installation costs of solar PV for households over multiple years. Participants in the Alkimos Beach trial achieved an AUD 136.77 average annual saving. Participants in the PowerBank trials saved up to AUD 228 annually.

The recent easing of regulatory requirements, allowing community batteries to register as IRPs and participate in the NEM, should open up new revenue streams, making the projects more financially viable. Research by the ANU forecasts a substantial portion of battery revenue to come from the provision of FCASs in all models, except the DNSP-owned community battery model, on account of its inability to participate in FCASs owing to market competition concerns (Shaw, Ransan-Cooper, et al., 2020).

Likewise, community batteries could find an additional source of revenue from energy arbitrage, i.e., the buying and selling of power on electricity markets. This, however, is only viable if the battery is connected to the wider grid. The study by ANU (ibid) identifies this as the second-highest source of potential revenue for community batteries in two out of the four models. The DNSP-owned community battery models are lower on this potential revenue stream due to their inability to participate in power markets directly, on account of competition concerns outlined above.

For network-owned batteries, as providers of a regulated service, being able to attribute a significant portion of the battery cost to their Revenue Asset Base (RAB) would contribute significantly to their financial viability (ibid). The RAB is a model in which an infrastructure manager performing a regulated function is permitted to include the capital expenditures incurred — such as the installation of a community battery — to its regulated asset base, upon which a regulator determines appropriate rates of return and price caps in the regulated market. By allowing DNSPs to include community batteries to their asset base, AEMO would permit DNSPs to add these capital expenditures to their charges or get compensated for them in other ways, such as with subsidies.

Other network services that have not yet been monetised due to DNSPs being their sole providers include the provision of backup power, deferrals in expensive network upgrades owing to battery installation and their subsequent benefits from demand shifting, network congestion relief, and network resource adequacy (ibid).

Finally, the savings achieved by customers earning credits for producing excess solar power are additional sources of revenue. As highlighted by the Alkimos Beach trial, the monthly usage charge of AUD 11 was insufficient to keep the project financially viable, and the community battery project was discontinued after the trial. While this fee was heavily subsidised, allowing the participating households to achieve savings (Synergy, 2021), the savings in electricity costs could have been more adequately split between participants and battery owner in the form of higher usage fees. However, given that lower savings might discourage additional participation, a combination of the outlined policy interventions in which participating households are allowed to maintain higher savings is recommended.

2.4.6 Discussion

Given Australia's high rooftop solar PV uptake and the associated pressures it places on the grid, a solution that can retain excess solar energy and improve grid reliability brings benefits for all stakeholders, including those not involved in the project but benefitting from more reliable electricity grid. Since the first trial at Alkimos Beach, community battery projects have sprung up across the country. Their potential to avoid the high investment costs of traditional network upgrades makes them financially attractive to networks. Likewise, the ability to retain solar energy for use during peak periods can make a big difference to customers' electricity bills.

The trials show that community batteries work. The assistance they offer the grid in areas with high rooftop solar uptake has garnered national attention as a possible key technology for the grid's transition to a clean energy future. The ever-growing number of trials and the Labour Party's explicit support demonstrates that. Australia's high uptake of rooftop solar has meant that the need for technologies such as community batteries arrived earlier than for other countries. Yet, as solar uptake increases elsewhere, it is likely that other parts of the world, including Europe, will face similar pressures on the grid. The Australian trials, as well as the associated regulatory obstacles, thus provide early learning lessons for other countries who are following a similar path of household solar uptake.

2.5 Lessons for the European Union

The analysed case studies offer numerous lessons that could be applied at the EU and member states levels to make its policy framework to shape the electricity sector better suited for a significantly higher share of electricity from variable sources. These lessons can be divided into those concerning prosumers, energy communities, and the establishment of a regulatory sandbox framework.

2.5.1 Empowering prosumers

The role of electricity prosumers in the EU electricity sector increased significantly over the last two decades. However, their potential to contribute to making the electricity system smarter and more resilient, especially with the prospect of the share of electricity from sun and wind increasing dramatically, cannot be fully utilised in the existing regulatory framework. The peer-to-peer electricity trading is made difficult by the taxation system implemented in many EU countries. The individual flexibility in electricity consumption, depending on energy generation from renewables, is not rewarded due to the lack of suitable electricity tariffs and low roll-out of smart meters. The potential of the increasingly widespread home batteries, soon to be complemented by bidirectionally chargeable vehicles, cannot be used to stabilise the electricity grid.

The European legislation constitutes a significant step in the right direction, with a directive on the internal market for electricity, aimed at empowering electricity consumers to participate in "all forms of demand response" for which smart metering systems and dynamic electricity price contracts are essential. The directive is less straightforward in terms of reducing legal and commercial obstacles, that prevent prosumers from selling self-generated and stored electricity to the market; while such obstacles should be reduced, member states are allowed to have different provisions in respect of the taxes and levies charged on the electricity traded to ensure "adequate contribution to the system costs" (Council of the European Union & European Parliament, 2019). This de facto allows member states to keep the status quo in terms of keeping these obstacles unchanged. In addition, the directive does not refer to electricity that could be taken from the grid to be stored during times of low electricity prices and sold when electricity prices increase.

The opportunity was wasted, to use the flexibility offered by individual electricity consumers, who would like to help make the electricity grid integrate a larger share of renewables, while reducing their electricity costs or decreasing the payback time of the investment in battery systems — either at the household level or as part of the bidirectionally chargeable electric vehicle. While the EU and its member states are very careful in ensuring that each consumer contributes "adequately to the system costs", such contributions are not taken into consideration in many, if not most, other areas (e.g., construction of fossil fuels infrastructure). The financial benefits of taxation of electricity that is stored twice are small in comparison to the potential contribution offered by to make electricity grid more flexible.

While a complete abolishment of fees and taxes for electricity stored and traded locally may constitute a too big step for many EU member states, the introduction of local use of service (LUoS) tariff for electricity exchanged between different prosumers may constitute an acceptable step in that direction. The level of the LUoS could be steadily reduced or replaced by a monthly fee to facilitate more active participation in electricity market.

However, to benefit from the trade in electricity or dynamic electricity tariffs that would benefit *prosumers* as well as *consumers* who do not want to or cannot generate their own electricity, smart meters need to be widespread. The slow roll-out of smart meters, which by 2025 are expected to only reach 80% of households and in some countries should only reach all consumers by 2032 (Jones, 2022; Parliament of the Federal Republic of Germany, 2016), is difficult to comprehend bearing in mind the high levels of digitalisation in other areas. The high installation costs and additional annual fee charged in some countries (Verbraucherzentrale, 2022), could be one of the reasons for the slow roll-out. The introduction of such a fee ignores the potential that prosumers and energy communities offer to stabilise the grid. Especially at the time of the ongoing high, but also volatile, electricity prices, the broader deployment of smart meters, combined with dynamic electricity prices with an upper limit, could reduce peaks of electricity consumption, reducing system costs and natural gas consumption. In that context, the example of the Alkimos Beach community, in which each household received an AUD 4150 Energy Smart Home Package, offers some lessons for the EU and its member states. While this level of support, which included rebates for solar PV systems, heat pumps, and energy-efficient air conditioning systems, would be too expensive for broader roll-out, in the framework of the ongoing support programmes aimed at mitigating the high energy prices, EU member states could consider a small but more targeted package that would empower electricity consumers to lower their electricity bills by providing some flexibility to the system.

2.5.2 Community energy

The Virtual Power Plants and Community Batteries projects adopted in Australia provide an example of potential benefits resulting from the introduction of an additional level between prosumers and the large-scale electricity market. Although empowering prosumers to participate in making the electricity grid dominated by variable sources of energy offers a significant potential, many of them may not be able to reap the full benefits due to time and expertise constraints.

Energy communities already well established in the EU create a potential that the EU may build on in developing such a level. Community energy is currently defined in two European Directives. The Electricity Market Directive (Council of the European Union & European Parliament, 2019) includes a definition of *citizen* energy communities, whereas the recast of the Renewable Energy Directive from 2018 (Council of the European Union & European Parliament, 2018) speaks about *renewable* energy communities. While there are some differences between these two, what they have in common is their non-commercial character. This means that their contribution should be limited to facilitating electricity exchange between the participants and, in this way, lower their electricity bills. Their roles in increasing the flexibility of the electricity grid, to increase the uptake of variable sources of energy, has largely been ignored. This constitutes a wasted opportunity to create benefits, not only for their participants, but also to the market beyond.

With the VPP and Community Battery initiatives, Australia has demonstrated the financial viability of such business models, which, under some conditions, not only create savings but also may be a source of additional revenue streams. Key to this is allowing such communities to participate in the markets when established as IRPs. Europe's equivalent, of allowing energy communities to register as DSOs, although a recent step in the right direction, still does not allow these community DSOs to participating in profit-earning in the market.

2.5.3 Establishing an EU 'Regulatory Sandbox' framework

Including new actors in the policy framework that shapes the electricity market brings numerous risks. To avoid negative repercussions for the whole electricity system resulting from introducing significant and untested policy changes, the case studies analysed in this report constituted, in some cases, of pilot projects that relied on exceptions from the general rules.

The concept of a regulatory sandbox is not unique to the energy sector; it describes a 'safe' experimental regulatory environment, in which innovative regulatory approaches to various topics can be tested. Here, policy-makers can test business models and technologies that are only partially compatible with the existing regulatory framework under a relaxed or altered regulatory setting, with a view to subsequently developing new accommodative regulations or amending existing regulations as needed.

The VPP Demonstrations Project can be seen as a kind of precursor to a national regulatory sandbox, as it entailed a trial of an amended FCAS specification that enabled greater participation within the trial. This served to maximise the possible insights gained over the trial's duration without requiring a suspension of specific regulations governing the operation of the electricity network. Since the completion of this trial, however, the Australian government has established a power sector regulatory sandbox toolkit. This 'Energy

Innovation Toolkit' provides resources to answer common energy regulation questions, an enquiry service providing informal guidance on various topics, and, most importantly, the authority to authorise regulatory sandboxing trials (Australian Government, 2022). This authority is currently limited to trials that require regulatory relief from regulations in the state of Victoria, which has established its own regulatory sandboxing function. Authority to grant relief from national energy market regulations will only be forthcoming once planned national regulatory sandboxing legislation is passed.

In relation to the European energy sector, several EU member states have implemented such an approach, to test and encourage innovative participation in the electricity market, including Austria, Germany, Italy, and the Netherlands. So far, at the EU level, progress on a regulatory sandbox approach to electricity market innovation has been limited to a single proposed directive to member states. As part of its REpowerEU package of proposals for amending key EU regulations and directives in May 2022, the EU Commission directed EU member states to:

> "…promote the testing of new renewable energy technologies in pilot projects in a real-world environment, for a limited period of time, in accordance with the applicable EU legislation and accompanied by appropriate safeguards to ensure the secure operation of the electricity system and avoid disproportionate impacts on the functioning of the internal market, under the supervision of a competent authority." (European Commission, 2022j).

This is the EU's first attempt to regulate the introduction of an energy sector sandbox, but it lacks detail and leaves key questions unanswered, therefore falling short of the type of legislation necessary to facilitate transformative and rapid change. To be clear, given the divergence in member state regulatory and administrative landscapes, a balance must be found between EU-wide harmonisation and member state agency; therefore, an EU-wide regulatory sandbox is not recommended (Sunila & Ekroos, 2022). A compromise solution, however, could entail an EU framework consisting of general objectives which national sandboxes should uphold. Ideally, such a framework would lay out a common European vision, that does not limit the scope of potential technological solutions, but with certain safeguards that guide member states in creation of their own regulatory sandboxes.

Such safeguards are already put forward under the EU's proposed REpowerEU package of amendments, for example, limiting initiatives to testing technological solutions, and excluding social and systemic innovations (European Commission, 2022). In establishing a comprehensive EU framework, however, these aspects should not be excluded. Other aspects to include could reflect a list of viable project types, criteria for approving projects, a maximum project timeframe, a list of possible deviations from established provisions, and a list of those from which there can be no deviations (Sunila & Ekroos, 2022).

The proposed amendments to the Renewable Energy Directive, encouraging the promotion of trials of innovative DER under the supervision of a competent authority, is a reasonable first step, but could be further improved. As was utilised during the VPP Demonstrations Project, an explicit stipulation that the testing of innovative or more accommodating electricity market specifications is to be promoted could be included in this proposed amendment.

2.6 Conclusion

As the EU reduces its dependency on fossil fuels and sets its future on climate neutrality, the role of electricity from wind and solar energy will increase significantly. This comes with numerous benefits, such as energy independence, job creation, and democratisation of the energy sector. However, it also poses numerous challenges, especially resulting from variable character of the two sources of energy that will dominate future electricity market.

The existing policy framework, which served the centralised electricity sector well, is not fit for purpose anymore as it makes it challenging or even impossible to use the potential of other actors to contribute to solving these challenges. With the increasing role of distributed electricity generation and storage, combined with a remarkable advancement of technology in the area of digitalisation, there is a significant potential to empower individuals and communities to contribute flexibility to the electricity grid, while saving, or even earning, money.

This aspect gains even more importance in the context of the ongoing energy crisis; empowering citizens and communities to reduce their energy costs by providing flexibility to the grid could constitute part of the support schemes currently developed and implemented at the EU and national levels. Even though, in the case of Australia, savings per household were not as significant as expected in community battery trials, both VPP and community battery trials received positive feedback from communities and consumers. In the case of the EU, the increasing electricity prices and the need to wean EU off natural gas create political momentum for involving electricity consumers, not only as individuals but also as members of an energy community, supported by a virtual power plant or community battery.

In 2022, the electricity market in the European Union (and beyond) experienced an unprecedented number of challenges: the manyfold increase in gas prices, the changing dominance of nuclear power in France, Switzerland, and Sweden, the drought that affected combustion power plants, and the low electricity generation from wind power plants during the summer. While the absence of major blackouts during this time (but with electricity prices reaching exorbitant levels) indicates the network's resiliency, the challenges made it clear that all instruments and actors are needed to prepare it for what might lie ahead. A much more proactive involvement of prosumers and energy communities in contributing to grid flexibility, through the creation of virtual power plants or participating in community battery schemes, is an opportunity that the EU and its member states cannot afford to miss.

3. Archetype 2: Innovation

3.1 Introduction

One of the biggest problems facing our generation and the ones that will follow after is the transition to a climate-neutral economy. While the COVID-19 crisis temporarily curtailed carbon dioxide emissions as a consequence of the accompanying economic recession, the levels of greenhouse gases in the atmosphere are still rising, posing a serious threat of hazardous future warming. In addition, the ongoing energy crisis made it clear that reliance on fossil fuels — imported or domestic — is damaging, not only for the climate, but also for our economy and increases the problem of energy poverty.

Innovation is essential for reaching the EU's goal of climate neutrality by 2050. However, the EU should also find ways to develop and deploy low-carbon innovation that will have an impact in the short term. According to the OECD, technology and innovation are critical pillars of robust economic growth as well as fundamental building blocks for achieving the substantial reductions in carbon emissions necessary to achieve the transition to a net-zero carbon future. The OECD continued by stating that the rapid adoption of currently accessible technology is vital for structural transformation, in addition to greater innovation in game-changing technologies that are not yet commercially available (OECD, 2021). Additionally, as stated by the International Energy Agency (IEA), half of the global reductions in energy-related CO_2 emissions by 2050 will need to come from technologies that are currently in the demonstration or prototype stage (IEA, 2021b). As per Skillings (2020), achieving net zero GHG emissions by 2050 while fostering economic growth through the European Green Deal demands game-changing policies that must be reoriented, with the Innovation policy as one of such. Skillings (2020) emphasised the importance of directing the conversation away from straightforward technical delivery and towards economic opportunities.

Innovation is crucial, not just for its role in achieving climate change goals, but also for its ability to provide a greener future that coexists with increased product development and new growth prospects. Innovation is the main driver of modern economic growth. Success is dependent on both active and instrumental engagement of the world's top corporate R&D investors, with an emphasis on intellectual property rights as well as considerable behavioural changes among EU residents. Also, the development of the appealing new lifestyle options needed to garner the public's support for the transition will rely heavily on innovation. The enabling framework must be in place to support the financial risks and account for the unavoidable failure associated with innovation to achieve carbon neutrality (Amoroso et al., 2021; ECF, 2022; European Commission, 2022c; Skillings, 2020).

Innovation is essential, especially for sectors that are challenging for decarbonisation, such as energy-intensive industries including materials and chemicals — steel, plastics, ammonia, aluminium, and cement (14% of the EU's total emissions) or aviation, which are critical to Europe's economy and supplying several major value chains (European Commission, 2022k; McKinsey, 2022). Major policy innovation and entrepreneurialism will be required to establish a new economic and low-CO_2 agenda for EU heavy industry. Innovation is being developed to generate high-temperature heat using electricity (Material Economics, 2019).

The IEA proposed four major technology groups, including hydrogen, direct electrification, carbon capture, utilisation and storage (CCUS), and bioenergy. For instance, coal is most frequently used to reduce iron while making steel. Innovative technologies, however, enable this process to be carried out with carbon-neutral hydrogen or methane. The direct electrolysis of iron ore to directly reduce iron using electricity is another innovative technique being researched for the production of low-carbon steel (Herbst et al., 2021a; J. Kim et al., 2022a; Nuffel et al., 2018a). In the cement industry, new products using innovative binders, such as mechanically activated pozzolans and calcined clays, are being developed to reduce process emissions.

The innovative solution in the chemical industry is using non-fossil feedstock including biomass or end-of-life plastics or H_2 for ethylene production (Methanol-to-Olefines, MtO), methanol and ammonia production based on renewable electrolysis, and is believed to occur on a large scale (100% of ethylene, ammonia, and methanol). Due to the energy-intensive nature of the iron and steel industry, efficiency and energy-saving have been the top priority (Herbst et al., 2021b; J. Kim et al., 2022b). In conclusion, hydrogen can play a key role in the decarbonisation of a variety of industrial processes, where using electricity directly is challenging or even impossible. If the gas and power industries are better integrated, it will be possible to manufacture this hydrogen in the most economical manner (Nuffel et al., 2018b).

In addition, we need to investigate new, innovative ways in which different sectors can be integrated. As part of the Paris Agreement 1.5, sector coupling that connects power and end-use sectors provides a new way for renewable energy to be integrated into the energy system (Olczak & Piebalgs, 2018). The goal of sector coupling is to unite the energy sector with the industry, transportation, and building sectors so that they can all be optimised together. In accordance with this theory, CO_2 emissions can be decreased if all sectors are integrated by connecting directly to the power grid or converting to green hydrogen made from renewable sources. Thus, storage technology can provide a counterbalance to the variable renewable energy sources (EWI, 2022; UNEP, 2020). The cost and performance of enabling technologies for sector coupling will alter as a result of innovation. This technique gives the energy sector more flexibility so that decarbonisation might well be accomplished more affordably (Nuffel et al., 2018b).

Further, digital technology has the potential to assist other businesses in reducing worldwide CO_2 emissions by 20% by the year 2030 (DigitalEurope, 2021). To create and put into practice the solutions required for green and digital transitions, a functional innovation and data ecosystem is required (EC (b), 2022). Hence for European businesses, embracing advanced digital technologies is a primary concern. These technologies promote improved company productivity, which can result in higher investment levels and, at the same time, facilitate the process of increased innovation activity (Firoiu et al., 2022). Digitalisation provides the opportunity for new forms of transparency, cooperation, and control, offers the data necessary for more informed decisions regarding production and consumption, and creates novel environmental policy measures (Teufel & Sprus, 2020).

The purpose of this section is to find out what the EU can learn from the experiences of the United States in driving innovation. The three case studies presented here are based on desk-research and expert interviews. While the first case study — the Department of Energy Loan Program — focuses strictly on innovation in the energy sector, and increasingly on solutions to climate change, the remaining two — the SBIR and STTR programmes — have a broad focus on innovation. However, they can very well be used in the European context to foster innovation in the climate change mitigation area.

During the research, we identified important explanatory factors with the help of grey literature and academic publications. In addition, we analysed official policy documents as well as media reports. These helped to identify the relevant actors, institutions, policies, and processes. Next to desk-research, we conducted five semi-structured interviews with EU experts, focusing on innovation, also from trans-Atlantic perspective. Interviews helped to identify the main barriers of permitting in the EU, the advantages and disadvantages of the EU system, and to triangulate findings. Based on the collected information from the case studies and expert interviews, a comprehensive narrative was drawn in order to improve and accelerate the use of modern and innovative technologies in the EU as well as general lessons for the EU.

The report proceeds as follows. The next section (Section 3.2) expresses the reasons for improving European innovation framework. The Section 3.3 discusses the case study of the Department of Energy Loan Program. Section 3.4 presents the case study of the Small Business Innovation Research programme. Section 3.5 presents the case study of Small Business Technology Transfer. Section 3.6 draws some lessons for EU policy-making, and the last section concludes.

3.2 Why consider an improvement of the European innovation framework

As more and more actors enter the scene to tackle the challenges and issues, innovation and investment will need to be integrated. Through its broad wingspan of investment into innovation, the EU is clearly serious about advancing innovation towards its areas of priority. Climate change mitigation has been one of these priorities and an area that will require continuously growing attention. Current funding mechanisms using public funds finance innovation across several fields and scopes. However, efforts are so widespread that coordination at a high overarching level can be challenging. It can be the case the beneficiaries (be they individuals, groups or consortia) of these funds. Simultaneously, the private sector, with its growing climate action awareness can appear to be left outside the fold. If we were to talk about investment in innovation in general (i.e., across all sectors, not only climate) globally the EU is one of the largest spenders of R&D using public funds but lags incredibly behind when it comes to private investment into R&D. Private companies in Europe contribute to about 19% of the global total investment, surpassed by China (24%) and the United States (28%) (Bughin et al., 2019). When discussing climate innovation specifically, the same trends are to be assumed. This warrants the need to question whether the EU innovation framework can do more to facilitate better synergies with the private actors to boost innovation in Europe.

Box 2.1. Funding innovation in Europe

Apart from being important to promote economic growth, innovation will be crucial to advance the diversity of solutions available in Europe's arsenal to address climate issues both within and outside of Europe's borders. The latter here being a case for increasing Europe's competitiveness in a growing race to adapt to climate impacts, as well as venturing into newly developing markets that are changing, becoming more climate conscious.

Horizon Europe is core to the EU's innovation framework, from the scope setting to finance perspective especially. In recognition of Europe growing need to foster synergies of the EU's innovation investments Horizon Europe recently announced in 2021 a project call "Maximising the impact of synergy of European climate change research and innovation" with an indicative budget of EUR 9 million (European Commission, 2022d). The call is an exercise in synthesising knowledge and valorising the outputs and results from previous and ongoing EU funded projects working on climate. More importantly, it will seek to maximise the synergy between climate research and innovation along the science-policy interface. Under this action, the EU hopes to foster better dialogue on climate R&D to policy-makers to improve prioritisation of investments in climate

In a nutshell, the rationale for the consideration of improving the European framework is to increase the effectiveness and impact of innovation through the building of synergies, hand in hand with reducing or where possible eliminating inefficiency. Taking these factors, the US model was selected for this Archetype based on the three components that facilitate innovation, here presented as three individual case studies.

The Department of Energy's 'Loan Program', works towards making financial investments available to large project stakeholders that would otherwise not have access to funds (for example due to investor hesitancy), through a due-diligence procedure that credits the a company/project with a degree of confidence making it eligible for additional funding and opening the gates to investment from large private venture capital firms. The second component is the Small Business Innovation Research (SBIR) programme makes available millions in funding to small companies distributed by several US government agencies. Grants are designated to enhance R&D towards areas of priorities identified by the US agency offering the grant. A noteworthy point here is that these grants are issued by different US government agencies that have a specialised area of focus and therefore better understanding of where investments should be targeted compared to a general centralised agency. The objective of this programme is to have as many entities apply for the grant. To this end the programme took special attention to ensuring a simplified application process so as not to dissuade companies. The third component is the Small Business Technology Transfer (STTR) programme. It operates in a similar fashion to the SBIR but instead its goals is to roll out funding towards enabling technology transfer and knowledge sharing between businesses and research institutions to foster synergies, cooperation and coordination between the different actors (SBA, 2022a). These programmes are harmonised through a search engine which provides an integrated platform that showcases concreated areas of R&D that enables business and other actors to work towards thus close the gap on existing and emerging gaps in research and technology.

While the EU has taken one approach to facilitating innovation, mainly along the lines of improving climate research for policy-making, the US has taken a slightly different approach in which private actors play a more significant role, both in financing as well as driving innovation. The US government still plays a role in steering the financial streams and scopes of innovation. A critical difference to that of the EU is that private companies, at least until now, have largely not been the focus of EU climate innovation investments. EU climate innovation has largely been focused on research. The benefit of the US model as that it introduces free-market actors that can drive diversity and competitiveness in innovation.

3.3 Case study 1: Department of Energy Loan Program

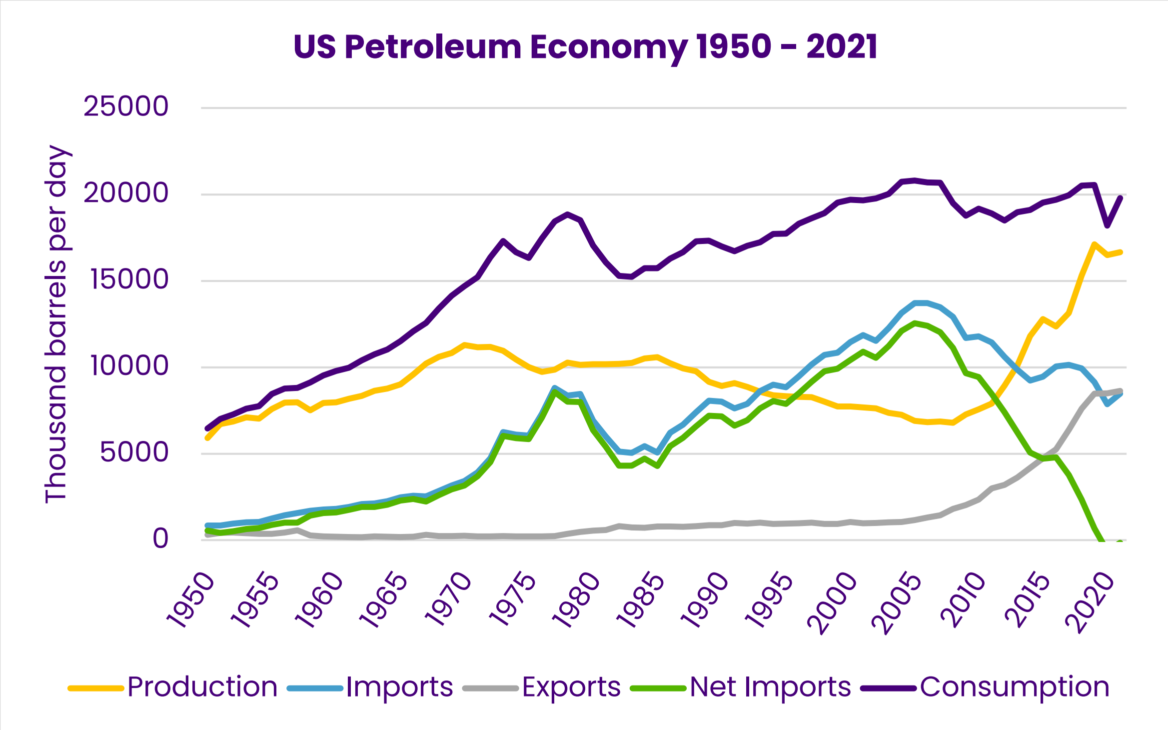
This case study looks at how the U.S. Department of Energy established the 'Energy Loan Program' to bolster innovation through appropriating investments and the necessary channels to facility its distribution. Section 3.3.1 opens with an introduction to the conditions that led the US to warrant a response to energy imports and exports and how state sides, issues, and policies were developing across the country. Section 3.3.2 explains how the affairs and situation of the time led to the legislative development of the Energy Policy Act, the precursor for the establishment of the Energy Loan Program, followed by Section 3.3.3, which goes into detail about the content and function of the ELP. Upon the establishment, Section 3.3.4 talks about how the policy experienced several changes, on account of responses to lessons learnt and administrative changes, while Sections 3.3.5 and 3.3.6 discuss in detail the implementation and evaluate of its impacts, respectively. These changes and their impacts are discussed in Section 3.3.4. Lastly, Section 3.3.7 closes off the discussion by extracting key take away points as a prelude to Section 5 which discusses lessons for the EU.

3.3.1 Context and Background

The development and implementation of the Department of Energy Loan Program was heavily influenced by the increasing reliance of the US economy on energy imports and exploding oil prices in the 2000s. When President George W. Bush took office in 2001, the US was enduring rapidly rising energy prices, creating economic ramifications in daily life. The United States produced, and mainly consumed, energy derived from petroleum, gas, and coal because the renewable energy sector was not fully developed and unable to support much of the energy demand (Desilver, 2020a). The US depended on several other nations exporting mostly gas and petroleum to the US to meet its energy needs.

In his 2006 State of the Union address, President George W. Bush asserted that "America is addicted to oil", reinforcing the lack of energy diversity and sustainability of the US economic system (Bumiller & Nagourney, 2006). In 2004, the US imported 58% of its oil, and these imports were expected to increase to 68% by 2025 (U.S. Energy Information Administration, 2022b). **Figure 3.1** illustrates how quickly US energy imports and consumption grew, while production declined slowly but continuously since the mid-1980s.

Figure 3.1: U.S. Petroleum Consumption, Production, Imports, Exports, and Net Imports.



Source: U.S. Energy Information Administration (EIA) (2021).

Due to the potential risk of foreign entities exploiting the US dependency on imported fossil fuels, energy dependence became a national security concern (Morse & Jaffe, 2001). Therefore, this topic was put front and centre by the US's decision to invade Iraq, which had implications for oil prices globally. The 2003 US invasion of Iraq did not appear to impact the oil markets directly, but it did highlight how susceptible oil markets were to conflict and supply disturbances (Looney, 2003). The US invasion of Iraq took 2.5 million barrels of oil per day off the market, further squeezing supply (Reuters, 2008).

The situation was worsened by the fact that global oil demand continued to increase, despite the falling supply. Between 1995 and 2005, China's economic growth depended on oil, making it quickly the second largest oil consumer, behind the US (Reuters, 2008). Similarly, other economies were also growing and demanding significantly more oil to keep up with their growth (Reuters, 2008). In 1995, there was a surplus of 70 million barrels in oil produced, and oil demanded globally. Four years later, there was an oil supply deficit of 42 million barrels. In 2002, the surplus was only 1 million barrels, highlighting the fluctuations in the supply-demand gap (IEA, 2021c).

Conflict, changing demand, and geopolitical tensions all contributed to fluctuating oil prices in the US between 2000 and August 2005, when the DoE Loan Program was enacted, prices fluctuated from a low in November 2001 of USD 32.04 to a high of USD 102.58 (Macrotrends, 2022). This caused the Consumer Price Index, a measure of price variation for common retail goods as an indicator for inflation, to increase from USD 172.2 in 2000 to USD 195.30 in 2005, an average of 2.7% increase annually (Federal Reserve Bank of Minneapolis, 2022). Comparatively, between 1995 and 1999, the consumer price index increased by 2.4% annually.

The rising energy costs created shifting public opinion on energy sources. In a 2005 survey, respondents listed energy costs as one of the most important problems (Teixeira, 2007). The public viewed developing long-term solutions to energy concerns as more important than temporary solutions that would lower gas prices (Bolsen & Cook, 2006). Attempts to mitigate the energy crisis driven by high energy costs came at a high environmental cost. Many US states weakened their emissions standards to produce more energy, but that did not stop manufacturers from shutting down because energy costs were too high. Experts agreed that, without policy changes, the US risked having future energy crises (Morse & Jaffe, 2001).

In addition to increasing energy prices, California began experiencing rolling blackouts and surging energy prices in 2000 and 2001. Beginning in the spring of 2000, energy prices increased dramatically until they suddenly and quickly declined again a year later (Weare, 2003). Energy prices in 2000 and 2001 were USD 27 billion per year, a four-fold increase over 1999 prices. Rolling blackouts started in San Francisco in the summer of 2000, and in 2001, the blackouts started impacting the entire state (Smilinich, 2022).

A few years prior, California deregulated electric utilities, allowing higher wholesale energy costs, creating issues for state-owned electric utilities. Eventually, the federal government intervened and required electric companies to sell electricity to California, but the blackouts continued. Faulty market design, lack of energy generating capacity, and regulatory mistakes contributed to this crisis. California's energy crisis highlighted how susceptible part of the US energy grid is to energy price and production fluctuations (Smilinich, 2022).

A few years after California's energy crisis, on 14 August 2003, the American east coast and Ontario, Canada, experienced the largest blackout in history. One of the power grids that electrified the east coast was overloaded, causing circuit breakers to trip at generating stations across the US and millions lost power. New York City officials shut off the power manually to stave off a more extensive blackout. During the outage, there were concerns that it was a terrorist attack on the American electrical grid, highlighting the fundamental concerns over how much of a role the energy grid can play in national security (Barron, 2003). The increase in the energy prices and the dilapidated state of the US electricity grid that resulted in the 2003 blackout made the need for innovative energy solutions much more urgent. Following issues with electricity grids affecting millions of Americans, President Bush stressed that the country needed "to modernise the electrical grid" (CNN, 2003).

The barriers to innovation from an investment point of view also contributed to the lack of new technologies that could have otherwise reduced the cost of cleaner energy or increased performance. In 2000, only 14% of US energy consumption came from renewable energy sources (Desilver, 2020b). The minor role of renewables reflected the lack of action of the US federal government (VandeHei & Blum, 2005). Private markets viewed renewable energy sources as riskier than alternatives. The lack of investment made it much more challenging for renewable energy sectors to get off the ground and past the "valley of death", the barrier between technology development and its deployment (McDonald et al., 2021).

It was assumed that by supporting the potential of clean energy industries through innovation, American manufacturers would have been better positioned to be the leading suppliers for the global market. The general narrative at that time was that more innovation in the energy sector would also support American economic growth through job creation and building out the US supply chain for these energy sources (The White House, 2005). While addressing environmental concerns was not the primary goal of the DoE Loan Program, addressing climate change and pollution from energy extraction and consumption were among the issues that this policy aimed to approach.

Adoption of the Energy Policy Act

Following the blackouts in California and on the east coast, George W. Bush's administration and many members of Congress were in agreement that policy action was needed to solve the energy issues facing the United States (Hulse & Janofsky, 2005). In 2005 the Energy Policy Act was adopted as the first energy-related legislation in over ten years, and created a basis for the DoE Loan Program.

Along with many other actions, it enforced mandatory electricity standards, increased renewable fuel minimums, provided tax incentives to domestic energy producers for energy efficiency to encourage domestic energy production, and improved energy efficiency through new means (Holt & Glover, 2006). The policy was expected to start the long process of optimising renewable and non-renewable energy and, as a result, to for the US economy and security of supply in the long run. According to surveys, this long-run approach represented what many US residents hoped for (Bolsen & Cook, 2006).

It was promoted as a way to facilitate economic growth and decrease energy costs, both of which were among the most important topics for the public. Representatives of energy-producing states were especially keen on the bill because it would have additional positive benefits in these states (Korte, 2012). As representatives faced re-election, public benefits reaching a representative's community were especially attractive.

Given the sweeping legislation, it had broad support from various business, labour, financial, and consumer groups, including the American Iron and Steel Institute, Association of Financial Guaranty Insurers, International Brotherhood of Electrical Works, Public Interest Research Group, and Small Business Legislative Council (Congressional Research Service, 2006). These interest groups mainly represented the industries that would see the largest benefit from the bill. Also, manufacturers and suppliers of innovative energy were interested in the business that this could provide for them.

The Senate Energy and Natural Resource Committee provided the legislative and institutional framework for this bill to emerge. Their twenty-two members, twelve Republicans and ten Democrats from twenty states, shaped the bill to its final edition during committee meetings and negotiations. It provided the essential adjustments to the bill so that it could be edited and shaped into a bill that could pass the House and Senate (United States Senate Committee on Energy & Natural Resources, 2006).

Apart from creating a basis for the DoE Loan Program, that will be looked at in the section below, the Energy Policy Act had numerous drawbacks in terms of climate change mitigation. In fact, issues that impacted the economy and the environment were among the most contentious problems during negotiations. While some Democrat members of Congress attempted to include restrictions on carbon dioxide emissions and other greenhouse gases, this proposal was rejected due to the potential concerns over the economic repercussions of such restrictions (Congressional Research Service, 2006).

Also, the possibility of including a Renewable Energy Portfolio Standard (RPS) was considered during negotiations. The Senate version of the bill included a requirement for electricity suppliers to provide 10% of their electricity from renewable energy sources by 2020 (Congressional Research Service, 2006). Many states already had RPS, so Congress considered a compromise, to include nuclear and hydroelectric facilities in the RPS. Still, ultimately, the bill dropped the RPS.

Overall, the goal of ensuring energy security was perceived as a much more important one than environmental protection. The bill granted additional support for coal-fired power plants, which was expected to lead to a 2.4% decrease in US dependence on foreign energy sources and contribute to a 7.4% reduction in US demand for OPEC oil. Furthermore, it was expected that the possibility of drilling in the Arctic National Wildlife Refuge could provide an additional 1.1 to 1.64 million barrels of oil per day of domestic energy sources, further reducing foreign oil dependence. However, despite the attempts of some conservative representatives, the question of drilling remained unaddressed (Congressional Research Service, 2006; Solte, 2007).

According to the estimates of the Congressional Budget Office (CBO) estimated that the Energy Policy Act would increase direct spending from 2006 to 2010 by USD 2.2 billion and from 2006 to 2015 by USD 1.6 billion (Holtz-Eakin, 2005).

3.3.2 Energy Loan Program

Three streams of funding

The Energy Policy Act of 2005 created three loan guarantee programmes: the Title XVII Innovative Energy Loan Guarantee Program, the Advanced Technology Vehicle Manufacturing (ATVM) programme, and the Tribal Energy Loan Guarantee Program (TELGP).

The Title XVII Innovative Energy Loan Guarantee Program provides projects developing innovative energy projects with access to debt capital for their projects. Several criteria need to be fulfilled for the projects to benefit from the funding in the framework of this stream of funding. The projects must:

- use technology that is not widely deployed in the US,
- avoid, reduce, or sequester greenhouse gas emissions,
- be located within the US or its territories,
- have a high likelihood of being able to repay the loan.

Title XVII was to cover up to 80% of eligible costs for 30 years or 90% of the life of a project, whichever is shorter, with fixed interest rates. In terms of energy sources, the programme covers renewables and nuclear and "advanced fossil fuels" projects (Brown, 2012).

The second loan guarantee programme focused on vehicles and vehicle manufacturing. ATVM projects had to have a connection to the manufacture of eligible advanced technology vehicles or components designed for these vehicles. These loans were to be awarded to companies achieving a 25% better fuel efficiency than comparable 2005 vehicles (Canis & Yacobucci, 2015). In a similar way to Title XVII projects, these projects had to be based in the US or its territories. Unlike Title XVII, the ATVM programme offered low-cost *direct* loans in addition to loan *guarantees*. The DoE was to provide leverage up to 80% of the eligible costs for 25 years or the life of the project, whichever is shorter.

Finally, the last stream of funding, the TELGP, was to focus on large-scale projects completed by federally recognised tribes and Alaskan native corporations. Loan guarantees for commercial debt support the projects. Unlike the ATVM and Title XVII, the TELGP does not require innovation because this programme focuses on helping economic opportunities and increasing energy independence on reservations through partnerships with the DoE.

The roles of the main actors

Congress approves and then grants the DoE the funding to guarantee these loans. It can also pass amendments to change the policy in any way. In 2009, the DoE changed the regulations to provide more flexibility in determining appropriate collateral packages ("U.S. Department of Energy", 2009). To reduce paperwork and increase transparency, in 2016, the DoE amended its policy interpretation to clarify when projects can meet with the Loan Program Office and condensed the application process ("U.S. Department of Energy", 2016).

According to the policy, the Department of Energy was permitted to issue the loan guarantees through the Federal Financing Bank (FFB). The FFB is a government corporation that works under the supervision of the Secretary of the Treasury to provide federal agencies financing to support lending projects (Federal Financing Bank, 2022). In order to set the loan programme's budget, the Department of Energy submits a budget proposal ahead of time, with its requests broken down by loan programme and intended use. The 2023 fiscal budget request was fully granted and the programme operating budget will be USD 180 billion (Loan Programs Office, 2022d).

The Department of Energy is responsible for implementing the programme, allowing it to interpret Congressional legislation to represent the administration's priorities better. It can adjust policy interpretations on the application process, application solicitations, and other specifics within the framework of the Energy Policy Act. However, when the DoE changes its policies, it must release a Notice of Proposed Rulemaking (NOPR) and be open to public comments ("U.S. Department of Energy", 2009). The DoE can and does usually respond to these comments. Once it has received public input, the DoE will send a Congressional Notification, and then the Secretary of Energy will approve the policy changes (The Energy Gang, 2021).

The application process

The Energy Policy Act of 2005 does not specify any procedural requirement for the loan programmes. Before applying, companies will have pre-application consultations with the LPO to discuss the application process and the proposed project. The Energy Policy Act stipulates a guaranteed agreement that includes detailed terms and conditions as the Secretary of Energy deems appropriate (United States House of Representatives, 2005). The secretary is responsible for protecting the United State's interests, which ensures that all technologies and patents are available for the project. Still, those are the only process requirements (Loan Programs Office, 2022a).

Once the applying companies have consulted with the LPO, they submit the formal application. Title XVII and the TELGP both accept applications in response to solicitations for applications. In 2009, the DoE released a solicitation for applications with up to USD 8.5 billion in loan guarantees (Loan Programs Office, 2009). In 2014, the DoE issued another solicitation that would be open for applications for 11 years and authorise up to USD 3 billion in loans (Loan Programs Office, 2022b). Nine years later, the DoE issued a solicitation for loan guarantees under the TELGP (Loan Programs Office, 2022b). ATVM loan applications are accepted on a rolling basis (Loan Programs Office, 2022b).

In the Title XVII stream of funding, companies submit the application to determine technical eligibility in the first part of the application. The business plan and financial structure are not reviewed. ATVM projects submit one application, focusing on determining eligibility and project viability. The TELGP requires tribal borrowers to engage with commercial lenders, who apply for the loan on behalf of the borrower and project.

The next step focuses on due diligence and term sheet negotiations. The term sheet is an initial non-binding agreement between the DoE and the project managers to list the basic terms and conditions for the loan. The applicant pays for the third-party advisor to support this step. Title XVII and ATVM projects focus on confirming all the documents and due diligence before negotiating the term sheet. TELGP projects require the borrower, lender, and the DoE to mediate due diligence and term sheet negotiations. Once the term sheet negotiations finish, the credit approval proofs begin to formally approve the term sheet alongside interagency consultations for Title XVII, ATVM, and TELGP projects. Once the credit has been approved, the DoE can offer a conditional commitment for a loan or loan guarantee.

In the final step, the DoE and the project developers negotiate and execute loan documents using the approved term sheet. Final conditions and loan documents are negotiated before the loan closes. Once the loan closes, the applicant pays all the costs. Once the loan has been dispersed, the LPO monitors the loan to ensure the loan is repaid and conditions are met.

The application costs depend on the specific programme under which the applicant applies. For Title XVII projects, the application fee is either USD 150,000 if the loan amount does not exceed USD 150 million or USD 400,000 if it does (Loan Programs Office, 2022a). The ATVM programme has no fees for the application. The TELGP charges reduced prices to USD 10,000 for Part One and USD 25,000 for Part Two of the application (McDonald et al., 2021). As of 2021, upfront application fees are no longer required for Title XVII projects (McDonald et al., 2021).

3.3.3 Policy changes

The most significant change to the DoE Loan Program was adopted in 2009 under the Obama administration. During the worst of the 2008 Great Recession, the American Recovery and Reinvestment Act (ARRA) of 2009 was intended to support the domestic economy. Embedded in ARRA were the Clean Energy and Electric Transmission Provisions that directly complemented the existing programmes.

ARRA provided an additional USD 6 billion to the DoE to cover loan guarantee costs under Section 1705 (Sachs et al., 2009). Section 1705 created three project categories that were eligible to receive loan guarantees: renewable energy systems and facilities that manufacture renewable energy components; electric power transmission systems, including system upgrades and restoration; and innovative biofuel projects that could be commercially applied. Biofuel project funding is capped at USD 500 million. Projects that secure funding had to start before 30 September 2011. Section 1705 expired in 2011 and, during its time, it provided over USD 16 billion in loan guarantees (Congressional Research Service, 2011).

In December 2009, a DoE policy change impacted the existing regulations determining appropriate collateral packages. This policy change provided a more flexible interpretation of provisions that focus on how the DoE treats collateral to make it more consistent with the intent and purpose of the Title XVII programme ("U.S. Department of Energy", 2009).

In 2012, the Department of Energy released the Consolidated Appropriations Act, which introduced further changes to the DoE Loan Program. Contrary to the earlier changes, which made it easier to apply for the loan, under these changes, no guarantee could be made until appropriations for the cost of the guarantee were made; the Energy Secretary received payment for the cost of the guarantee from the borrower and the total amount was either deposited in the treasury, or the borrower made several payments to cover the cost of the guarantee (Consolidated Appropriations Act 2012, 2011).

In 2014, the DoE adjusted the ATVM programme to focus less on the vehicle manufacturers and more on component manufacturers. This change resulted from the recognition that the fuel economy of the cars would need to improve quickly and could only do so with more efficient components (Canis & Yacobucci, 2015).

During the time of the Trump presidency, the DoE Loan Program was not actively used. The only meaningful change was introduced with the Energy Act of 2020, which eliminated the upfront application fees for Title XVII and ATVM loans and loan guarantees. It also increased the role of the Secretary of the Treasury to review application status, outreach, and coordination, and to report to Congress. The Energy Act of 2020 also amended the role of the Treasury by requiring it to consult with the Secretary of the Treasury when considering restructuring terms and conditions of any guarantees. The stated goal of the changes was to provide additional layers to the loans to ensure that they will be profitable and successful; however, it made the process of applications more cumbersome (United States Senate, 2020).

The Biden administration increased the role of the Loan Program in facilitating large scale innovation. The Infrastructure Investment and Jobs Act (IIJA) of 2021 clarified and expanded the Loan Program. The IIJA provided more context for the reasonable prospect of repayment criteria for Title XVII and ATVM projects. The IIJA also expanded Title XVII eligibility to support projects that aim to increase the domestic supply of critical minerals. The IIJA expanded the ATVM programme to include heavy-duty vehicles, trains, aircraft, maritime vessels, and hyperloop technology under the IIJA (National Conference of State Legislatures, 2017).

Most recently, in August 2022, the Inflation Reduction Act (IRA) passed along party lines, including some provisions affecting the DoE Loan Program. In Section 50141, the IRA grants USD 40 billion in loan guarantee authority to the DoE in addition to the USD 24 billion the DoE already has in commitment authority (Bond & Picone, 2022; J. McCarthy, 2022). The USD 40 billion is separated out for the three different programmes: USD 21.9 billion for Title XVII, USD 15.1 billion for the ATVM programme, and USD 2 billion for the TELGP (Bipartisan Policy Center, 2022). The Title XVII programme will receive USD 3.6 billion for the costs of guarantees made under the loan programme (Anstey et al., 2022).

Beyond the additional funding, the IRA also amends Title XVII to include the new Section 1706 on Energy Infrastructure Reinvestment Financing, equipped with USD 5 billion (Anstey et al., 2022). Section 1706 allows the DoE to make loan guarantees, and refinancing, for projects that retool, repower, repurpose, or replace existing energy infrastructure that has halted operations, and enable currently operating energy infrastructure that avoid, reduce, utilise, or sequester air pollutants or greenhouse gases. This new stream of funding defines infrastructure as the facility and the associated equipment that is used for the generation or transmission of energy or the production, processing, and delivery of fossil fuels. The programme expansion into repurposing fossil fuel infrastructure aims at reducing the political costs of fossil fuel phase out by potentially repurposing the sites for low-carbon sources of energy (e.g., energy storage or hydrogen) and keeping a large share of the existing jobs.

3.3.4 Policy implementation

Once the Energy Policy Act was passed, in 2005, the DoE created the Loan Programs Office (LPO) to manage the new programmes and issue the loans. LPO is composed of seven divisions: Outreach and Business Development, Origination, Portfolio Management, Risk Management, Technical and Project Management, Legal, and Management Operations Divisions (Loan Programs Office, 2022d). These seven divisions are responsible for all aspects of the loan programmes.

It took about four years to translate the policy directive into action: only in 2009 did the DoE give its first direct loan, to Ford Motor Company for USD 5.9 billion under the ATVM programme (Loan Programs Office, 2022f). The impact of the loan to Ford Motors was significant considering the context of the 2008 recession, when investment capital became very expensive. The loan guarantee was given to upgrade 13 manufacturing facilities in six states (Loan Programs Office, 2022e). The resulting highly advanced assembly and manufacturing plants are more flexible and able to produce multi-platform, fuel-efficient advanced technology vehicles as the market demanded and emissions standards were tightened. These facilities have since created and maintained 33,000 jobs and produced more than 6 million vehicles (Loan Programs Office, 2022e). The vehicles built due to the loan guarantee are estimated to have saved 268 million gallons of gasoline and prevented over 2.38 million metric tonnes of carbon dioxide emissions. Ford Motors repaid the loan in June 2022 (Loan Programs Office, 2022f).

In 2010, Nissan was granted a USD 1.45 billion loan to build and upgrade manufacturing facilities in Tennessee (Overly, 2017). The manufacturing upgrades supported the assembly of 4.4 GWh of battery packs and up to 150,000 LEAF vehicles annually (Loan Programs Office, 2017b). The vehicles and facilities will save approximately 13.5 million gallons of gasoline and prevent 120,000 metric tonnes of carbon dioxide emissions annually (Loan Programs Office, 2017b). In addition, the facilities have created 1300 new, permanent jobs. Ford and Nissan's loans are sometimes considered bailouts because the recession was about to cause irreparable damages to both companies and the loans saved them. The ATVM programme offered a clear path towards government support during a crisis for these American vehicle manufacturers.

In 2010, the DoE issued its first two loan guarantees to a solar project and a wind energy project for USD 1.45 billion and USD 1.3 billion, respectively (Loan Programs Office, 2022f). Shepherds Flat received USD 1.3 billion in Title XVII funding in December 2010 for their wind energy project in Oregon. In Arizona, Solana also received a USD 1.45 billion loan guarantee through Title XVII to fund their solar energy project (Loan Programs Office, 2022f).

One of the best-known successes of the ATVM programme is the Tesla Model S from the Tesla Motors loan. In 2010, the DoE provided Tesla Motors with USD 465 million to upgrade their manufacturing facilities, to switch from the sports car to sedan production, ultimately supporting the invention of the Tesla Model S (Overly, 2017). Tesla sold over 150,000 Model S in the first five years of production (Overly, 2017). With the vehicle's overwhelming success, Tesla could repay their loan nine years ahead of schedule (Robertson, 2013). Tesla's manufacturing plants could employ 1500 additional people with the ATVM funding (Loan Programs Office, 2017a). The Tesla loan is estimated to have saved 5.87 million gallons of gasoline and avoided 52,000 $MtCO_2$ emissions annually (Loan Programs Office, 2017a).

There were also some less successful examples, of which Solyndra was the best known. Solyndra was a solar panel start-up that received its first loan under ARRA. Solyndra was granted a USD 535 million loan in 2009, and the Californian Agency for Alternative Energy gave them a USD 25 million tax break (Andrzejewski, 2021). In May 2010, President Obama even visited the factory, despite concerns of impending bankruptcy (Weiner, 2012). In December 2010, Solyndra informed the DoE that they would not be able to make their loan payments, and a couple of months later, Solyndra was granted USD 75 million in additional financing (Weiner, 2012). By the end of 2011, Solyndra had declared bankruptcy. This was partially a result of Chinese policies supporting Chinese companies and crowding out the market, making Solyndra much less profitable. Following this public default, Republican members of Congress began investigating the DoE Loan Program, turning this policy from a bipartisan into a highly politicised endeavour (Weiner, 2012). Despite evidence alleging Solyndra misled the DoE, much blame is still placed on the DoE for rushing the loan announcement.

Similarly, Fisker publicly defaulted on their USD 529 million ATVM loan. In late 2008, the DoE granted Fisker a loan to build their "Karma vehicle" despite the company having bad bond ratings and an unproven track record (Rascoe & Seetharaman, 2013). In June 2011, when it was discovered that Fisker would not be able to honour their financial and project development requirement, the DoE halted the rest of the loan payments, after having given Fisker USD 192 million (Rascoe & Seetharaman, 2013).

Fisker and Solyndra represent the most public and the high value defaults that the Loan Program Office has faced. These failures gave politicians an apparent reason to investigate and attempt to dismantle the programme. In 2012, House Republicans tried to stop the programme in the 2013 Energy and Water Appropriations Bill. Despite Section 1705 expiring in 2011, the No-More-Solyndras amendment would have prohibited the DoE from spending funding under Section 1705, demonstrating the symbolic nature of the bill. Representative Marsha Blackburn, a Republican from Tennessee, spearheaded an attempt to halt the DoE from being able to spend their budget on creating new loan guarantees (Gallucci, 2012). Representative Cliff Stearns suggested an amendment to stop the DoE from subordinating loan obligations and which would require the DoE to be paid back first should a project become bankrupt (Gallucci, 2012). These Republican-led attempts to strip the programme of essential components highlight how politicised it has evolved over its lifespan. Despite all the attempts to halt the programme, it has endured.

The politicisation of the programme, but more so programme failures, has distracted from the significant successes of the programme. Furthermore, it has meant that these programmes are underutilised. Under the Trump administration, the programme was essentially halted. The only loan approved between 2017 and 2020 was for a Georgia nuclear reactor project that started the loan process under the Obama administration (Collins, 2020). The Trump administration left USD 43 billion worth of loan guarantees unused, despite the economic crisis brought on by the emergence of COVID-19. The Trump administration left billions of dollars unused.

The Biden administration is considerably more active in the programme, having already issued two loans in 2022 alone (Loan Programs Office, 2022f). In June 2022, the DoE issued a loan guarantee to Advanced Clean Energy Storage, a hydrogen project for USD 504.4 million. Advanced Clean Energy Storage is developing clean hydrogen and energy storage facilities that can function as long-term, seasonal energy storage facilities. The facilities will provide an additional 25 permanent jobs and 400 construction jobs. The stored hydrogen will fuel a combined-cycle gas turbine that is being built to replace a retiring 1800 MW coal-fired power plant (Loan Programs Office, 2022b). Eventually, this project will prevent emissions of approximately 127 $MtCO_2$ annually (Loan Programs Office, 2022f).

A month later, a direct loan was issued to Syrah Vidalia Facility for USD 102.1 million to support the creation of a necessary material for lithium-ion batteries domestically. Syrah Vidalia Facility is expected to create 98 permanent jobs and 150 construction jobs, in addition to saving 52 million gallons of petroleum annually (Loan Programs Office, 2022c).

3.3.5 Policy evaluation

The respective presidents' priorities strongly influenced the policy's impact on driving innovation. Enacted under the George W. Bush administration and first executed under President Obama, the DoE Loan Program symbolised bipartisan efforts to support energy infrastructure changes. Yet, each president has viewed this programme differently. President Bush saw it as an opportunity to increase energy independence and update the energy sector; President Obama viewed it as investing in the recessing economy and promoting clean energy; the Trump administration saw it as irresponsible spending (The White House, 2018).

These differing perspectives from the highest level of office highlight the shifting political landscape. Initially, there was a bipartisan commitment to ensuring the programme moved quickly and smoothly (Korte, 2012). Despite initially supporting the policy, Republican representatives have asserted that the government does not have the right to support individual private energy companies (Collins, 2020). Nineteen Republican members of the House stated that they no longer wish to continue the programme and would like the money to be returned to the Treasury. Representative DesJarlais, a Republican Congressmember from Tennessee, alleged that the DoE "cannot or will not properly administer" the programme (Korte, 2012). The few failures have significantly contributed to the negative attention because "when you have losses, people talk about it a lot" according to LPO Director Jigar Shah (Shah, 2021).

Most people familiar with the programme see it as an overwhelming success. As of July 2022, the programme had issued USD 35.5 billion in loan guarantees to 24 projects: 20 Title XVII projects and four ATVM projects (Brentan, 2020; Loan Programs Office, 2022f). As of February 2022, LPO is reviewing 77 formally submitted, active applications for loans and loan guarantees, totalling requests of approximately USD 70.8 billion (Loan Programs Office, 2022b). LPO has a budget of over USD 40 billion to support projects (Loan Programs Office, 2022b). The programme has earned USD 3 billion in interest, making this programme profitable, even with the few defaults (Brentan, 2020). Once the current loans are repaid, interest is expected to be USD 5 billion (Levin, 2017).

From an economic perspective, this programme has supported growth and innovation. The loan guarantees have supported projects that have created 37,000 new, permanent jobs and 12,900 construction jobs (Levin, 2017; Loan Programs Office, 2022f). One in every 50 new jobs is in the solar sector (Levin, 2017). The programme played an important role in accelerating the development of solar PV. Before the programme, there were no commercial solar projects in the US with a capacity of over 100 MW. The programme triggered the deployment of such massive projects by funding the first five solar projects larger than 100 MW. Since then, 131 privately funded large-scale projects have been developed (Levin, 2017). Shepherds Flats, which received USD 1.3 billion in December 2010, was one of the first big solar projects in the US and helped reduce uncertainty about any future solar projects (Loan Programs Office, 2022f). Former Secretary of Energy, Moniz, in the Obama administration asserted that this programme "literally kick-started the whole utility-scale photovoltaic industry" (Brady, 2014).

The programme also helped to accelerate the deployment of wind energy. In 2000, the US generated 5.6 TWh in wind energy; by 2021, generation increased to almost 380 TWh (Jaganmohan, 2022). Record Hill was a smaller project, which got USD 102 million in August 2011, and further contributed to wind energy development (Loan Programs Office, 2022f). The Kahuku and Granite projects, that were issued loan guarantees in 2010 and 2011, respectively, continued the development of the American wind sector.

The DoE estimated that the ATVM programme, focusing on more efficient vehicles, alone will reduce oil consumption by 282 million gallons of gasoline annually, which is about 0.2% of US gasoline consumption and avoid the release of 2.4 $MtCO_2e$, 0.04% of US emissions, every year (Canis & Yacobucci, 2015). ATVM-supported projects produce about 250,000 low-emission vehicles annually (Loan Programs Office, 2022b).

The programme also impacted decarbonisation by driving the private sector — especially venture capital — to finance large-scale innovation. The private financing sector is now better equipped to fund innovative research, development, and commercialisation projects (Shah, 2021). The LPO is trying to recreate the best practices of the commercial banking sector when considering the loans and this cycle between banks and the LPO to learn about how to support these technologies will significantly benefit these types of projects (Shah, 2021). The DoE demonstrated to the private sector how to fund these projects while keeping losses at a relative minimum and making a profit. By 2015, private investors were already more capable of giving innovative projects cheaper access to financing (Energy Futures Initiative, 2022).

3.3.6 Discussion

The DoE Loan Program underwent numerous changes since its creation in 2005. However, for many innovators it was the instrument to apply for, to realise ambitious proposals. While the programme was ready to take the risk and support innovative ideas, the proposals are also in-depth checked and accompanied by the experts assessing the proposals. This engagement of the DoE experts helps to ensure the comparably high success rate of the projects financed and opens the door to private capital.

The programme is persistently under fire for taking too many or too few risks. There have been failures, but the LPO has been able to adjust their policies and processes to prevent any mistakes from happening twice. The willingness to take the risks turned out to be one of the drivers of innovation in the United States.

Not all these innovations were targeting decarbonisation. In fact, after the economic crisis of 2008/2009, the DoE Loan Program was used to revive the US car industry with only modest improvements in energy efficiency of the vehicles produced. However, with some changes and a more targeted mission to drive low-carbon innovation, the programme could be a powerful tool that could be used to achieve the goal of climate neutrality. Section 5 investigates the main lessons that could be learnt from this programme for the EU's innovation framework.

3.4 Case study 2: Small Business Innovation Research programme (SBIR)

The second case study investigates the development of the Small Business Innovation Research programme which was started to help create a level playing field between small and large firms in the areas of research and development. Section 3.4.1 delves into the history rationale behind the SBIR, exploring the funding needs to boost the US competitiveness in research and development. Section 3.4.2 looks at how the policy developed over time, the structure of the programme with its different phases and eligibility requirements. Sections 3.4.3 and 3.4.4 evaluate the strengths and weaknesses of these programmes and how they were implemented. Lastly, Section 3.4.5 presents a brief discussion on the applicability and suitability of this model to a European context.

3.4.1 Context and Background

During the 1980s, genuine concerns were raised about the United States' ability to compete economically with other countries, especially in terms of promoting innovation. The main reason for this concern was the United States' slow pace in commercialising new technologies compared to the global manufacturing and marketing success of Japanese firms in cars, steel, and semiconductors (Link & Scott, 2018; National Research Council (U.S.), 2008a; SBIR, 2022h). In this regard, Lester Thurow, a well-known American political economist, lamented that the United States was losing economically because "today it's very hard to find an industrial corporation in America that is not in really serious trouble basically because of trade problems." (Link & Scott, 2018).

While large businesses, universities, and government laboratories have conducted the vast majority of federally funded R&D, there was a slower growth of corporate research laboratories, which had been pioneers of American innovation after World War II. At the same time, a growing body of research has shown how important small enterprises are to innovation and job development (Link & Scott, 2018; National Research Council (U.S.), 2008a). David Birch — a pioneer in entrepreneurship and small business research — emphasised the competitiveness that can be achieved by promoting and building national policies that consider small businesses (National Research Council (U.S.), 2008a). This coincided with federal commissions' urge since the 1960s to direct R&D funds towards creative small businesses (National Research Council (U.S.), 2008a).

In fact, not only were small businesses largely missing on innovation funding, but they were negatively affected by policies and regulations which address small and large firms equally. Due to their small scale and often the lack of a designed department in a small or medium enterprise to adapt to these regulations and promote innovation, they tend to be in a weaker position than large companies. This constituted an issue, as businesses with less than 250 employees were responsible for 90% of the 6.8 million jobs created between 1965 and 1976 (U.S. Senate, 1984).

The main challenge was the high risk of research and deployment of new, but not yet tested, technologies and solutions. To increase the US competitiveness and national security, it was considered essential to address the issue of optimising the ability of innovative small businesses to develop and commercialise new products (National Research Council (U.S.), 2008a).

The concept of early-stage funding of high-risk but commercially promising technologies was first developed by Roland Tibbetts, Senior Program Officer at the National Science Foundation (NSF). Tibbetts was aware of the importance of small, advanced tech firms to the economy and believed that these businesses played a crucial role in transforming government R&D into the public good through technological advancement and commercial applications, promoting overall economic growth. Additionally, Senator Edward Kennedy acknowledged the vital role that small enterprises play in the expanding American economy. Tibbetts and Senator Edward Kennedy diligently fought for NSF to fund the research of capable, innovative, and technology-based small firms throughout the majority of the 1970s (National Research Council (U.S.), 2008a; SBIR, 2022c).

3.4.2 Policy Development

After recognising the need for ongoing support for small businesses, NSF established the SBIR programme in 1977 (SBIR, 2022c). This motivated small firms to lobby other agencies to follow NSF's lead (National Research Council (U.S.), 2008a). Due to the success of the NSF SBIR programme, in 1979 the Small Business Administration (SBA) concluded that all government research organisations should implement SBIR programmes to promote innovation and technology development in the United States (SBIR, 2022c). When no immediate response occurred, small businesses took their case to Congress and higher levels of the executive branch. During a conference on small businesses in January 1980, the White House pointed out that only small shares of the Federal R&D budget were dedicated to small businesses (National Research Council (U.S.), 2008a).

As a result of the mounting pressure, in 1982 Congress passed the Small Business Innovation Research Development Act, which established the Small Business Innovation Research (SBIR) programme, the country's most extensive innovation programme, aimed at driving innovation by small companies (Audretsch, 2003; National Research Council (U.S.), 2008a; SBIR, 2022h). Apart from making the US economy more competitive, this programme was expected to be capable of creating much-needed new employment opportunities in the 1980s (United States Senate Subcommittee on Innovation and Technology, 1984).

Policy goals

A central policy challenge that the Small Businesses Innovation Research programme aimed to address was to expand better incentives to stimulate innovative ideas, technologies, and products and ultimately supply them to the market. Therefore, the mission statement of the SBIR programme was formulated "to support scientific excellence and technological innovation through the investment of Federal research funds in critical American priorities to build a strong national economy" (SBIR, 2022c). In a nutshell, SBIR was designed to achieve the following goals:

1. Regain the US leadership in the field of innovation and technology advancement by the United States.
2. Stimulation of job production in the private sector.
3. Ensure a significant return on federal R&D investment, at the time of increasing federal deficits.

The law stated that small businesses could drive high-technology innovation-driven economic growth in the United States, creating remarkable recruitment, new markets, increasing productivity, and high-growth industries. Innovation driving productivity was also perceived as reducing inflation levels, which was approaching 15% in the early 1980s. Moreover, it was expected that by increasing domestic production, small businesses' innovation would help reduce the US trade deficit (Rudman, 1982)

The Act defined four main criteria for selecting the projects covered by the stream of funding. Aside from stimulating technological innovation, it also aimed at using small businesses to meet federal R&D needs. It explicitly fostered the participation of minority and disadvantaged communities. Finally, it was expected that the innovations derived from the federal R&D funding would be commercialised (Rudman, 1982).

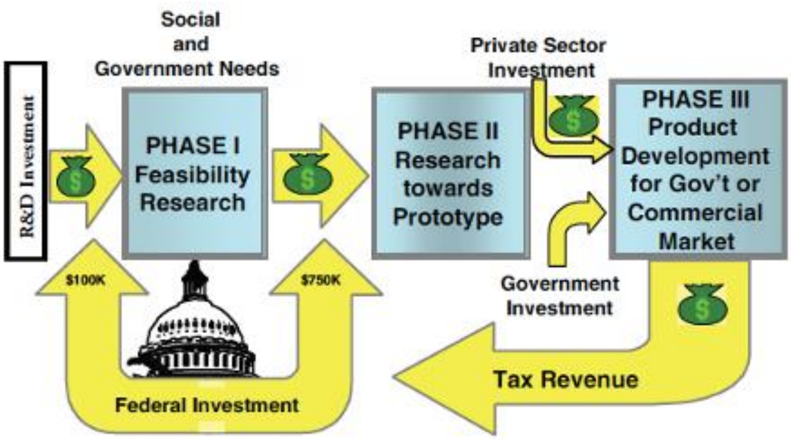
The programme targeted small, yet innovative, firms with the potential of commercialisation using federally funded research and development. The principle of this knowledge-based economic development programme was to meet needs of different federal agencies and contribute to the growth and strength of the US economy. The SBIR programme was expected to ensure that each eligible and ambitious small business benefitted from the opportunity to participate in a federal agency research programme. For this purpose, it developed a master release schedule of the solicitations to increase the predictability of the calls for proposals to address a challenge faced by a US federal agency (Glover et al., 2021a; Rudman, 1982; SBIR, 2022h).

Phases and eligibility

The funding was granted in three phases (see **Figure 3.2**). During Phase I, the technical merit, feasibility, and commercial potential of the proposed R/R&D efforts were evaluated. The Phase I awards were generally USD 50,000 to USD 250,000, for six months. During this phase, the respective agency investigated the quality of performance of the small business awardee organisation before providing further federal support in Phase II.

During Phase II, the results achieved from research and development efforts initiated in the first phase were to be pursued to develop the proposed idea to meet the particular need of a federal agency. Funding in this stage was only eligible for phase I awardees based on the commercial potential of the project. The Phase II awards were generally USD 750,000, for 24 months. Phase III was not funded by the SBIR programme anymore. Instead, it focused on the commercialisation of the products developed in the preceding phases and potentially supported by private capital. This may also include non-SBIR-funded manufacturing contracts with the federal agency for products or processes used by the United States Government (Rudman, 1982; SBIR, 2022f).

Figure 3.2: Diagram illustrating the structural procedure of the SBIR programme.



Source: National Research Council (U.S.) (2008a).

To be eligible for SBIR funding, small businesses had to employ fewer than 500 employees and have a for-profit character, be located in the United States and be more than 50% owned and controlled by one or more individuals who are citizens, or permanent resident aliens, of the United States (SBIR, 2022e).

Agencies involved and the level of funding

The Small Business Innovation Development Act (1982) stated that each federal agency with extramural research and development budgets over USD 100 million was obligated to operate SBIR programmes. Initially, these agencies were obliged to utilise 0.2% of the total funding for innovation for small enterprises to perform innovative R&D that has the potential to reach commercialisation stages and benefit the public. This share was set to increase to 1.25% in 1987 and 3.2% in 2017 — the latest increase so far.

Currently, 11 federal agencies support for-profit small business companies and their partners, with more than USD 2 billion annually. The federal agencies participating in this programme include the Departments of Education, Agriculture (USDA), Commerce, Defense (DoD), Energy (DoE), Health and Human Services (HHS), Homeland Security, Transportation; the Environmental Protection Agency (EPA), the National Aeronautics and Space Administration (NASA), and the National Science Foundation (NSF). The US Department of Education operates its SBIR programme through the Institute of Education Sciences (IES). The United States Department of Defense (DoD) has historically been the largest agency in this programme, with approximately USD 1 billion in SBIR grants given annually (Qian & Haynes, 2014).

Each agency issues solicitations — sometimes referred to as Requests for Proposals, Funding Opportunity Announcements, or Broad Agency Announcements — which differ in scope, on their respective websites. All solicitations are listed on the SBIR website, which allows for filtering according to the responsible agency, phase, and programme. However, applications must be submitted through the agencies that issues the respective solicitation (SBIR, 2022d).

The SBIR statute determines a cap for the maximum monetary amount of award provided by the federal agencies. If it is exceeded, the respective government's agency must obtain a waiver that has been approved by the Small Business Administration (SBA). This maximum amount must be adjusted to inflation every year. The updated cap is valid for all solicitations and related topics published on or after the adjustment date. Agencies may make the necessary changes to their solicitations and other programme requirements. They may also consider awards that are less than the maximum amount. In addition, they may exceed the monetary limit in favour of a specific topic, with the consent of the SBA and before the announcement of the solicitation, award, or modifications to the award for a topic issued on or after the date of adjustment (SBIR, 2022a).

The federal agencies must ensure that they stick to the guidance provided by the SBA in the Policy Directive (see next subsection) and ensure consistency with its goals (SBA, 2019a). Within four months of the passing of each agency's annual Appropriations Act, they must also report to the SBA on the calculation of the agency's extramural R/R&D budget, to determine the financing for the SBIR programme, including compliance with the expenditures of funds according to the requirements (SBA, 2019a).

3.4.3 The role of the Small Business Administration

The US Small Business Administration is the coordinator for SBIR programme implementation (SBIR, 2022a). The SBA is obligated to compile the Policy Directive (PD) for general SBIR that determines the provision of funding. The SBIR law lists several requirements that the Policy Directive needs to fulfil. Their primary focus is on keeping the application process unbureaucratic for small businesses. The SBIR solicitations should also be simplified and standardised to facilitate application and increase programme efficiency. The SBIR law requires involving several actors in developing the Policy Directive, including the Administrator of the Office of Federal Procurement Policy, the Director of the Office of Science and Technology Policy, and the Intergovernmental Affairs Division of the Office of Management and Budget. The Policy Directive is subject to public comments before finalisation (SBA, 2019b; SBIR, 2022e).

The SBA is also in charge of setting up databases and websites to gather and store data in a uniform format, required to support small businesses. The SBIR law requires the Director of the Office of Science and Technology Policy, in consultation with the Federal Coordinating

Council for Science, to unilaterally monitor and evaluate all the phases and operations of SBIR within agencies, as well as report to the House of Representatives at least once a year on all SBIR programme implementation phases and include appropriate suggestions (SBA, 2019a). The Comptroller General must send a report to the Senate and the House of Representatives no later than five years following the enactment (Small Business Innovation Development Act, 1982).

Furthermore, the SBA is responsible for supervising and keeping track of how the SBIR programmes are implemented at the agency level. This monitoring takes into account the review of policies, rules, regulations, interpretations, and procedures generated to facilitate intra and inter-agency SBIR programme implementation, including SBIR funding allocations, programme solicitation, and awards status, follow-on funding commitments, fraud, waste, and abuse, performance areas, metrics, and goals, additional efforts to improve the performance of the programme, Federal and State Technology (FAST) partnerships programme (SBA, 2019a).

To increase awareness about the programme, the SBA engages in outreach. Outreach programmes include educating the public about the SBIR programme through conferences, seminars, and presentations; publishing success stories to specify the successes achieved in the programme; and maintaining the public online platform of www.SBIR.gov, which offers thorough information regarding the programme (SBA, 2019a).

3.4.4 Policy Implementation

The Small Business Innovation Research programme has undergone several reauthorisations and extensions. The main reason is the law's automatic cessation unless legislative actions lead to the extension (SBIR, 2022e). The first reauthorisation took place in 1992 and took place in the context of concerns regarding the capability of the United State's economy to commercialise inventions. Following the US technological performance challenge, the National Academy of Science (NAS) recommended an increase in SBIR funding. Hence, the Small Business Research and Development Enhancement Act introduced a requirement that federal agencies were to double the set-aside rate to 2.5% (National Research Council (U.S.), 2008a; SBIR, 2022e). Along with this rise in the percentage of R&D funding allotted to the programme, there was a larger focus on promoting the commercialisation of technologies supported by SBIR. Legislative language was subsequently introduced that emphasised commercial potential as a requirement for awarding SBIR funds (SBIR, 2022a).

Before the new Policy Directives, the SBA issued guidelines to agencies for Fiscal Year (FY) 2012, increasing the set-aside share to 2.6%. The share increased by 0.1% in each subsequent fiscal year until it reached 3.2% in FY 2017 (**Table 3.1**). It remains at the same level today (SBA, 2022a).

Table 3.1: Set-aside funding percentage by fiscal year.

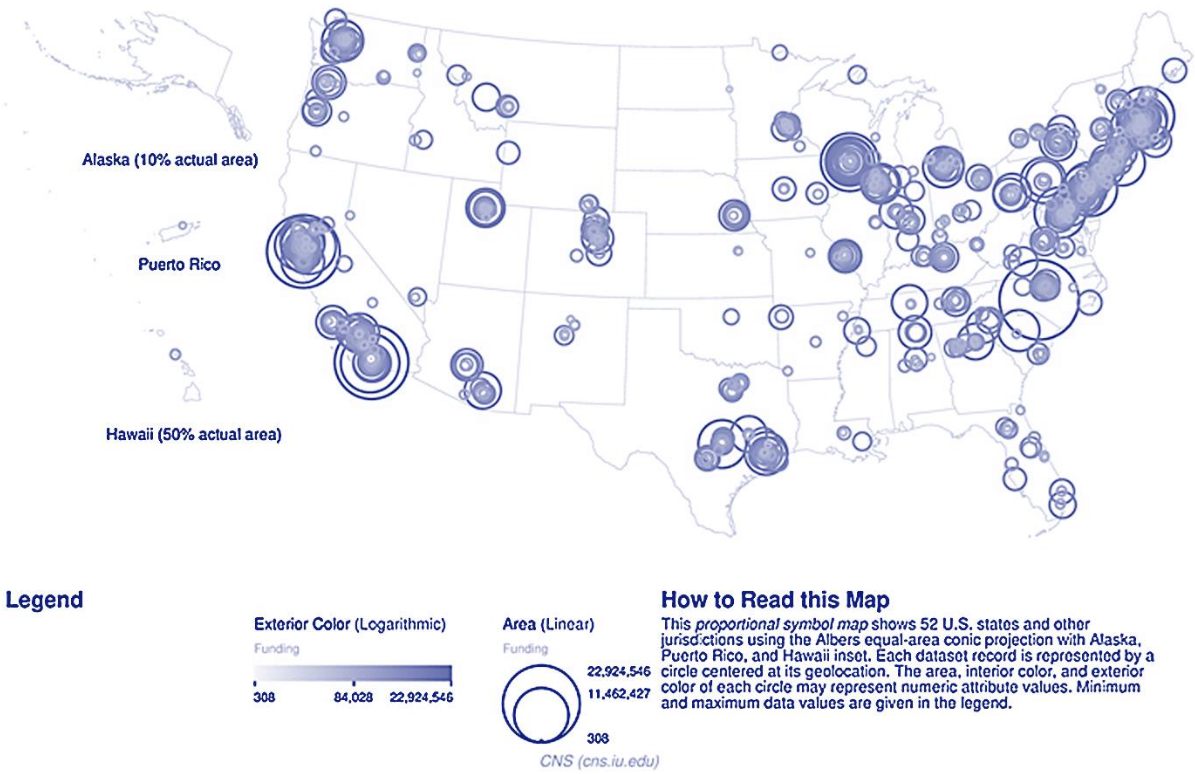
Fiscal Year	Set-aside Funding Percentage (%)
1982	0.2
1987	1.25
1992	1.5
1997	2.5
2012	2.6
2017 to present	3.2

Source: Audretsch et al. (2002), SBA (2022b).

In 2000, the SBIR programme was reauthorised by the Small Business Reauthorization Act, with an extension of the programme until September 30 2008. Additionally, it demanded that the National Research Council evaluate the programme's broader effects, including those on employment, health, national security, and competitiveness (National Research Council (U.S.), 2008b). In 2011, the National Defense Authorization Act reauthorised the SBIR programme for FY 2012. Since then, the SBIR programme has undergone additional modifications and extensions from Congress, the most recent of which extends it through 2022, pushing the expiration date to September 30 2022 (SBA, 2019a; SBIR, 2022e).

To increase SBIR's impact, 14 states have developed initiatives to offer matching funds to successful SBIR applicants within their states. The SBIR Reauthorization Act of 2011 sought to increase funding to states with historically low levels by requiring coordination with other federal research grant programmes designed to increase the geographic distribution of federal funds for R&D. This was done to further stimulate small business R&D within each state. One such initiative is the Institutional Development Award (IDeA) programme administered by the National Institute of General Medical Sciences (NIGMS), which is a part of the National Institutes of Health (NIH). The NIH funding for biomedical research is more widely distributed geographically (**Figure 3.3**), thanks to the IDeA programme. Additionally, it encourages health-related research and increases the competitiveness of researchers at institutions in locations where the overall success rate for NIH application submissions has historically been low (Onken et al., 2019).

Figure 3.3: The geographic distribution of all NIGMS funding for SBIR for fiscal year 2017.



Source: Onken et al. (2019).

One of the changes that took place during the modification of the programme was an increase in the cap of funding. As of November 2021, agencies may issue Phase I awards up to USD 275,766 and a Phase II award up to USD 1,838,436 without seeking SBA approval (SBIR, 2022a). In 2018, as part of the John S. McCain National Defense Authorization Act for FY 2019, Congress expanded the scope of already-existing pilot programmes promoting innovation, and established new ones tied to the SBIR and STTR programmes, along with other initiatives. The act mandated that federal agencies with SBIR and STTR programmes establish a Commercialization Assistance Pilot Program. It also developed pilot programmes authorising the use of SBIR and STTR funds for administrative costs, outreach, and contract processing facilities and for technology development, testing, evaluation, and commercialisation assistance activities to be extended (Gallo, 2021).

3.4.5 Policy Evaluation

SBIR success and achievement

The Small Business Innovation Research programme successfully incentivises research, experimentation, and innovation in various sectors by small businesses. Over 179,000 awards, totalling more than USD 54.3 billion, have been made before 2019 (Feldman, 2022; SBIR, 2022a).

The success of this programme has been notable in various aspects. Given the early stages at which SBIR funding is provided and the high level of technical risk, it is noteworthy that a substantial percentage of initiatives make it to the market in some capacity. The SBIR programme shows that successful public-private collaborations are crucial for advancing science commercialisation and maximising the innovation economy's potential in the United States.

The SBIR programme has been successful in achieving the goals set in Congress when the programme was adopted. Addressing the purpose of stimulating technical innovation has successfully contributed to the nation's stock of new scientific and technical knowledge. The programme also meets the R&D needs of the federal agencies by introducing novel, scientific solutions to meet the various mission requirements of each of them. Regarding the goal of supporting disadvantaged minorities, the SBIR has successfully supported a broad range of small businesses, including minority, women-owned firms through providing market access, funding, and recognition. Eventually, when it comes to the goal of commercialising private sector innovation, the programme enabled small businesses to contribute to R&D investments in commercialisation, through both private commercial sales and government purchase, thereby improving American health, welfare, and security by introducing innovative goods and procedures (National Research Council (U.S.), 2008b). The policy's outstanding success in several areas explains Congress's numerous extensions (Feldman, 2022).

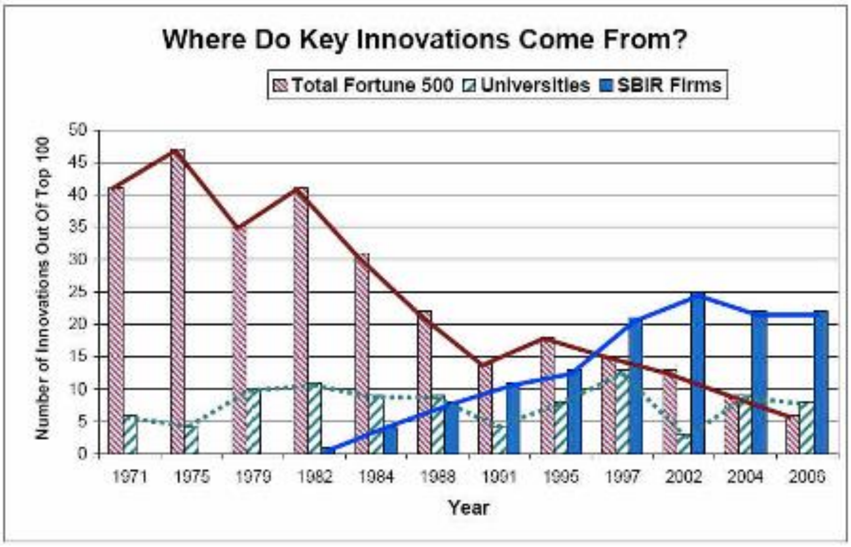
The SBIR programme encourages the advancement of scientific and technological knowledge, and its beneficiaries have produced many patents and publications. Additionally, it connects universities with both public and private markets. Projects supported under the programme frequently have a high level of technical risk, suggesting unique and challenging research instead of incremental improvement. The main advantage of the SBIR programme is that it provides funding at the early stages and, in this way, allows for the development of technical expertise. The further development of the respective innovations can then be picked up by other actors, including various public and commercial sources (National Research Council (U.S.), 2008b).

SBIR companies have created life-changing breakthroughs in the fields of bioscience, communication, energy, and defence that have transformed these industries and provided the foundation for future American manufacturing. This indicates that each agency is successfully advancing its individual funding agency's purpose while achieving the goals of its missions. Among these, the success of DoD in reducing expenses while enhancing capabilities is notable. Moreover, the Air Force saved over USD 500 million on the F-35 aircraft (Glover et al., 2021a; National Research Council (U.S.), 2008a).

According to the Small Business Technology Council (2021), the SBIR programme was essential in leveraging small businesses' entrepreneurship, innovation, drive, and competitive adaptability. It also allowed small businesses to benefit from university research: between 50% and 70% of SBIR work is either done directly by involving university faculty or employing previous university faculty, focusing on factors influencing small business growth. Successful SBIR-funded projects also attract further venture capital investments due to moving closer to products and market entry. At the same time, the programme is very competitive: only one in twenty submissions are accepted for the main Phase II R&D work (Glover et al., 2021a).

The success of the SBIR programme is shown in **Figure 3.4**. The SBIR programme's initial budget was a modest USD 45 million, equal to only 0.2% of the extramural R&D budget. Up until 2021, over 28,000 businesses have succeeded in winning SBIR awards, totalling over 127,000. The SBIR programme now accounts for about USD 3 billion, equivalent to 7000 awards annually, and has grown to 3.65% of extramural R&D funds (Glover et al., 2021a).

Figure 3.4: Number of innovations out of the top 100.



Source: Glover et al. (2021a).

SBIR's weaknesses

Despite several significant successes, the SBIR programme also suffers from certain drawbacks. One issue criticised was the high overhead cost of administering the programme. Uncertainty concerning the impact of funding on innovation in each case is another challenge, as many recipients of funding have not been involved in such projects before. Moreover, for small businesses, the time required for agencies to solicit, evaluate, select, and make rewards can be challenging. Finally, award sizes have not increased to reflect inflation. The number of resources provided to support the Phase I award has, in fact, diminished. This decrease affected the scope and complexity of activities that can be financed in the funding framework. Additionally, it might affect the quantity and quality of proposals (National Research Council (U.S.), 2008b).

Furthermore, the diversity in agencies' missions leads to the necessity to use metrics and indicators that encapsulate shared objectives to assess results and impacts. In this regard, there is a basic distinction between agencies that typically do not purchase items financed by SBIR and those that do due to their different goals. The methods employed by the respective agency to carry out the SBIR programme reflect these substantially different purposes through differing mechanisms and metrics (National Research Council (U.S.), 2008b).

Finally, the need to extend the programme every few years increases the insecurity of small businesses, who cannot be sure if this source of funding will be available in the future. The Department of Defense in Section 809 Panel recommended making the SBIR programme permanent and double the increase in its allocation to 7% (Glover et al., 2021a).

While it is admirable that numerous agencies have made the initiative to adjust their programmes to better serve the demands of their missions, these efforts need to be periodically evaluated to see if these "operational experiments" are successful and to pinpoint the pertinent lessons gained. Certain significant advances do not seem to be founded on any thorough analysis of the issues with the current mechanisms. Therefore, there is a requirement for ongoing internal and external assessment (National Research Council (U.S.), 2008b).

In addition, better documentation of results can make a difference. In the majority of the agencies examined, commercialisation outcomes are still not sufficiently documented. Very little is being done to monitor the development of firms that have received SBIR awards. Effective programme management requires an understanding of outcomes and the effects of programme changes on those outcomes (National Research Council (U.S.), 2008b).

EPA success story under the SBIR programme

As stated earlier, the US Environmental Protection Agency is one of the agencies that issue solicitations under the SBIR programme. In this way, it is fulfilling its mandate of encouraging the advancement of new research and technology that addresses the agency's mandate to conserve the environment and human health. The EPA's SBIR funding places a particular emphasis on projects that address drivers of climate change.

One of the beneficiaries of funding through EPA’s SBIR funding is Lucid Design Group, which developed energy-use feedback software. The software uses multicoloured, internet-connected LEDs that motivate users to conserve energy in commercial buildings. LED lights and Lucid's software were coupled to create "Building Orbs”, which alter the ambient colour of the lights based on real-time electricity usage data, to inform building occupants of their energy consumption. As connecting people to their energy use on an individual basis will become even more crucial for conservation, Lucid predicted that individual building occupants will have more power over their energy usage over time through behaviour than facility managers. Lucid expanded its technology into the BuildingOS® business intelligence platform. Moreover, Lucid has been used by more than 500 customers and surveyed 15,000 buildings' energy consumption (Glover et al., 2021b).

3.4.6 Discussion

A significant advantage of the SBIR programme is its flexibility. Due to its design, it allows different federal agencies to use the programme to meet their needs. The SBA and agency leadership have allowed the programme managers to adapt the programme to meet the demands of certain technologies and unique mission requirements. Despite considerable operational variances, reflecting different missions and operational cultures, the administration of the many departments, services, and agencies has successfully adopted the SBIR programme.

While the SBIR programme is not focused on climate action, with adequate goal setting, it offers a significant potential to facilitate targeted innovation to address gaps in the technological solutions needed to transfer to a low-carbon economy. These gaps could be identified by a broad scope of actors, e.g., EU or national agencies focusing on energy and environment or even private companies whose business model cannot be implemented due to lacking certain elements. An example could be finding an innovative solution to efficiently transport hydrogen, even at a smaller scale, or integrating different energy sectors to make the electricity grid better prepared for taking up a high share of variable renewables. The funding for such innovation could also be coming from different sources as is the case for SBIR. Section 5 offers a more in-depth assessment of the ways in which some lessons learnt from the programme could facilitate innovation development in the EU.

3.5 Case study 3: Small Business Technology Transfer (STTR)

The third case study covers the Small Business Technology Transfer (STTR) programme, an initiative started to help boost research to address core scientific inquiries and challenges for the benefit of the public and increase the competitiveness. In the form of grants, the STTR programme allocates funds to support small businesses in their research and development efforts. In Section 3.5.1, the scene is set for the rationale behind the STTR programme, exploring the funding needs to boost the US competitiveness in research and development. The history of the policy development is then expanded in terms of the STTR programme's structure and eligibility. Section 3.5.2 explains the role the Small Business Association plays in the implementation of the SBIR and STTR programmes, with Section 3.5.3 explaining the difference between the two programmes. Sections 3.5.4 and 3.5.5 evaluate the strengths and weaknesses of these programmes and how they were implemented. Lastly, Section 3.5.6 presents a brief discussion on the applicability and suitability of this model to a European context.

3.5.1 Context and Background

The drivers for the creation of the STTR stream of funding were to a large degree similar to those behind the SBIR programme, with the main one being concerns about the United States losing its competitiveness to Japanese industrial growth, especially in industries that were previously dominated by American companies (e.g., semiconductors, steel, and cars). For the STTR specifically, the main worry was America's inability to convert its scientific expertise into economic advantage. Although the United States dominated fundamental research, most of which was financed by the Federal Government, it was still challenging to translate this knowledge into the expansion of innovative products and technology. As the impact of the corporate laboratories on innovation decreased, new models, such as the cooperative model used by certain Japanese keiretsus (i.e., companies characterised by cross-sharing and long-term transactional relationships among their constituents) appeared to offer greater sources of dynamism and more competitive enterprises (National Academies of Sciences, Engineering, and Medicine, 2016a).

One of the solutions to this challenge was to combine the forces offered by academia and small businesses to foster innovation in different areas. Even if energy was one of the areas considered, the focus on solution to climate change was not yet one of the main foci. (National Academies of Sciences, Engineering, and Medicine, 2022).

The objectives of the programme were two-fold:

1. Providing "a transparent, competitive, and reliable source of early-stage funding for R&D based entirely on scientific merit”; and
2. Ensuring that “the government [could] obtain needed R&D that the private sector could not otherwise provide” (National Academies of Sciences, Engineering, and Medicine, 2022, p. 22).

Roland Tibbetts, Senior Program Officer at the National Science Foundation (NSF), who also played an instrumental role in development of SBIR, suggested allocating some National Science Foundation (NSF) funding for this endeavour in 1976. However, it was only in 1992 that the Small Business Technology Transfer (STTR) programme was established through the adoption of the Small Business Research and Development Enhancement Act with the stated goal of bridging the gap between basic science and commercialisation of innovations (Bingaman, 1992; National Academies of Sciences, Engineering, and Medicine, 2016a).

The STTR programme was modelled on the SBIR programme, but instead of fostering cooperation between small businesses and federal agencies, it focused on increasing joint venture opportunities between small businesses and non-profit research institutions (Gallo, 2021; National Academies of Sciences, Engineering, and Medicine, 2016b; SBIR, 2022g). Hence, the most crucial function of STTR was to gain ground between the application of basic science and the commercialisation of related innovation through cooperation between Research Institutions (RI) and Small Business Concerns (SBC) (Gallo, 2021; SBIR, 2022g). Thanks to this cooperation, small businesses were expected to have access to streamlined technology transfer processes. On their side, non-profit research institutions could be supported in testing their research in practice and in facilitating their commercialisation.

The STTR programme officially started making awards in FY 1994. Like the SBIR, it is coordinated by the Small Business Administration (SBA) to enable access for small businesses to federal R&D funds. Through collaborations with universities and research institutes, STTR aims to ease the commercialisation of research and innovation through small businesses’ entrepreneurship and boost private-sector commercialisation of innovations resulting from federally funded R&D (Gallo, 2021; Inc., 2022; SBIR, 2022e).

Apart from the general goals of encouraging technological innovation and satisfying the needs of federal agencies, it also has a much more concrete aim of promoting and stimulating women’s entrepreneurship and facilitating socially or economically disadvantaged individuals' engagement in innovation and research. By integrating entrepreneurial abilities with state-of-the-art research initiatives, STTR was expected to combine the strengths of RIs and small businesses. The goal of this design was to facilitate the transition of products and technologies from the lab to the market (National Academies of Sciences, Engineering, and Medicine, 2016a).

To be successful, the applicant company must prove that it will use the available research of the partner research institute to build a viable product and promote it either directly or through various commercialisation techniques. Therefore, obtaining financing for unrestricted R&D is achievable if skills and interests match the particular needs of a federal agency. The suggested strategy should be untested and have some technical risk (SBIR, 2022h).

The scope of the programmes was defined very broadly and included the goals of increasing national health, wealth, and welfare while also securing national security and advancing scientific advancement. The programme has no topical or procurement focus, which is meant to encourage as many qualified small firms engaged in science and technology as possible to bid for funding. Possible topics such as advanced manufacturing, artificial intelligence, digital health, energy technology, and environmental technology, are explicitly mentioned. However, the programme is frequently open to applications that concentrate on technical and market issues that are not specifically included in the aforementioned subjects. Therefore, by converting scientific discovery and invention into both social and economic value and by placing a focus on private sector commercialisation, the NSF STTR programme is in a unique position to accomplish both the aims of NSF and the purpose of the STTR legislation (National Science Foundation, 2019).

3.5.2 Phases and structure of the STTR programme

As conceived in the 1992 Act, and similar to the SBIR, the STTR programme consists of three main phases. During Phase I (Start-up), the federal agency participating in the programme requests contract proposals or grant applications to carry out experimental or theoretical studies related to feasibility or R&D to meet agency objectives. Before considering additional federal funding in Phase II, Phase I awards are designed to evaluate the scientific and technical value and viability of the projected effort and the quality of performance of the small business with a relatively small agency investment (Gallo, 2021; SBIR, 2022e; United States Senate, 1992). Phase I awards shall not exceed USD 100,000 and are intended for approximately one year's worth of study and research (Inc., 2022).

Phase II (Development) aims to support additional R&D initiatives started in Phase I that address *specific* programme needs and represent the commercial potential (Gallo, 2021; SBIR, 2022g; United States Senate, 1992). The funding is determined according to the Phase I results, the Phase II project's technical and scientific excellence, and its potential for commercial success. Only Phase I award recipients are typically eligible for a Phase II grant (Inc., 2022; SBIR, 2022g). The grants in this phase reach up to USD 500,000 for no more than two years, unless in exceptional cases (Gallo, 2021; SBIR, 2022g). Additionally, to continue the work of an original Phase II award, agencies may make a subsequent Phase II award. Some agencies demand third-party matching of the agency's STTR funding for consecutive Phase II awards (Gallo, 2021).

During Phase III (Introduction to market), where applicable, the objective is for the small business to pursue commercialisation goals that originated from the R&D efforts of Phases I and II. Phase III is not funded by the STTR programme. At some federal agencies Phase III can entail the continuation of non-STTR-funded R&D or production contracts for products, processes, or services designated for the US Government (Inc., 2022; SBIR, 2022g). In general, funding for Phase III is anticipated to arise from the private sector. By using Phase III grants, including sole-source awards, the STTR Act instructs agencies and prime contractors to aid in the commercialisation of STTR initiatives "to the greatest extent practicable" (Gallo, 2021).

According to the STTR Act, no less than 40% of the R/R&D work must be carried out by a small business for both Phase I and Phase II, and no less than 30% must be carried out by a single, partnered RI. Even though they must determine so in the solicitation, agencies may choose to calculate these percentages using either contract money or labour hours (United States Senate, 1992).

Requirements and eligibility

To receive the award, both small businesses and partnering research institutions must fulfil a number of criteria. They must:

- be independently operated and principally located in the United States;
- be more than 50% owned and controlled by one or more individuals who are citizens, or permanent resident aliens, of the United States, or by other small business concerns that are each more than 50% owned and controlled by one or more individuals who are citizens, or permanent resident aliens, of the United States; and
- employ no more than 500 employees, including affiliates (Inc., 2022; National Science Foundation, 2019; SBIR, 2022g).

While there is no workforce size limit for RIs (Inc., 2022), the following requirements must be met when choosing the partner. They must:

- be either a non-profit college or university, a domestic non-profit research organisation, or a Federally Funded Research and Development Center (FFRDC); and
- principally located in the United States (Gallo, 2021; Inc., 2022; SBIR, 2022g, 2022h).

Generally, R/R&D under STTR must be conducted in the United States. However, the agency may allow a part of the work to be performed or procured outside of the United States in "rare and unique" circumstances (Gallo, 2021).

There are also very specific requirements that need to be fulfilled by the primary Principal Investigator (PI) leading the project. The PI must be 51% employed by the small business firm and be able to demonstrate that they are legally permitted to work for the prospective company in the United States through citizenship, permanent residency, or a valid visa. Interestingly, the PI is neither required to be accredited by an academic institution nor hold any degree. One identified PI cannot be listed for more than one proposal submitted for the solicitation (National Science Foundation, 2019).

To qualify for the Phase I award, the applicants must have met specific milestones for development towards commercialisation if they have previously earned several SBIR/STTR contracts (Gallo, 2021). Only one STTR Phase I proposal from a single organisation is allowed throughout each complete proposal submission window. When an invited STTR Phase I full proposal is submitted during a designated submission window, the same applicant is disqualified from the concurrent SBIR Phase I solicitation. If an organisation submits more proposals than allowed, the first one will be accepted, and the additional ones will be returned un-reviewed (National Science Foundation, 2019).

Financing and Participating Agencies

In the same way as for the SBIR programme, the STTR Act determines a cap for the amount of the award provided by federal agencies. This amount must be adjusted for inflation every year. Agencies may choose to consider awards that are less than the maximum amount. In exceptional cases, conditionally on the approval by the SMA, they may also exceed the monetary limit in favour of a specific topic (SBIR, 2022g). Apart from the funding itself, the programme is expected to offer its recipients access to a network of scientists and engineers collaborating on a variety of technologies, support with product sales, intellectual property protection, market research and validation. (Gallo, 2021).

The funding for the programme comes from the budgets of federal agencies for research. According to the law establishing the STTR, each agency whose research budget exceeded USD 1 billion was to spend 0.05% of their respective budgets on the programme in 1994. By 1996 this budget was expected to increase to 0.15% (United States Senate, 1992). This was significantly below the level of funding for the SBIR programme which came into force with a higher share of 0.2%, from the very beginning in 1982.

As of 2022, five federal agencies are required to use part of their funding on the STTR programme, including the departments of Defense (DoD), Energy (DoE), and Health and Human Services (HHS), along with the National Science Foundation (NSF) and the National Aeronautics and Space Administration (NASA) (*United States Senate Subcommittee on Innovation and Technology*, 1984; SBIR, 2022e, 2022g).

Under the terms of the legislation and regulations, as well as with the guidance provided by the SBA in its Policy Directive (PD), STTR programmes are managed and administered differently by each agency (Gallo, 2021; National Science Foundation, 2019). In certain situations, they are managed and operated differently by various DoD and NIH components (National Academies of Sciences, Engineering, and Medicine, 2016a). This ensures that STTR programmes are generally consistent, while giving each agency a significant amount of control and flexibility in how its programmes are carried out in accordance with their overall purpose and priorities (Gallo, 2021). However, this feature is seen differently by agencies. Some, like NASA and the DoD, see it as a link between fundamental research and acquisition programmes. On the other hand, agencies such as the NIH, NSF, and DoE, consider STTR as having goals similar to SBIR and, hence, run the two programmes concurrently (National Academies of Sciences, Engineering, and Medicine, 2016a).

3.5.3 The role of the Small Business Administration

The U.S. Small Business Administration serves as the coordinator for both SBIR and STTR programmes implementation (SBIR, 2022g). One of its main tasks is to prepare Policy Directives after consulting with the heads of each participating federal agency, the Commissioner of Patents and Trademarks, and the Director of the Office of Federal Procurement Policy. The Policy Directive should include simplified, standardised, and timely STTR solicitations while also defining the funding process, which should include outside peer review. The application for the funding and its execution should be executed in a way which minimises regulatory burdens. The Policy Directive also clarifies the guidelines for the distribution of the property rights resulting from the cooperation between the beneficiaries (United States Senate, 1992).

As in the case of SBIR, the SBA is responsible for establishing databases and updating the website to collect and retain data in the consistent fashion needed to support SBCs and assess the STTR programme. To create policy and procedure for the programme, the SBA also publishes and updates the PD and passes new rules. The SBA is in charge of monitoring and overseeing how the STTR initiatives are being carried out at the agency level. This monitoring considers the evaluation of policies, rules, regulations, interpretations, and procedures developed to facilitate intra and inter-agency STTR programme implementation, including allocations of STTR funding, programme solicitation and awards status, follow-on funding commitments, fraud, waste, and abuse, performance areas, metrics, and goals, additional efforts to improve the performance of the programme (SBA, 2019a).

An important role in the programme management is also played by the Comptroller General, who is required to provide a report to Congress and the head of each agency participating in the programme. The report should outline the Comptroller General's evaluation of each of these agencies, including the quality of research carried out under funding agreements granted by that agency under the STTR programme since the programme's inception, whether the STTR programme has had an impact on the performance of that agency's research programmes, and the commercial potential of research carried out under the STTR programme if sufficient data are available (United States Senate, 1992).

3.5.4 Differences between SBIR and STTR programmes

The STTR programme differs from the SBIR programme in several ways. The main difference is the role of the not-for-profit actors. While the SBIR does permit the involvement of research institutes in the project, their role is *limited* to a third of the Phase I work and half of the Phase II work (National Academies of Sciences, Engineering, and Medicine, 2016a). On the contrary, projects under STTR must result from cooperation between businesses and research institutes: the small businesses are obligated to complete at least 40% of the work, while the research institutes are required to complete *at least* 30%. The remaining 30% can be executed by either of the two beneficiaries or another third party (Gallo, 2021; National Science Foundation, 2019; SBIR, 2022g).

The involvement of more actors under the STTR funding requires clarification of the intellectual property for the innovation or product developed as a result of the cooperation. Therefore, the projects must outline the distribution of intellectual property rights and the right to conduct subsequent research, development, or commercialisation activities (Gallo, 2021; SBIR, 2022g). Finally, under the SBIR, the small business must employ the Principal Investigator at the time of award and for the length of the project. In the case of the STTR, the PI may be principally employed by either the SBC or the partnering non-profit RI at the time of award and for the duration of the project period (Gallo, 2021; National Science Foundation, 2019; SBIR, 2022g).

Another difference concerns the scope of funding (**Table 3.2**). While the SBIR outweighs STTR in size, the SBA considers STTR to be a strategy to raise funding options for federal innovation. In essence, STTR was established with the purpose of integrating the capabilities of research institutions and small businesses through the application of entrepreneurial expertise to state-of-the-art research initiatives. The goal of this design was to facilitate the transition of products and technologies from the lab to the market (National Academies of Sciences, Engineering, and Medicine, 2016a).

Table 3.2: The aggregated amount of funds for SBIR/STTR awards from the five participating agencies for fiscal year 2015.

	Funding (in thousands of USD)	
	STTR	**SBIR**
DoD	118,840	1,070,758
HHS	86,933	65,648
DoE	23,464	169,797
NASA	18,531	139,184
NSF	154,52	131,305
Total	263,220	2,167,524

Source: National Academies of Sciences, Engineering, and Medicine (2016).

Since STTR places a stronger priority on commercialisation than SBIR, universities, federal laboratories, or non-profit research institutions must collaborate with businesses to bring the product to market. This makes participating agencies more critical when reviewing applicants. Participants are given the opportunity to combine entrepreneurial initiative and creativity with the knowledge, facilities, and other capabilities of non-profit laboratories through SBC and non-profit RI partnerships (Inc., 2022).

Further, STTR in some respects exceeds SBIR with regard to achieving the congressional objective of increasing collaboration between small businesses and research institutions. It is also in accordance with agency missions and technological adoption across acquisition agencies. STTR awards have a considerably richer and deeper university connection than SBIR awards, hence STTR more directly satisfies the congressional mandate to encourage collaborations between small business concerns and research institutions than SBIR does (National Academies of Sciences, Engineering, and Medicine, 2016a).

3.5.5 Policy implementation

The Small Business Technology Transfer programme has received numerous extensions and reauthorisations under the Small Business Research and Development Enhancement Act of 1992. After the Small Business Reauthorization Act of 1997, it was extended in 2001 (United States Senate, 1992, p. 115).

The STTR programme underwent a series of changes as a result of the STTR Reauthorization Act of 2011, including increases in the set-asides for the following six years and extended eligibility for STTR recipients to participate in technical assistance programmes (National

Academies of Sciences, Engineering, and Medicine, 2016a). Subsequently, the National Defense Authorization Act for FY 2012 authorised the establishment of the Phase 0 Proof of Concept Partnership Pilot Programme. Through this pilot initiative, the National Institute of Health (NIH) was able to provide grants to research institutes to hasten the formation of small businesses and commercialise promising projects (SBIR, 2022g). In 2016, the most recent extension and modification came into force by the 'National Defense Authorization Act' of FY 2017. It extended the programme until September 30 2022, and increased the set-aside funding percentage to 0.45% for each Federal agency with extramural R&D expenditures of over USD 1 billion (Gallo, 2021; SBIR, 2022g).

Furthermore, in 2018, as part of the John S. McCain National Defense Authorization Act for 2019, Congress expanded the scope of already-existing pilot programmes and established new ones related to the SBIR and STTR. As one of its provisions, the legislation extended (until FY 2022) the pilot programmes permitting the use of SBIR and STTR grants for administrative expenses, outreach initiatives, and contract processing activities, as well as financing for technological development, testing, and evaluation. It also authorised federal agencies with SBIR and STTR programmes to develop a Commercialization Assistance Pilot Program. Finally, it mandated the Department of Defense to establish a pilot programme to speed up the process of awarding SBIR and STTR (Gallo, 2021).

Since March 2019, Phase I proposals for the NSF SBIR and STTR programmes have been required to include a three-page "Project Pitch" that describes the project's goals, technical innovations, and associated technical risks. The goals of this novel approach are to give potential applicants detailed feedback about whether their proposed project is aligned with the programme before starting the full proposal submission process and to allow for greater agility and flexibility in receiving and evaluating full proposals. These goals aim to prevent applicants from devoting time and resources to the design of full proposals where the proposal aims are unacceptable given the NSF SBIR/STTR programme goals (National Science Foundation, 2019).

The reauthorisations have also affected the award's monetary amount. As of November 2021, Phase I and II awards (including modifications) may be issued up to USD 275,766 and USD 1,838,436, respectively, by agencies without obtaining SBA approval. Any award higher than those values will still require a waiver (SBIR, 2022a).

3.5.6 Policy evaluation

STTR success and achievements

In the United States, there is a clear perception of innovation as the driving force behind the country's economic growth, as it helps develop cutting-edge solutions to complex issues and successfully promote new products. Despite the challenges of globalisation and associated effects, small businesses continued to produce and commercialise new products for the market. Since small businesses are typically more agile and swift to adapt to market changes than their larger competitors, they fuel the innovation sector and increase economic agility on a global scale (House Committee on Small Business, 2014).

In this regard, the STTR programme has demonstrated impressive success and is often referred to as America's largest source of early-stage/high-risk investment for start-ups and small businesses (SBIR, 2022e). Since it is approved by Congress and requires a periodic extension, its implementation has been accompanied by a comparatively high level of evaluation. This evaluation has been carried out by prestigious organisations like the National Research Council or numerous blue ribbon panels, which are independent and have exclusive committees of nonpartisan professionals (Gray et al., 2014).

Over the last 30 years, the STTR programme has contributed to funding innovations worth close to USD 40 billion in a variety of industries. This initiative has benefitted the new drug cure development, homeland security technologies, and energy-saving technologies. These innovations contributed to economic growth and job creation, illuminating the potential for collaboration between small firms and the government (House Committee on Small Business, 2014). Furthermore, small businesses participating in this programme benefitted from funding which did not require any changes to ownership or the taking out of additional loans (SBIR, 2022e). In FY 1994, the STTR programme started by issuing 198 awards for approximately USD 19 million, increasing to 614 awards for Phase I and 195 for Phase II, totalling over USD 198 million in FY 2004 (Inc., 2022). Subsequently, as of FY 2018, 171,680 awards, totalling USD 51 billion, had been given by federal agencies under the SBIR and STTR programmes. Agencies provided USD 382 million in STTR grants in that fiscal year.

Similar to the SBIR programme, the majority of STTR grants (72%) were designated for Phase I awards, while the majority of funding (68%) went to Phase II awards as illustrated in **Table 3.3** (Gallo, 2021). This exponential trend continued, with 179,000 awards worth more than USD 54.3 billion. Accordingly, a study conducted by the National Academy of Sciences discovered a commercialisation rate of between 50% and 60% for SBIR/STTR investments, making the programme a win-win programme for the American economy and taxpayers. This phenomenal growth continues in spite of the shutdown of many commercial and governmental functions during the first year of the COVID-19 pandemic. The total number of SBIR/STTR awards given to innovation-focused businesses experienced an increase over record-breaking 2019 levels, reaching 3.7% (SSTI, 2022). In addition, an assessment conducted by the Department of Defense revealed that the SBIR/STTR programmes have generated a 22:1 return for every federal dollar spent (Day, 2022). In general, simple input/output measurements are only marginally useful since STTR delivers results over multiple dimensions. The programme produces economic benefits that greatly outweigh its expenses (Gaster, 2017).

Table 3.3: The STTR grant quantity and amount between fiscal years 1994 and 2018.

Fiscal Year	Amounts Awarded (in USD millions)	Number of Awards		
		Phase I	Phase II	Total
FY 1994	18.9	198	-	198
FY 1995	33.7	238	22	260
FY 1996	64.5	238	88	326
FY 1997	69.0	260	89	349
FY 1998	64.8	208	109	317
FY 1999	64.8	251	78	329
FY 2000	69.8	233	95	328
FY 2001	77.5	224	113	337
FY 2002	91.8	356	114	470
FY 2003	91.8	397	111	508
FY 2004	190.0	674	195	869
FY 2005	220.3	611	221	832
FY 2006	226.2	644	234	878
FY 2007	242.9	634	213	847
FY 2008	239.6	483	251	734
FY 2009	269.6	588	242	830

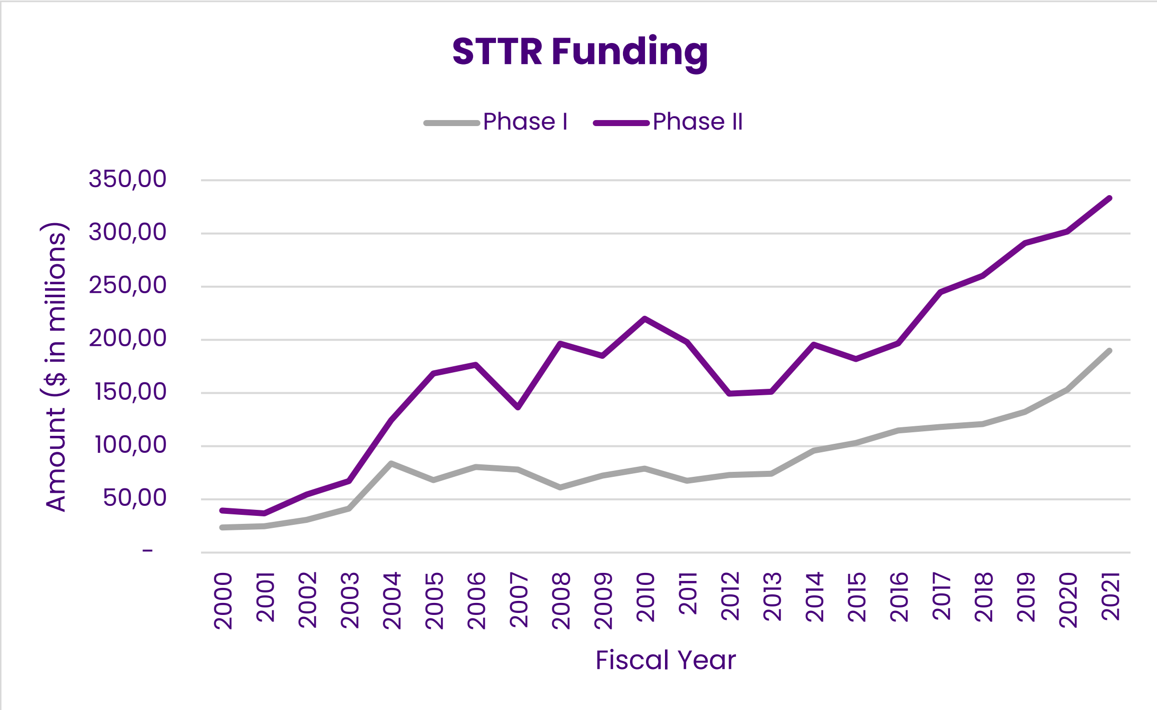
FY 2010	279.3	625	256	881
FY 2011	251.2	482	238	720
FY 2012	228.2	492	168	660
FY 2013	250.4	476	193	669
FY 2014	228.0	492	213	705
FY 2015	289.9	553	173	726
FY 2016	308.3	595	200	795
FY 2017	365.3	613	234	847
FY 2018	381.7	568	224	792

Source: Gallo (2021, p. 20).

With this impact in mind, Congress has shown continued interest in the amount of agency funding set aside for the programmes, the success of initiatives to improve commercialisation outcomes, and the geographic distribution of awards and financing received by women-owned and minority-owned businesses, as well as the SBA's duties under the programmes, including agency coordination, policy advice, and data collection (Gallo, 2021).

As is shown in Figure 3.5 the minimum amount that participating agencies were obligated to reserve for the STTR programme increased from 0.15 to 0.30% in FY 2004. To FY 2011, the STTR set-aside remained at 0.30%. Once more, the set-aside doubled in the first year (FY 2004) and STTR funding as a whole nearly doubled. However, Phase I aggregate spending decreased between FY 2004 and FY 2011 by nearly 25%, while Phase II aggregate money increased by roughly 74%. The STTR set-aside increased incrementally from 0.30 to 0.45% between FY 2012 and FY 2016. Total funding for STTR increased by 67% between FY 2012 and FY 2018. Over the same time period, aggregate funding for Phase I climbed by 72%, and aggregate funding for Phase II increased by 65% (Gallo, 2021).

Figure 3.5: STTR fundings for Phase I and II

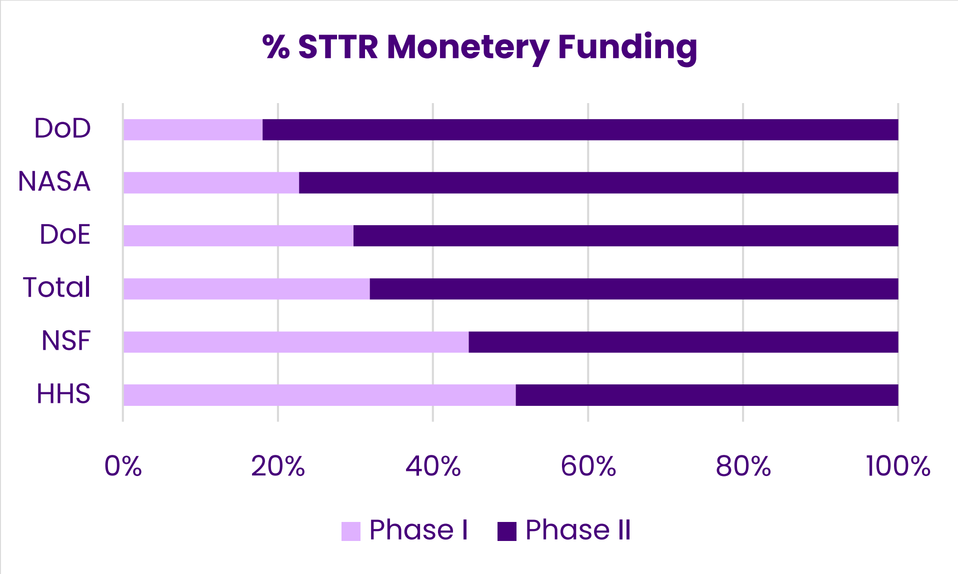


Source: SBIR (2022b).

Agency allocation of awards

In FY 2018, two Federal agencies — the DoD, with USD 175.4 million, and the HHS, with USD 131.8 million (**Table 3.4**) — were responsible for granting four out of every five STTR funding awards. Agencies allocate varying amounts of STTR funds to Phase I and Phase II awards (**Figure 3.6**). In FY 2018, HHS awarded Phase I the greatest share of its STTR funds, equivalent to 51%, while DoD granted Phase II awards the biggest share, of 82% of its funding (Gallo, 2021).

Figure 3.6: Phase I and II STTR funding agency distribution for fiscal year 2018.



Source: Gallo (2021, p. 18).

Table 3.4: STTR awards quantity and the amount (in millions of dollars) for Phases I and II by each five-participating agency in the fiscal year 2018.

Department/ Agency	Total Amount Awarded, Phase I and Phase II / USD MM	Phase I		Phase II	
		No. of Awards	Total Amount Awarded / USD MM	No. of Awards	Total Amount Awarded / USD MM
DoD	175.4	192	31.6	133	143.8
DoE	31.6	58	9.4	20	22.2
Dept. of Health and Human Services	131.8	237	66.8	37	65.0
NASA	24.2	44	5.5	24	18.7
National Science Foundation	18.6	37	8.3	10	10.3
Total, All Agencies	**381.7**	**568**	**121.6**	**224**	**260.1**

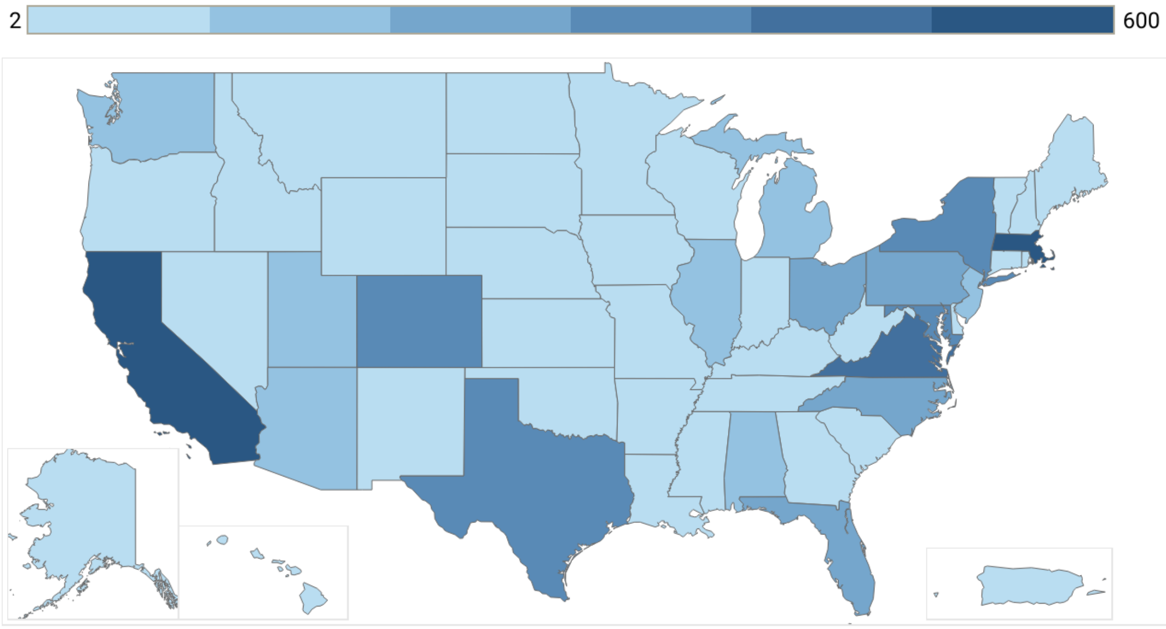
Source: Gallo (2021, p. 19).

The STTR actively encourages the inventions developed by federal R&D to be commercialised (National Academies of Sciences, Engineering, and Medicine, 2016a). According to the National Academies, 40% to 70% of initiatives (depending on the agency) report reaching the market (Gaster, 2017). On the other hand, STTR is not just about specific projects; it also offers vital capital for businesses to survive and expand. Without STTR support, almost 70% of initiatives would either not have begun or have started much later. Over 18% of STTR businesses at NIH and DoD (representing three-quarters of the federal programme) were established directly from STTR awards. A further third said that SBIR/STTR had an impact on company formation. Given the falling launch rate in the US, this is particularly crucial. Several studies provided examples of how STTR funding impacted important critical moments in a company's history. Many SBIR/STTR companies are purchased out for their technology, while others are spun off into new businesses that create new jobs and opportunities (Gaster, 2017).

3.5.7 Criticism of STTR

However, there are also some criticisms of the programme. Although in 2020, California (1489), Massachusetts (731), Virginia (452), Texas (380), and Maryland (362) received the highest total numbers of SBIR/STTR awards, as shown in **Figure 3.7** (SSTI, 2022), they continue to receive the majority of the awards given to agencies. California and Massachusetts, which together represent 14% of the population, receive 35% of the overall funding from these programmes. Only ten states are granted 70% of the total funding distributed in the framework of the programme. This is frequently caused in part by agencies giving the awards to the same companies year after year. It is unclear why only a few new businesses are successful in applying for funding in these programmes (House Committee on Small Business, 2014).

Figure 3.7: Distribution of awarded SBIR/SSTR awards (number) across states in 2020.



SSTI (2022).

Regarding scrutinising the participation of women-owned businesses in STTR, in FY 2018 such businesses were granted only 13% and 15% of all Phase I and Phase II fundings, respectively. Only 42 Phase I grants, totalling USD 6.9 million, went to socially and economically disadvantaged businesses, as did 21 Phase II awards, totalling USD 11.2 million (Gallo, 2021). This results from the fact that the participation of minority and women-owned businesses is limited and not proactively encouraged (National Science Foundation, 2019; *House Committee on Small Business*, 2014). One of the identified factors contributing to this issue is that the SBA definition of socially or economically disadvantaged groups is insufficient to reflect congressional intentions (National Academies of Sciences, Engineering, and Medicine, 2016a).

It should be noted that STTR is less appealing than SBIR to small company concerns because it is more complicated to use. As conceived, the small business concern and the research institution must *formally* cooperate to get an STTR award, but their requirements and goals may differ. The key component of research institutions' missions is the creation and widespread transmission of technical information. On their part, small businesses prioritise the commercialisation of knowledge, which may necessitate taking measures to restrict how others might access technical information through the use of trade secrets or patents. Additionally, the administrative burden at research institutions might be onerous. Negotiating with research institutions can take a small business a remarkable amount of time and resources if there is not a clear road to partnership. Moreover, university administrators frequently strive to make sure that a distinction is made between research conducted inside of universities and activities conducted outside, as faculty members engage in commercial operations outside of the research institution (Gaster, 2017).

3.5.8 Discussion

The STTR offers a solution to the problem of the separation between the academia and the private sector, especially for small companies. While large companies may afford creating their own research units, focusing on development of innovation, this may not normally be the case of enterprises where most of the proceeds is spent on covering the running costs. Cooperation with research institutes creates an opportunity to decrease this competitive disadvantage.

While similarly to SBIR, STTR does not have a clear focus on promoting innovation in the area of climate mitigation, and funding from Department of Energy constitutes a comparably small share of the overall budget; its potential to facilitate innovation resulting from cooperation between research institutes and companies in the area of low-carbon technologies is enormous. The following, Section 5, looks at how it can be used in the EU to facilitate innovation necessary to reduce EU's energy dependency in the short term and reaching climate neutrality in the long term.

3.6 Lessons for the European Union

The three case studies analysed in the preceding sections come with several lessons that can be applied to the EU's innovation framework in the area of climate change mitigation. It does not mean that any of the programmes should replace the existing instruments or that they could be implemented without any significant changes. Instead, the EU policy framework can be complemented with similar tools, or existing tools can be improved by incorporating some of the lessons learnt.

For large scale innovation, the DoE Loan Program offers a number of elements that could help trigger radical innovation. Firstly, the existing support for innovation could be complemented with a stream of support focusing on more risky proposals that may not qualify to receive funding from the Innovation Fund. In the framework of the Fund, there are five criteria defined in the respective Delegated Regulation, all of which need to be fulfilled to move to the next stage. These are: (1) degree of innovation, (2) effectiveness of emissions reductions, (3) project maturity, (4) scalability, and (5) efficiency (European Commission, 2022b). This may exclude projects that score well on most of the criteria, but are e.g., not (yet) mature, scalable, or innovative enough to receive support. This could potentially exclude many of the projects that turned out successful under the DoE Loan Program.

Broadening the criteria would make even more projects eligible for funding than is the case currently. However, already the first call for proposals for the Innovation Fund was significantly oversubscribed with the value of the large-scale proposals applying for funding totalling almost EUR 22 billion and the available budget is set at EUR 1 billion (European Commission, 2022b). The total amount to be distributed, estimated at EUR 38 billion for the period 2020 to 2030 at the assumed carbon price at EUR 75/MtCO_2 (European Commission, 2022g) is far from what is needed to kick-start and deploy technologies needed for carbon neutrality for the EU. The scope of the funding needs to be significantly increased to fund more transformative technologies, as well as those at a less mature stage of development.

Finally, the role of the experts assessing the proposals should move from merely evaluators to co-creators. This task is partly fulfilled by the Project Development Assistance provided by the European Investment Bank for *selected* projects (European Commission, 2022e). This practice should be expanded and mainstreamed. A permanent group of experts should not only review the submitted proposals but also actively engage in their improvement.

The SBIR and STTR programmes offer several lessons that could complement the EU's innovation framework to significantly broaden the scope of the companies benefitting from funding for innovation, and thus make the European economy much more innovative, especially in the area of climate change mitigation.

Firstly, while the EU's funding for research and innovation in the framework of the Horizon Europe programme is well known, it is lacking a clear stream of easily recognisable funding for small businesses. Such funding does exist but is spread over different priorities and operates under different programmes in the member states. Before small businesses apply, they have to make their way through the rather complicated architecture of the European funding governance. The SBIR programme offers recognisability and a clearly defined scope of recipients.

Secondly, the SBIR/STTR website lists very *concrete* challenges that require a solution. This targeted character of the solicitations allows for the identification of problems and challenges that an average small or medium business may not be familiar with, but may focus on practical solutions too. When applied to the European framework, such targeted solicitations may come from a much broader set of actors, such as European and national agencies, but also corporate actors that may require some support in closing a research gap, necessary to complete an innovative value chain. An example could be the deployment of the hydrogen economy — while a company or a project consortium may be familiar with hydrogen generation, they may need some support in terms of hydrogen transport and utilisation.

Thirdly, when implementing an innovation stream of funding for small business, the EU could deal with some of the programme weaknesses. While the amount of funding available for the programme could be determined by the research needs of the agencies and private actors, there should be a permanent character in the framework of the Horizon Europe programme to increase familiarity with the programme all over the EU. It could also focus on testing practice solutions developed by research institutes, e.g., resulting in electrification, sector coupling, or energy efficiency. The implementation of solicitations announced by private actors could be funded jointly by the private organisations and public funding, with the shares of funding depending on the risks and benefits for the actors involved.

Fourthly, a dedicated stream of funding within this instrument could focus on facilitating an exchange between academia and small businesses. Such cooperation could trigger a wave of innovation with significant benefits, especially in energy efficiency and in moving towards renewable sources of energy. It could be mutually beneficial to small companies and research institutes. On the one hand, it would provide companies with easy access to state-of-the-art research. While some ideas may exist on the drawing boards of research institutes, small businesses may not have the capacity or resources to familiarise themselves with new opportunities. This is of great importance, especially given the ongoing energy crisis in the EU. On the other hand, by cooperating with companies, research institutes which, in many cases, design their solutions in labs or situations only remotely resembling the challenges faced by companies or private consumers, would gain an opportunity to test their innovative low-carbon solutions in practice and even facilitate their commercialisation. A continued exchange with businesses that either try to implement innovative solutions resulting in lower emissions, or sell products driving decarbonisation to final consumers, would provide research institutes with empirical knowledge that can make their research more relevant to instigate change in the short term.

However, in the case of both actors, additional motivation and resources are needed to facilitate the exchange. Private companies' focus is to generate profit in a competitive situation. This requires focusing on commercial activities, with little or no resources available for exploring new, innovative processes — an area in which they differ from large companies that may have a research team at their disposal. For research institutes, deploying innovation in real-world environments is often only a small element of a project — if at all. Therefore, additional funding would be needed to create capacities for these two groups of actors to facilitate productive cooperation.

As mentioned, the STTR programme was developed based on experiences with the SBIR programme. This came with a certain path dependency in terms of an important role played by the federal agencies. A European version of the programme should focus on the needs of the businesses, with the managing agency — e.g., CINEA — playing only a controlling function. As a result, calls for proposals should target the needs of the small businesses to either reduce their energy costs and emissions or create products that will facilitate decarbonisation by their consumers.

Finally, the question of the Intellectual Property Rights for innovations resulting from the projects funded by the programme should be clarified. Open-source innovation may not be the preferred option for all innovations resulting from the cooperation between SME and research institutions as it would remove commercial interest in additional investment. However, the level of the potential fees and their duration should be as harmonised as possible, with a "standard option" available to simplify the negotiating process between the inventors and actors willing to use the inventions to reduce their emissions (S. E. Hertig, personal communication, September 8, 2022).

3.7 Conclusion

Despite the temporary reduction of greenhouse gases during the COVID-19 pandemic, the amount of these gases in the atmosphere is still rising, and now is the time for the EU to take an ambitious and decisive step towards reducing the threat of global warming. Now that the time has arrived for Europe to recover from the fragile economy caused by COVID-19, it may replace it with a clean and carbon-neutral economy. Additionally, the EU is experiencing issues with the supply of energy due to the conflict in Ukraine and the European Union's restricted access to energy.

The development of the economy, as well as the mitigation and adaptation to climate change, can be accomplished through innovation and the use of cutting-edge technology. Without the employment of innovative technologies, achieving a carbon-neutral future will be close to impossible. Many of the current problems of the European Union members in trying to transition to a carbon-neutral economy can be resolved with the help of technologies and ideas that are currently being developed in labs.

The case studies examined in this Archetype provide strong support for the notion that an efficient policy can result in outstanding accomplishments. Meanwhile, small businesses have the potential needed to achieve economic prosperity, jobs creation, and the goals set by governments. With the help of appropriate frameworks concentrating on financial support, many of the problems faced by start-ups can be resolved.

Innovation has the power to address the challenges of sectors trying hard for decarbonisation. There is still room for beneficial improvements, notwithstanding the energy intensive sectors' success in achieving carbon neutrality. Therefore, the eyes are directed towards the skilled experts in these sectors who will accompany the development and expansion of appropriate technologies for today and future generations. However, the question that arises in this context is can innovation alone provide solutions to the problems and issues brought on by climate change? At any point, collaboration between sectors, concepts, and ideologies is always considerably more effective.

4. Archetype 3: Policy driven fossil fuel phase-out in heating and transport (exnovation)

4.1 Introduction

Essential societal functions, such as mobility and heating have evolved into deeply entrenched socio-technical systems. These systems have evolved around high-carbon technologies that are not compatible with the drastic reductions of greenhouse gases that will be needed in the coming decades. For the EU to meet its ambitious target of reducing emissions by 55% by 2030, and to reach climate neutrality by mid-century, it is crucial not just to develop and roll out new, low, or zero-carbon technologies, but also to phase out the old, fossil-intensive technologies. Until now, new energy sources have mainly been used to satisfy increasing energy demand, rather than replacing existing energy sources and associated technologies. To align with the necessary pace of the transformation, a systemic approach to climate policy is needed which actively addresses the phase-out of such technologies — to avoid carbon lock-ins, to create planning certainty for firms and consumers, and to contain political backlash through managed decline (Görlach et al., 2022).

EU climate policy in the past was largely geared at incremental improvements and optimisation, but there are fewer elements geared at delivering the necessary transformative change to climate neutrality. Furthermore, the Russian attack on Ukraine and the resulting turmoil in resource markets has showcased the risks of the EU's dependence on imported fossil fuels and the benefits of eliminating these. It also shows the need for a managed process rather than a crisis response, creating strategic long-term planning as opposed to crisis responses that create incompatibilities between energy security and climate policy goals — such as replacing gas with coal instead of investing in renewables and energy efficiency, where solutions require longer lead times.

In recent years, there has been growing attention to phase-out policies to achieve the opposite of innovation: exnovation, or the managed phase-out of fossil-based technologies driven by deliberate policy interventions (David, 2017). Such phase-out policies can take different forms; most common are phase-out timelines — specified end dates after which the purchase, operation, supply, consumption, or financing of fossil-based technologies is banned. These represent one type of exnovation policy that has commonly been applied to other environmental issues for several decades (e.g., CFC/HFC phase-out, asbestos, or traditional light bulbs), but was less common as a tool for climate policies. In recent years, however, such policies have been applied to various types of high-carbon activities, notably coal-fired power generation. It has also been proposed (and applied in several EU member states) for the end of internal combustion engine vehicle (ICEV) sales or the end of fossil-based heating technologies, but also for the use, or production of, fossil fuels, or financing for fossil exploration projects. Such phase-out policies will often involve long lead times between announcement and when the ban takes 132ifere — which has the potential to transform the global market 132iferen for 132iferente sectors.

This archetype of best practice investigates policy-driven fossil fuel phase-outs in two jurisdictions outside of the EU: Norway and Vancouver, Canada. It analyses the Norwegian case for both heating and transport, having completed a 2020 phase-out for existing oil-fired heating systems and is currently on track to phase out ICEV cars by 2025, the earliest of any country worldwide. In addition, the analysis will draw on insights from Vancouver, Canada which has recently (2022) phased out fossil fuel boilers in new buildings, becoming one of the first countries to do so. While EU countries are among the leading countries in buildings and transport decarbonisation, Norway and Vancouver rank highly in both areas. Norway was the first country to stop the use of all fossil fuels for heating in new buildings (2017), and is the only country to have successfully banned the use of mineral oil for boilers in existing buildings (2020).

4.1.1 State of decarbonisation in the EU building sector

Buildings account for 36% of the EU's carbon dioxide emissions (European Commission, 2020a), so it is essential to decarbonise and achieve climate neutrality in the sector. However, reducing emissions from the EU building sector remains a persistent challenge: greenhouse gas emissions in the sector have declined by only 29% between 2005 and 2019, which is not sufficient to meet the EU's 2030 target of reducing emissions by 55% compared to 1990 levels, which would require a 60% reduction from the building sector (EEA, 2021b). Furthermore, the sector is largely dependent on fossil fuels, with renewables accounting for only 22% of total heating and cooling energy demand (Braungardt et al., 2021).

Across the EU, renovation rates remain far below what would be required to meet 2030 emissions targets and climate neutrality by mid-century. The EU failed by 3% to meet its target of 20% overall energy efficiency improvement in the buildings stock by 2020 (Vandenbussche, 2021). At the same time, it is becoming increasingly clear what needs to happen to put EU buildings on the path to climate neutrality: scenarios indicate that annual renovation rates would need to double, from 1% to 2% across the EU by 2030 to lower the final energy consumption in buildings by 14% (European Commission, 2020a). The remaining energy needs for heating and cooling would increasingly be supplied by heat pumps (electrically driven), with an estimated 3.75 million additional heat pumps installed every year by 2030 (Kurmayer, 2022). Scenarios also assume that for the EU to be compatible with a rise in global temperatures of no greater than 1.5°C, then oil and gas must be replaced by electricity or renewables-based fuels by 2050 in the building sector (4i-TRACTION, 2022).

Many barriers and obstacles currently impede the progress of the decarbonisation of the building sector in the EU. These include split incentives between landlords and tenants, lack of financing for energy efficiency, skills and labour shortages, supply chain disruptions and slow emergence of business models centred around decarbonisation of the building sector, subsidies for fossil-based heating systems, as well as heterogenous building stocks and socio-economic situations across member states. Lenient or partial phase-out regulations create lock-in effects, such as renewable energy use obligations that mandate low shares of renewable energy where fossil fuels remain the main energy source used in heating. As a result, in comparison with other sectors, such as power and industry, the EU lags in its efforts to decarbonise buildings.

EU policy-makers have long recognised these challenges and have attempted to address them through the Energy Performance of Buildings Directive 2010/31/EU (EPBD) and the Energy Efficiency Directive 2012/27/EU (EED), as well as the Renewable Energy Directive 2009/28/EC (RED) and the Ecodesign Directive 2009/125/EC. However, most of the EU building stock has yet to be affected by the EPBD or other efficiency requirements set for new buildings. A key problem with the EPBD is that it only requires certain performance levels when a 'major' renovation is carried out, but does not include any regulatory requirements to trigger renovation. There is also a core problem, in that the EU can only regulate products in markets, while it relies on the member state, national, or subnational levels to implement the stronger policy instruments of tax incentives.

Several countries have implemented various types of policies for phasing out fossil-based heating systems. These can be explicit phase-out policies, by mandating restrictions on heating equipment to be used and installed, restrictions on buildings connections to the gas grid, or bans on selling or using fossil fuels for heating. They can also be implicit, e.g., in the form of energy efficiency thresholds that are unattainable with conventional technologies, or use obligations for renewable energies which mandate a net renewable share in heating of 100%. Such policies amount to a fossil phase-out requirement without specifically banning the old high-carbon activity. Economic instruments — such as energy taxation or emissions trading — can also amount to a de-facto phase-out policy, by making the use of fossil fuels economically unviable in certain applications. While these conditions hold in theory, the current gas crisis highlights how the economics of phase-outs can change rapidly in practice, where certain technologies or fuels that may have seemed unviable become more attractive again, such as coal-fired power.

At the EU level, there is currently no explicit phase-out goal or policy for fossil fuel heating systems. Recently, as part of the REPower EU package, the EC has proposed a phase-out of stand-alone fossil fuel boilers via Ecodesign standards by 2029 (Ruiz Fuente, 2022). However, several EU member states — and many other jurisdictions around the world — have adopted phase-out targets for fossil-based heating systems. **Table 4.1** provides an overview of such targets around the world, distinguishing the target years, whether the targets apply to new or existing buildings, as well as the fossil fuels they cover. The table shows that EU countries can be found among the forerunners, with e.g., Denmark mandating the phase-out of existing fossil heating as early as 2018 in areas that are connected to district heating. Beyond the EU, the pioneers in the field are Norway, which was the first to ban the use of fossil oil for existing heating technologies (rather than only in new buildings), as well as Vancouver, Canada, which was among the first cities to phase out all fossil-based boilers from new buildings (rather than gas or oil only).

Table 4.1: Overview of fossil fuel phase-out policies in the heating sector around the world

	Both/All FFs	Natural Gas	Oil
Existing Buildings	**Denmark (2018, in DH zones)** Denmark (2030, all)		**Norway (2020)** Finland (2030)
New Buildings	**Norway (2017)** **California, US** (different municipalities) **(2020 to 2022)** **Vancouver (2022)** **France (2022)** Luxembourg (2023) United Kingdom (2025)	**Netherlands (2018)** Austria (2023) Ireland (2025) Flanders, Belgium (2025) United Kingdom (2025)	**Norway (2011)** **Denmark (2013)** **Ireland (2022)** **Flanders, Belgium (2022)** Slovenia (2023) Québec, Canada (2024) Germany (2026)

**Bold = Policy has already taken effect. Colour coding: phase-out targets, in past, present, future*

Comparability between policies which set end dates for fossil-based heating systems is challenging as they often differentiate further with more design variables than are listed in the table. Key design features across phase-out timelines for heating include:

- **Scope**: coverage of building types (e.g., new, replacement, or existing) and fuels,

- **Timeline of implementation**: most policies (for heating) are enacted shortly after adoption of legislation, though Germany's oil boiler phase-out has a lead time of five years,
- **Stringency**: level of ambition,
- **Connection to spatial planning**: e.g., in Denmark, renewable energy use obligations are connected to zoning approaches, with different requirements applying to district heating areas and others connected to the gas grid,
- **Ownership structure of building**: public versus private (e.g., Finland has set an earlier phase-out date for oil boilers of 2024 for government-owned buildings, and 2030 for all other buildings).

These examples highlight variations across the different phase-out policies but also present different methods for implementing and sequencing them over time. A huge challenge in the building sector is heterogeneity across the listed differences or across economies or climates. However, despite the differences, the policies provide a clear signal that the use of the old high-carbon technology must come to an end. There are even instances where, once the phase-out timeline was set, it turned out to be feasible to bring this date forward. For example, the Flanders region in Belgium recently brought forward a ban on natural gas from 2026 to 2025, as did Austria, which changed from 2025 to 2023.

With a growing interest in the use of phase-out timelines for meeting climate objectives, there is a clear rationale for learning more about policies' impacts. Hence, as two leaders in the international context, this report undertakes studies on the Norway oil phase-out by 2020 for existing buildings, and the Vancouver phase-out of fossil-fuel boilers by 2022 in new buildings.

4.1.2 State of decarbonisation in the EU road transport sector

Transport is arguably the most challenging sector for reducing EU greenhouse gas emissions, responsible for 32% of EU-wide emissions in 2019, compared to only 24% in 2000 (EEA, 2021a). In contrast to other sectors, emissions from transport have increased over the last three decades, rising 34% by 2019 compared to 1990 levels (EEA, 2021a). The largest share of these emissions comes from road transport, accounting for 72% of EU transport emissions in 2019. Within road transport, cars have a dominant role and account for 61% of road transport emissions (EEA, 2022a).

Decarbonising the transport sector is not only a matter of replacing fossil fuels with another energy source, but it will require a systemic transformation of mobility across Europe — which includes a greater role for public transport, cycling, and walking, and a reduction in overall transport volumes. The electrification of road transport is one part of the solution, especially by scaling up the use of electric vehicles (EVs), in some cases also indirectly through synthetic e-fuels. This will coincide with a reduction (and eventual phase-out) of ICEVs. The sales of

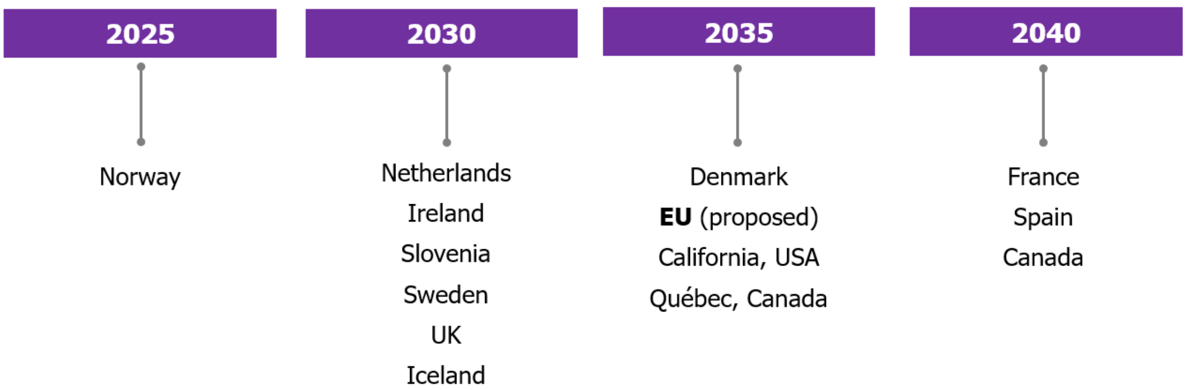
EVs have increased rapidly across Europe, accounting for 11% of total new car registrations in 2019 (EEA, 2021a), yet the overall share of alternatively-powered cars represents only 5.3% of the EU fleet (ACEA, 2022a).

Some of the manifold barriers facing road transport decarbonisation include the cost disadvantages of cleaner alternatives, i.e., electric vehicles or synthetic e-fuels, as well as (actual or perceived) less convenient usage, e.g., insufficient / uncoordinated charging infrastructure, charging times or driving range. While the relative cost disadvantages can be (and is being) addressed through taxation, subsidies, or other benefits (e.g., exemptions from parking fees or road charges), the roll-out of the infrastructure is first and foremost a commitment challenge: EVs will only be purchased in large numbers if a sufficient charging infrastructure is in place, but the infrastructure will only be built if there is sufficient demand. In this situation, signalling by the regulator can overcome the commitment problem and reduce the risks for investors and consumers alike.

EU policy for transport decarbonisation has been primarily based on setting emissions limit values for new passenger cars and new light commercial vehicles via the EU Regulation 2019/631. As part of the Fit-for-55 package, the EU Commission has proposed to amend the regulation by tightening these limits in such a way that the sale of ICE cars would, effectively, be banned by 2035.

While the EU as a whole still has to formally adopt an EU-wide target of the phase-out of ICEVs, several of its member states have already done so, as have other countries and jurisdictions around the world (**Figure 4.1**). Some EU member states have set targets for 2030 (Sweden, Ireland, Netherlands, and Slovenia), while others have set them for 2035 or later. Beyond the EU, countries, including the UK and Iceland, have set targets for 2030. However, the most ambitious target, of 2025, was set by Norway, which is why this experience will be evaluated in this case study.

Figure 4.1: Overview of phase-out timelines ICE cars around the world



Source: Author's representation.

4.2 Why consider phasing out fossil fuels in Norway and Canada?

Norway is one of the leading countries when it comes to phasing out fossil fuels from the heating and decarbonising sectors. The country has managed largely to electrify space heating and became the first country to ban the use of mineral oil in all residential buildings after 2020. This case study is therefore particularly interesting and relevant for the EU debate: as the pioneering country, Norway has largely concluded a transformation that other EU countries will need to achieve in the coming years. At the same time, Norway has many political, legal, economic, and socio-cultural similarities to the EU countries, which means that insights from Norway are more likely to be relevant and applicable to EU countries.

Vancouver will also be investigated as it was among the first jurisdictions after Norway to phase out both oil and gas boilers from new buildings after 2022. However, the Vancouver case is still ongoing and at a much earlier stage in the transition, compared to Norway. It is too early to evaluate the extent to which the policy has been a success, which is why this case receives less weight in our analysis. Nevertheless, the city has introduced innovative accompanying policies which enabled the implementation of its phase-out policy at the start of 2022, which is relevant for EU countries that are considering implementation of related policies.

For transport decarbonisation, Norway is once again the frontrunner, with over 80% of new car sales now from EVs. Norway has set a target of 2025, after which all cars sold must be of zero emissions. A package of incentives (mostly tax and behavioural incentives) has been introduced to ensure that they meet this goal.

All three case studies were evaluated using semi-structured interviews with reference to a range of secondary sources. Semi-structured interviews were chosen to help evaluate the best practices because the study is exploratory and the policies in question have been implemented recently and are rapidly evolving. Another justification for choosing semi-structured interviews was that questions were often complex and required context to ensure that the participant understood the question they were being asked.

Eight semi-structured interviews were carried out, to determine what were the changes that made the transition possible. We interviewed experts from municipal councils, environment agencies, industry associations, and one from a private-sector utility. To complement the interviews, a range of secondary sources were used to inform the analysis, including policy documents, reports from institutions, databases, websites, and newspaper articles.

4.3 Case Study 1: Phasing out fossil fuels in heating – Norway

As the first case study, Norway's phase-out policy to end the use of fossil oil for heating buildings by 2020 was chosen because it was the first country to mandate a nationwide phase-out of fossil oil heating in existing buildings for all homes connected to the electricity grid. As other EU countries are phasing out fossil fuel heating systems in the coming years, the Norwegian example shows that the transformation is possible if the right conditions are met. The case study opens with Section 4.3.1 which provides the context and background on Norway's energy system, its heating sector and development of its phase-out policy. Section 4.3.2 provides a description of the policy under evaluation, discusses how the policy was received by public and industry, and Section 4.3.3 provides indicators on the state of the heating transition – including cost of ownership comparisons after accounting for economic incentives. The policy is then evaluated in Section 4.3.4 before closing with a discussion and extraction of lessons learned in Section 4.3.5.

4.3.1 Context and background

Norway has set the ambitious goal to reduce its economy-wide greenhouse gas (GHG) emissions by 50% to 55% by 2030 compared to 1990. While Norway is a small country, of 5.4 million people, the country is rich in fossil fuel reserves and is the third largest exporter of natural gas in the world, behind only Russia and Qatar (IEA, 2022a). Even as a country richly endowed with fossil fuels, Norway has come close to full decarbonisation of its heating sector. Heating emissions accounted for only 2% of national emissions in 2020, compared to the EU average of 36%, despite having a much colder climate than most EU countries (European Commission, 2019).

Furthermore, since 2020, Norway has banned the use of fossil oil for heating buildings, making it the first country to mandate a nationwide phase-out of fossil oil heating in *existing buildings* for all homes connected to the electricity grid. As other EU countries are phasing out fossil fuel heating systems in the coming years, the Norwegian example is the first case of a largely completed phase-out and demonstrates that phasing out fossil heating is feasible if the right conditions are met. This case study assesses what drove this transition and extracts the lessons that can be learnt from Norway's experience.

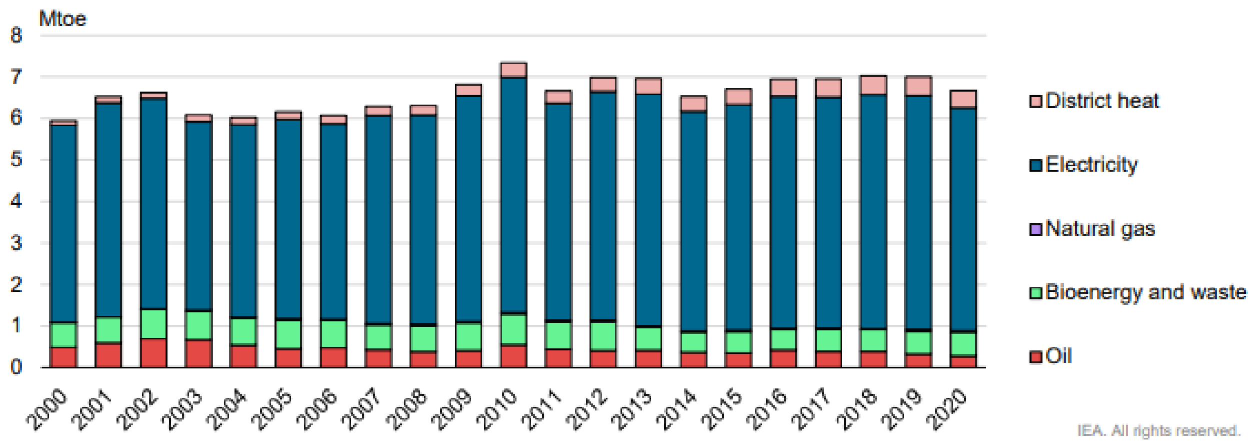
Energy system of Norway and overview of heating sector

The energy system of Norway is based predominantly on renewables. The country has been endowed with large hydropower resources (over 1500 plants) thanks to its mountainous landscape and meteorological conditions. Norway also benefits from large deposits of fossil fuels, mostly oil and gas found in the Norwegian and North Seas along its extensive coastline. Norway's exports from the oil and gas industry were estimated at over NOK 800 billion (EUR 80 billion) in 2021 (IEA, 2022a) — almost NOK 150,000 (EUR 15,000) per capita.

Norway's electricity mix consists of 99% renewables — 92% hydro and 7% wind. Combustion of fossil fuels, by contrast, supplies less than 1% of electricity (Ritchie & Roser, 2021). Next to being virtually carbon zero, Norway has historically benefitted from much lower electricity prices than its neighbouring countries.

The building sector in Norway accounted for 32.5% of the country's total final energy consumption (TFC) in 2020. Of this 32.5%, residential buildings make up 18.5% of TFC, whereas the remaining 14% comes from service sector buildings (IEA, 2022a). Buildings in Norway are predominantly electrified: 81% of the energy consumed in the building sector in 2020 is in the form of electricity. Oil has been almost completely phased out from the residential sector, but its use in service sector buildings has been slightly increasing in recent years, mostly in the defence sector. Energy demand has fluctuated over the last decade, depending on temperatures in winter.

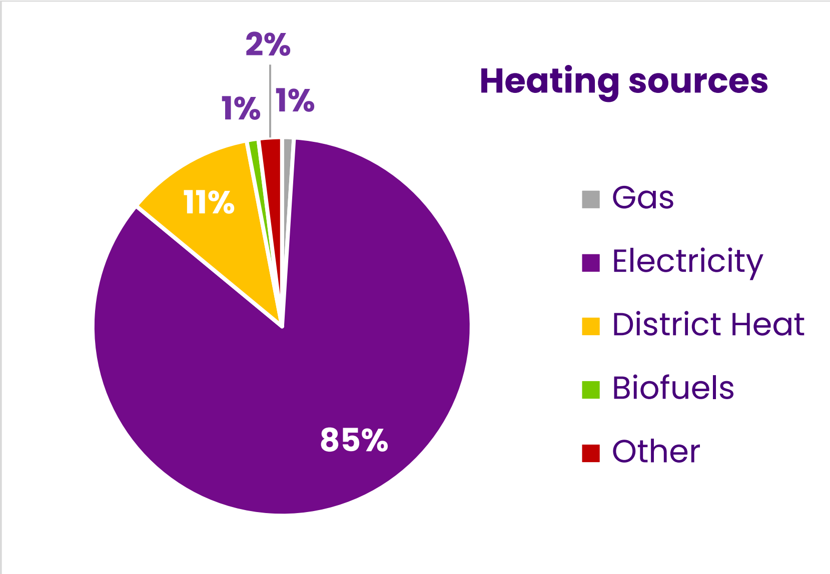
Figure 4.2: Total final consumption in the building sector by source in Norway, 2000-2020.



Source: IEA (2022a).

The most recent estimate of energy use in buildings specifically for heating was made in 2015 by Enova, based on a sample of 3415 households. Buildings in Norway are heated predominantly using electricity (85%), followed by district heating (DH) (11%), with the remaining 4% heated with biomass, biofuels, and fossil fuels (Patronen et al., 2017).

Figure 4.3: Norway residential and service sector heating types in 2015.



Source: Patronen et al. (2017).

The most common heating types in Norway are already electric based, mostly electric panel heaters, but also free-standing electric heaters or underfloor electric heaters. The adoption of heat pumps is increasing rapidly and is often complementing or substituting existing heating systems. Air-to-air heat pumps are popular for buildings that have electric heating without a waterborne heating system. In addition, many of these houses have wood stoves.

Norway has the highest number of heat pumps per capita in Europe, with over 1.1 million heat pumps in operation in 2022 — representing over one-third of total buildings (Agora Energiewende, 2021; Hagemoen, 2022). Out of the 1.4 million heat pumps sold between 1987 and 2020 in Norway, 89% of sales consisted of reversible air-to-air technologies (Hagemoen, 2022). Electric boilers, brine-to-water, or air-to-water heat pumps are common in small and big buildings with waterborne heating systems.

Around 11% of heating is delivered through DH, most commonly for commercial buildings and multi-family apartment buildings in urban areas. Incineration of municipal waste and extraction of excess heat from industrial installations is the primary source of energy for DH (60%), followed by biofuels (24%), electricity (10%), and fossil fuels (oil and gas) for the remaining 6% (Kerr & Winskel, 2021). Norway uses sea water heat pumps such that the DH system can be used for both heating and cooling. There are no heat pump manufacturers in Norway apart some that make high temperature industrial heat pumps (Interview 3). Some entrepreneurs in Norway still build heat pumps themselves with components purchased from the big brands, but it is more common to buy heat pumps directly from the factories or importers.

Historical context on the decarbonisation of the building sector in Norway

Norway began to invest significantly in the electrification of heating during the oil crisis of the 1970s. The government provided direct support for electric heating technologies, through research and development (R&D) grants as well as purchase incentives. Apart from mitigating the impacts of climate change, there were many, more mundane, reasons for Norway to pursue a strategy of decarbonising its heating system. Due to abundant hydropower, electricity prices have historically been low in comparison to its neighbouring countries — making the electrification of heating a more affordable strategy for households to pursue (IEA, 2022a; Naturvernforbundet, 2020). Furthermore, cleaner indoor environments and fewer local air emissions bring public health benefits. The expansion of the electric-based heating infrastructure created additional employment opportunities and allowed Norway to become one of the first countries to roll out heat pumps at scale. Around 3000 jobs in Norway are supported by heat pump installations (Agora Energiewende, 2021).

Norway is not a member of the EU, but since 1994 it has had full access to the single market and shares the internal EU market legislation through agreement on the European Economic Area (EEA). As a result, Norway has since implemented much of the EU's climate and energy-related regulations, including the EU Emissions Trading System (EU ETS). In 1991, Norway became one of the first countries to introduce a carbon tax, initially taxing mineral oil and petrol, as well as emissions from petroleum extraction. In 2005, the carbon tax was supplemented by a domestic ETS, before eventually joining the EU ETS in 2008.

The EU ETS covers around 50% of Norway's emissions (Government of Norway, 2019). Since the power sector is almost irrelevant in terms of emissions, these are mostly from heat production, energy-intensive industries, and aviation. It is estimated that the EU ETS covers 5% of fossil fuel use in Norway's residential and commercial sector (OECD, 2019). In total, carbon prices apply to 85% of domestic GHGs, either through the EU ETS, the carbon tax, or both. The Norway carbon tax is currently at NOK 775 (EUR 77.5) per tonne of CO_2e and was significantly higher than the EU ETS price for a long period.

Norway implemented the EU EPBD 2002/91/EC in 2010. Since then, it has been mandatory to hold an energy performance certificate when a building is constructed, sold, or rented. Lastly, the RED (2009/28/EC) applies to Norway, which required Norway to meet 67.5% of its final energy consumption from renewables by 2020 (which it surpassed).

Enova's role in accelerating the deployment of heat pumps

In its energy and climate policy landscape, the publicly owned enterprise *Enova* has a particular role in supporting innovation for the heating transition. Enova, administered through the Ministry of Climate and Environment, contributes to reducing greenhouse gas emissions and strengthening the security of supply — primarily through the development of energy and climate technologies. The enterprise was established in 2001, to support the development of new renewable energy capacity for the grid, but the focus of Enova has since shifted towards the heating, transport, and industrial sectors (Ćetković & Skjærseth, 2019). Enova invests more than NOK 3 billion (EUR 300 million) of public resources into climate change solutions each year (Enova, 2022a).

Despite the early state-led efforts to electrify heating, heat pumps remained niche for a long period, with less than 10,000 installations by 2005. A central policy instrument to accelerate the roll-out of heat pumps has been purchase subsidies. In 2003, a record cold winter and high energy prices put the government under great pressure (Interview 3). Subsidies in the form of grants were thereafter offered through Enova for a range of heat pump technologies, at a time much earlier than most other countries. The grants were available for almost two decades before being removed for most technologies by 2021. Subsidies for brine-to-water (ground source) heat pumps are still provided. Table 2 outlines the level of subsidy provided for different heat pump technologies from 2015 to 2022.

To further incentivise society to switch from fossil fuel boilers to heat pumps, subsidies were provided for replacing an oil boiler. For example, replacing an oil boiler in 2018 with an air-to-water heat pump resulted in a total financial support of NOK 30,000 (EUR 3000) to NOK 10,000 (EUR 1000) for the new heat pump, and NOK 20,000 (EUR 2000) for scrapping the oil boiler. Subsidies for heating installations totalled NOK 275 million (EUR 26 million) in 2018, an increase from NOK 165 million (EUR 17 million) in 2017 (Kerr & Winskel, 2021).

Table 4.2: National subsidies and support schemes for heat pumps for households[10]

	2015	2018	2019	2020	2021	2022
Air-to-air	N/A	N/A	N/A	N/A	N/A	N/A
Brine-to-water (ground source)	NOK 20,000 (EUR 2000)	NOK 20,000 (EUR 2000)	NOK 10,000 (EUR 1000)	NOK 10,000 (EUR 1000)	NOK 10,000 (EUR 1000)	NOK 10,000 (EUR 1000)
Air-to-water	NOK 10,000 (EUR 1000)	NOK 10,000 (EUR 1000)	NOK 5000 (EUR 500)	NOK 5000 (EUR 500)	N/A	N/A

[10] Source: Interview 3

Exhaust heat pump	NOK 10,000 (EUR 1000)	NOK 10,000 (EUR 1000)	NOK 5000 (EUR 500)	NOK 5000 (EUR 500)	N/A	N/A
Oil boiler replacement	NOK 10,000 (EUR 1000)	NOK 20,000 (EUR 2000)	NOK 10,000 (EUR 1000)	N/A	N/A	N/A

Source: Envova (2022) *Note*: Current subsidies can be found on Enova's website https://www.enova.no/privat/alle-energitiltak/

The prices for heat pumps in Norway differ depending on the size of the house and heating demand. Typically, the combined price for the technology and installation costs for an air-to-air heat pump (one indoor unit) is about NOK 15,000 to 30,000 (EUR 1500 to 3000), for an air-to-water heat pump from NOK 150,000 (EUR 15,000), and for brine-to-water (ground source) with energy well from NOK 250,000 to 300,000 (EUR 25,000 to 30,000). Today, only ground source heat pumps receive subsidies.

Beyond heat pumps, subsidies of 10,000 NOK (1000 EUR) are still provided for bio-based boilers which use bioenergy, including wood, pellets, or chips to produce domestic heat (Enova, 2022b). Biofuels in Norway are not taxed (OECD, 2019).

Through Enova, Norway provided 3301 grants for heat pumps in 2017, worth EUR 4.84 million, rising to 5085 grants in 2018, and 6675 in 2019, before falling to 2047 grants in 2020, at which point the ban had taken effect. In contrast, grants were provided for only 216 bio-boilers from 2017 to 2020. Enova also has support programmes for large heat pumps in commercial buildings, industry, and DH systems.

Table 4.3: Number of grants provided to heat pumps within the Enova Subsidy.

Heat pump technology	2017	2018	2019	2020
Air-to-air	N/A	N/A	N/A	N/A
Brine-to-water	1542	2194	3113	972
Air-to-water	1475	2444	3103	961
Exhaust heat pump	284	447	459	114
Oil boiler replacement	1044	2588	2848	N/A

Source: Enova (2021).

Table 4.4: Annual investment from Enova into heat pump grants 2017 to 2020, expressed in millions of Euros[11] (Table 2 * Table 3)

Heat pump technology	2017	2018	2019	2020
Air-to-air	N/A	N/A	N/A	N/A
Brine-to-water	3.08	4.39	3.11	0.97
Air-to-water	1.48	2.44	1.55	0.48
Exhaust heat pump	0.28	0.45	0.23	0.057
Oil boiler replacement	1.04	2.59	2.85	N/A

Accelerating the deployment of district heating

In 2001, a parliamentary decision agreed on setting up the Energy Efficient District Heating and Cooling Scheme through Enova, with the objective of enabling the channelling of finance towards energy-efficient DH and cooling systems based on renewable sources, to improve environmental protection. The estimated annual budget for the scheme was NOK 350 (EUR 35 million) and was envisaged to run from 2016 to 2020 (EFTA, 2016).

In 2009, a ban on landfill was introduced which stimulated investment in waste incineration plants, and DH facilities using the excess heat. Construction of DH facilities was funded by Enova as part of Norway's wider strategy for decarbonisation in the building sector. After the ban, the use of DH more than doubled in the decade from 2010 to 2020 (Kerr & Winskel, 2021).

The 2012 Climate Settlement

The government presented a white paper on climate policy to parliament in April 2012. This formed the basis for a new climate settlement between the same parties as those in the 2008 climate settlement (Norwegian Ministry of the Environment, 2012). For both agreements, all parties within the parliament, bar one, entered a cross-party settlement, agreeing on a wide-ranging set of recommendations for Norwegian climate policy. This came as a result of environmental associations and environmentally concerned parties in parliament that were pushing strongly for ambitious targets (Interview 3). However, influential economists from the academic community in Norway were critical to the climate settlement and its emissions reductions targets, arguing that all GHG emissions should be subject to a maximum carbon price and that double regulation should be avoided, to maximise cost effectiveness

[11] EUR 1 = NOK 10

(Hermansen & Sundqvist, 2022). As a result of strong disagreements amongst opposing sections of the government apparatus, the announced white paper was delayed four times over the course of more than two years.

The recommendations in the published report aimed to ensure that Norway would reduce domestic emissions levels to 30% below 1990 levels by 2020. Of the 14 climate policy measures included in the settlement, the following are most relevant for heat decarbonisation (Government of Norway, 2012):

- **The creation of a new fund for climate, renewable energy and energy conversion** from 2013 to 2016, amounting to NOK 50 billion (EUR 5 billion). This fund increased annually and covered additional heat pump subsidies. It was also agreed that, in order to raise revenue, the carbon tax covering the petroleum sector would be increased by NOK 200/tCO_2e (EUR 20).
- **The introduction of a ban on heating with fossil oil in households by 2020**. Parliament emphasised that the ban must be designed with the necessary exceptions for competitively disadvantaged sectors, to prevent health risks and to ensure that security of supply is safeguarded (Norwegian Parliament, 2012). It was agreed that the exemptions were to be investigated in more detail via an impact assessment before the ban was finally adopted (Norwegian Parliament, 2012).

It was the environmentally friendly parties that were pushing most for progressive climate politics. The biggest parties are dependent on support from these parties, which aided the process of coming to an agreement. There was no big debate around banning fossil fuels in buildings, as this was one of many proposals from the environment agency leading to the climate agreement in the parliament. Proposals concerning the oil and gas industry, transport sector, land-based industry, and agriculture contributed to much larger discussions, disagreements, and compromises within the climate settlement (Interview 3).

Norway has gradually phased out fossil-based heating systems, first by banning the use of mineral oil in new boilers by 2011, then prohibiting the installation of oil and gas boilers in new buildings by 2017, before phasing out the use of mineral oil from existing buildings by 2020.

Box 4.1 Stepped approach to phasing out fossil-fuel-based heating systems in Norway

2010: The use of mineral oil for baseload heating in new buildings was banned starting in 2011

2016: Fossil fuel boilers (oil and gas) were banned in new buildings and major renovations from 2017

2018: The use of mineral oil for heating of buildings was banned from 2020

2021: Extension of the 2018 regulation to include construction sites from 2022

4.3.2 Ban on the use of oil for heating buildings from 2020

Description of policy

On 28 June 2018, the Norwegian Government passed the regulation banning of the use of mineral oil[12] for heating buildings from 2020 (LOVDATA, 2021). The goal of the policy was to reduce GHG emissions, while, at the same time, ensuring security of supply.

The regulation stipulates a complete ban on oil-fired boilers from 2020. The ban sets an end point, after which oil cannot be used to heat buildings, rather than a point when new oil-fired heating systems must not be installed. The policy applies to both new and existing buildings, including private homes, businesses, and public facilities. Existing systems can only continue to be used with certain biofuels, which have been known to cause complications and are often much more expensive relative to conventional oil-fired boilers (Interview 1).

The law has a comprehensive scope, but still provides the following exemptions:

- Buildings without connection to the grid, such as holiday homes, small huts, lighthouses, or train stations.
- Buildings where the main purpose of the combustion plant is to supply energy for the manufacture or processing of materials, substances, or products.
- Farm buildings until January 2025.
- Hospital buildings with 24/7 care until 2025.
- Construction sites when used for temporary heating and drying of buildings until 2022.
- District heating systems powered by mineral oil are also exempt for thermal output greater than 1 MW.

[12] Mineral oil (essentially fossil oil) is defined in the regulation as light or heavy fuel oil, heating kerosene and other fuels of mineral origin.

It is forbidden to heat buildings using mineral oil unless the Norwegian Water Resources and Energy Directorate makes an exception due to security of supply concerns. If such an exception was mandated, for example, when the power grid risks becoming unstable, the body may decide to exempt from the ban a specific geographical area for a certain time period. Exceptions can also be provided in the event of operational disturbances or when other heating sources in the building, or the DH system, cannot be used. The Norwegian Water Resources and Energy Directorate is responsible for overseeing exceptions for both security of supply as well as for operational disturbances, whereas the Ministry of Climate and Environment and Ministry of Oil and Energy jointly oversee other provisions in these regulations.

In 2021, the ban was reformed to set an end date of 2022 for construction sites. In consideration of the extension, the Ministry of Climate and the Environment carried out a consultation process in 2019 to 2020. An impact assessment was also carried out for the construction sector, which projected annual emissions reductions of 0.085 $MtCO_2e$, which accounts for just over 0.1% of Norway's national GHGs (Norwegian Environment Agency, 2021).

The ban was seen as efficient by the Norwegian government because it reduces emissions at the source and provides more certainty on emissions reductions relative to alternative measures, such as an increased carbon tax (European Commission, 2020b).

Acceptance of policy from public and industry

The decision to phase out the use of oil for heating systems was based on input from the Norwegian Environment Agency and the Ministry of the Environment and was backed by a broad coalition in parliament, society, industry, and environmental groups. The climate settlement in the parliament in 2012 was agreed upon with cross-party support, but with no formal public consultations, whereas there was a public hearing in 2016 before the government decision in 2018 to phase out oil boilers (Government of Norway, 2016). The ban was met with little resistance, mostly because it affected only a few homeowners: approximately 80,000 residential properties still had oil-based heating systems at the start of 2018 (Enova, 2019). There were also only a few protests to the ban on fossil heating from the public, aided by an extended period of low electricity prices (Interview 3). Many of these oil boilers were old, and thanks to the subsidies both for heat pump installation and for removing the oil boiler, as well as high taxation on mineral oil, good and more environmentally friendly alternatives were available at reasonable costs (Interview 3).

Energy security was the largest motivation for public pushback (Interview 2). In response to these concerns from the public, and the fuel suppliers and distributors, the government added a caveat to the policy — that it can pause its application of the policy if energy security is at risk. When the intention to phase out oil boilers by 2020 was announced in parliament in 2012, many households initially did not believe that the ban would really be implemented (Interview 3). This could be explained by the government ordering of an impact assessment prior to legislating the ban. If the impact assessment had shown that the ban was economically costly, it may not have been extended. Right up until the policy was legislated in 2018, there were still some who did not believe that the government would go ahead with it (Interview 3). This case highlights the added confidence provided by legislating a policy rather than only announcing it or setting a target.

Most households replaced their oil boiler before the 2020 ban took effect. However, some households, opted to replace it with an electric boiler with cheaper upfront costs, as opposed to a heat pump (Interview 3). Information campaigns administered by Enova, the Norwegian Heat Pump Association (NOVAP), and Friends of the Earth Norway were crucial for improving acceptance (Interview 2).

There was minimal resistance to the ban from Norway's fossil fuel industry. There were various reasons for this. First, Norway's energy sector has traditionally been export-oriented, with almost 90% of production going into export (IEA, 2022a). As a result, the domestic market is not of great economic importance to these companies (and hasn't been for a long time before the ban was even brought up). Moreover, opposing the policy could have been seen as a reputational risk and would be seen to be at odds with the declared goals of the fossil industry. Some fossil fuel producers, including Equinor, had already begun diversifying their assets, to move away from a purely fossil-based value chain, and set course for achieving net zero by 2050 and reducing absolute emissions in Norway to near zero (Equinor, 2022). The industry showed minimal resistance to the ban as its export-oriented business model was not put into question.

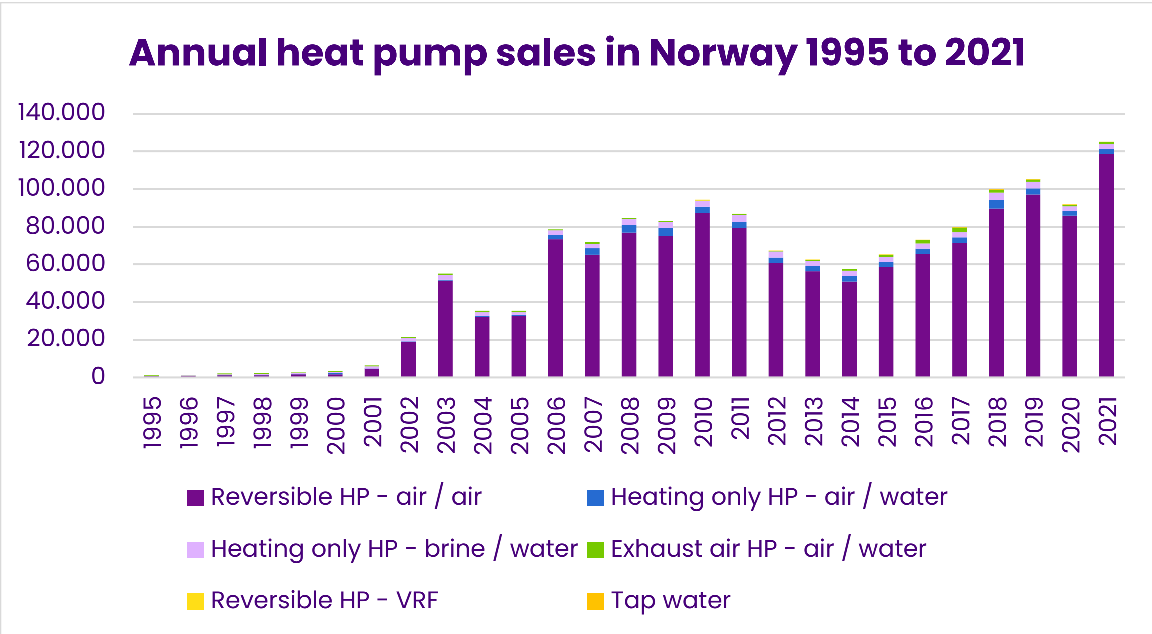
There was no big pushback from manufacturers of oil boilers to the ban, mostly because these manufacturers were based outside of Norway and sales levels were already low, partly because fossil fuels for heating had already been banned in new buildings since 2017 (Interview 3). There was, however, significant pushback from Norway's oil distributers and fuel oil dealers. They argued that the use of oil for heating could be more CO_2 friendly than using electricity when electricity is imported from Europe (even though 99% of electricity in Norway is renewable) (Interview 3). Furthermore, they claimed that the oil ban could weaken the security of supply and result in power shortages in the grid (Interview 3). However, these actors were in the minority and after the authorities carried out thorough analyses, the result was a recommendation to ban fossil heating in buildings. The government did, however, agree that it would pause the ban if the security of supply was at risk. For a transitional period, exceptions were introduced for oil for peak loads and the use of oil as a reserve load in some types of buildings.

4.3.3 Transition indicators and cost of ownership comparisons

Several indicators point towards the success of the phase-out of mineral oil from existing buildings by 2020 — including reduced national emissions, increased adoption rates of heat pumps, but also improved economics of heat pumps relative to oil boilers. However, it is important to note that Norway specific case with unique circumstances, as the shift towards electric heating was already nearing completion prior to policy announcement.

The proportion of national emissions from heating in buildings in Norway had declined steadily: from an already low base of 5% in 1990, declining to 2% in 2020 (Ritchie & Roser, 2021). Before the ban was legislated, in 2017, mineral oil accounted for 2% of Norway's heating use. Subsequently, this share declined to 0.32% in 2019 (Braungardt et al., 2021). The use of mineral oil in residential buildings has now been eliminated (bar a few exceptions) (IEA, 2022a). The remaining emissions come from exempted residencies consisting of predominantly off-grid buildings. Approximately 180,000 residential properties and 20,000 commercial properties were using some form of oil heating in 2009 (Norwegian Environment Agency, 2015). It was estimated in early 2018 that, for residential properties, this number had already more than halved to 80,000 still using oil-based heating systems (Enova, 2019).

Figure 4.4: Total market for heat pumps in Norway from 1995 to 2021



Source: NOVAP (2022).

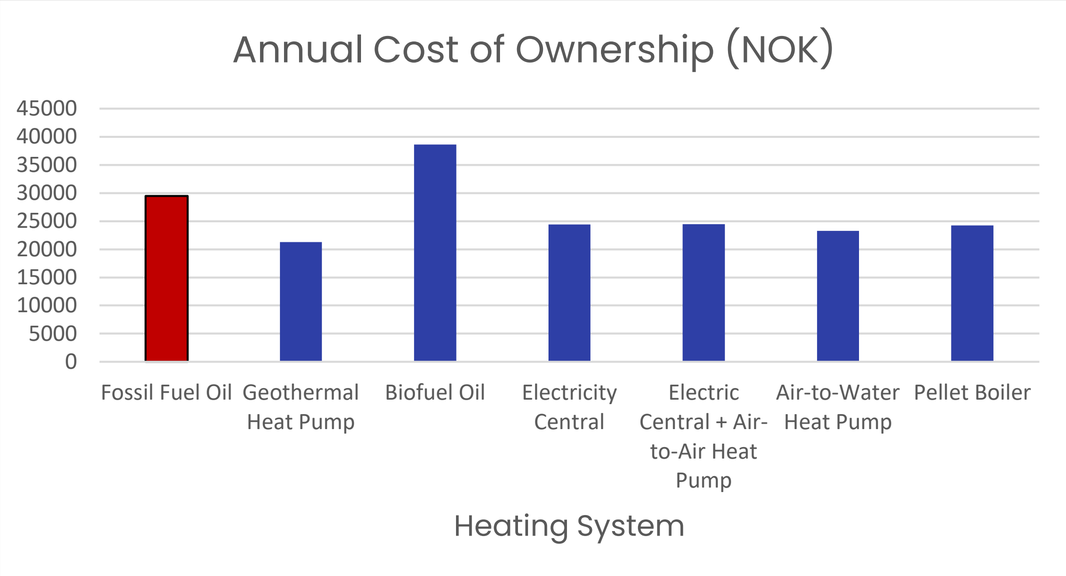
The market for heat pumps has grown considerably in the last two decades. In 2005, there were less than 10,000 heat pumps installed in Norway. By 2017, over 900,000 homes had an active heat pump, which has since increased to over 1.1 million heat pumps in 2022, representing over one-third of homes (Agora Energiewende, 2021; Enova, 2022c; Hagemoen, 2022). As can be seen from **Figure 4.4**, most heat pump sales in Norway are air-to-air heat pumps, accounting for over 90% of sales between 1995 and 2021.

Heat pump sales started to take off in 2003, a year with cold winter and higher electricity prices. In the coming years, subsidies for the different technologies became available. Spikes in heat pump sales occur predominantly in times of high electricity prices. This may seem counter-intuitive (higher electricity prices equals higher running costs of HPs), but this is because most heating systems were already electric-based (with direct-resistance heating and electric radiators), and the higher heat pump efficiencies reduce electricity bills for these consumers. Years 2003, 2006 and 2010 were years with higher electricity prices and more media attention on energy saving/efficiency (Interview 3).

Between 2006 and 2012, sales levels remained relatively stable and demonstrated signs of declining in years with low electricity prices but have since been gradually increasing, after the parliament agreed on the phase-out of fossil fuel boilers in 2012, as illustrated in Figure 4 (HPT, 2022). In general, heat pumps have become more popular and, as a result, Norway has Europe's highest heat pump installation rate, of 50 new heat pumps per 1000 households in 2021 (Vaughan, 2022).

For consumers, several online tools allow for a comparison of the cost of ownership for oil heating versus replacement technologies, such as different types of heat pumps, an electric boiler, an electric boiler heat pump combination, or a biofuel boiler. The calculator estimates the total cost of ownership based on many variables, including the age of the boiler, annual fuel consumption, subsidies, and energy prices. With typical inputs, the result is that the cost of ownership for an oil boiler is greater than all other technologies, apart from using biofuels (**Figure 4.**).

Figure 4.5: Annual cost of ownership comparison of heating technologies.



Source: Naturvernforbundet (2020).

We found similar results when comparing the annual costs of running an existing boiler in 2020 to an electric central and air-to-air heat pump combined heating system.

Starting with the running costs of an oil boiler: wholesale heating oil purchases corresponded to NOK 0.55/kWh at the start of 2020[13]. The carbon tax on mineral oil of NOK 548/tCO_2e[14] equated to an additional NOK 0.14/kWh. Furthermore, the excise tax on mineral oil of 635/tCO_2e corresponded to another 0.16 NOK/kWh, and the VAT on mineral oil a further 0.14 NOK/kWh. With maintenance costs of approximately NOK 0.08/kWh, this results in total annual running costs of an existing oil boiler in 2020 of **NOK 1.07/kWh (EUR 0.107/kWh)**. If a consumer has annual heating needs of 20,175 kWh and the boiler was installed in the 70s/80s with an efficiency ratio of 0.8 (Naturvernforbundet, 2020). This would require 25,219 kWh of purchased energy, resulting in annual running costs of approximately **NOK 27,000 (EUR 2700)** in annual running costs.

For an electric central and air-to-air heat pump combined heating system: the electricity price excluding taxes was around NOK 0.21/kWh in 2020 (Statistics Norway, 2022a). After accounting for VAT on electricity consumption of 25%, an additional consumption tax of NOK 0.16/kWh, grid rent (with taxes), and maintenance costs of NOK 0.06/kWh, the total electricity price paid by consumers amounts to **NOK 1.02/kWh (EUR 0.102/kWh)** (Naturvernforbundet, 2020; Statistics Norway, 2022a) Based on annual heating needs of 20,175 kWh and with a heating system efficiency of 1.3 (meaning that more heat energy is

[13] Based on price of US wholesale weekly heating oil prices on 6 Jan 2020 (2.166 USD/gallon) (EIA, 2022b).
[14] Carbon tax and excise tax levels from 2018-2022 are available online - (Government of Norway, 2022). Calculated from a carbon tax of NOK 1.45 per litre (Government of Norway, 2022).

produced than electrical energy is consumed). This would require 15,519 kWh of purchased energy, resulting in annual running costs of approximately **NOK 15,800 (EUR 1580)**.

Therefore, based on savings alone (NOK 11,200/year), an upfront investment for an electric central + air-to-air heat pump system of NOK 120,000 minus the subsidy paid for removing the oil boiler (NOK 10,000) can be repaid in 9 years and 11 months. If taking out a bank loan with 2.5% for 20 years (based on the lifetime of an electric heating system), the consumer would immediately save around **NOK 4100 (EUR 410) per year**. The savings would be even greater if the boiler was already at the end of its life and needing replacement. Furthermore, if a consumer has one of the very last remaining oil-based heating systems, they may save the cost of installing a new heating system but will find it more and more difficult (and expensive) to find a fuel supplier, or to get the system serviced or replaced.

4.3.4 Policy evaluation

The regulation on the banning of mineral oil for heating systems by 2020 has achieved its objective of phasing out oil from residential buildings (bar a few exemptions). Both the 2020 goal and the 2022 extension for construction sites were achieved on time without significant pushback. Several indicators point towards the success of the ban on the use of mineral oil for heating systems. Many conditions enabled the transition, which helps to explain how Norway was able to achieve its target phase-out date with few disruptions.

The 2020 ban was built on cross-party support for ambitious climate policy. Landmark agreements made in parliament in 2008 and 2012 were expressions of the country's ambitions and provided a clear legal mandate to act. Environmental groups and environmentally minded political parties played a strong role in driving the settlements and garnering support within parliament. There was a high public acceptance from the outset, particularly given that the ban affected relatively few, that many of the oil boilers were old, and because other climate friendly alternatives were available at reasonable costs. There was, therefore, weak pushback because the stakes for industry and households were low. Furthermore, there was no big debate on the ban itself as attention was focused on the other elements of the settlement that represented a larger share of Norway's emisisons, which were more costly to reduce.

As a result, the government made use of few complementary social policies to achieve its targets while ensuring a just transition. For instance, no compensation was provided for early retirement of the remaining boilers after the policy took effect. Moreover, subsidies for replacing oil-boilers and for installing cleaner alternatives were equal regardless of socio-economic background. Given the low number of boilers to exchange, the Norwegian government chose not to add social compensation policies, as this would have added administration costs.

High levels of home ownership was another enabling condition, as 81% of Norwegians own their own home (Trading Economics, 2022), meaning that the landlord versus tenant problem is less of a constraint — preserving the incentives for households to switch from oil-based heating systems to cleaner alternatives. Norway's social housing policy has historically consisted of subsidised loans and strict regulations on house prices, with the aim of providing affordable housing for all those who need it (Sandlie & Gulbrandsen, 2017).

Efforts from government to reduce the strain on the electricity grid resulting from increased electrification of heating, further aided policy implementation, by implementing EU directives to improve energy efficiency and reduce electricity demand, such as the EPBD introduction in 2010. However, strain on the electricity grid is less of an issue for Norway, as heating was already predominantly electrified and the switch to heat pumps lowers electricity consumption for most households due to higher efficiencies compared to typical direct electric resistance heating systems.

Norway has a strong power grid and historical access to cheap (prior to the 2021/2022 energy crisis) renewable electricity. Low electricity prices in the decade leading up to policy implementation reduced the need for further government intervention to facilitate the ban. The average electricity price (spot price without net cost, taxes and VAT) in 2020 when the ban took effect was at its lowest level (NOR 0.207/kWh, EUR 0.02/kWh) out of any other year from 2012 to 2021 (Statistics Norway, 2022a), due to a record amount of snow during the winter of 2019/2020 — providing a strong hydrological balance throughout the year. The average price level observed in 2020 was 57% lower than the year before, which smoothed the enactment phase of the policy by shielding some of the visible impacts of taxation on households. The most important determinants of consumers' economic decisions were electricity prices, oil prices, and heat pump installation costs.

However, there were four policy drivers that contributed most to the policy's success, which will be explored in more detail below:

1. Leveraging private investment through tax and subsidy design.
2. Building up installation capacities through reskilling and upskilling.
3. Joining forces through information campaigns.
4. Clear analytical process with long-term planning.

Leveraging private investment through tax and subsidy design

The Norwegian case provides a good example of how to align economic incentives through taxation and subsidies, to lower the costs of the phase-out and harness market forces. Starting with taxation, several mechanisms were introduced to increase the relative costs of oil boilers to cleaner alternatives. The carbon tax on mineral oil increased every year after agreeing on the goal in 2012. In 2018, when the ban was legislated, it reached NOK 503/tCO_2e (EUR 50) before increasing to NOK 548/tCO_2e (EUR 54.8) in 2020, when the bank took effect. In 2022, the tax level is now NOK 775/tCO_2e (EUR 77.5) (Government of Norway, 2022). In addition to the carbon tax, the separate excise tax has been increasing since 2014, reaching NOK 616/tCO_2e (EUR 61.6) in 2018 when the ban was legislated, before rising to NOK 635/tCO_2e (EUR 63.5) in 2020 when the ban took effect. The relatively high price on oil — despite the abundant domestic supply — strengthens the economic case for consumers to substitute from heating oil to electricity.

Table 4.5: Carbon tax and excise tax levels from 2018 to 2022

Year	Carbon tax (NOK/tCO_2e)	Excise tax (NOK/tCO_2e)	Combined equivalent tax (NOK/ tCO_2e)
2018	503	616	1119
2019	511	624	1135
2020	548	635	1183
2021	598	658	1256
2022	775	666	1441

Source: Government of Norway (2022).

Furthermore, we found that taxes (carbon, excise, and VAT) on the use of mineral oil represented 44% of total running costs of the oil boiler when the ban took effect in 2020. If these taxes were removed, then the total running costs of an oil boiler would almost halve and become much closer to that of a heat pump, significantly lowering the return on investing in the switch. However, electricity was also taxed heavily, at 42%, yet still heat pumps had lower operating costs and were the more economical option when the ban took effect in 2020.

While the upfront costs of an oil boiler remain cheaper, heat pumps have become profitable due to improved efficiency, low electricity prices, subsidies for the purchase and installation of heat pumps, high carbon taxes, and also, since the market has matured, more suppliers and greater competition. By 2020, even without subsidies, if using a bank loan, it would have been immediately profitable to install an air-to-air heat pump in combination with an electric-based heating system for a consumer with a relatively old boiler and typical energy needs. However, upfront costs of heat pump installations are still more expensive than oil-fired boilers and low-income households often have little capacity to bear these upfront costs, despite being a profitable investment with lower total costs over the long term. For this reason, it is important that these groups are compensated, through targeted subsidies, interest-free loans, or other mechanisms that benefit both vulnerable households and government.

Enova maintained subsidies for a long period, from 2003 to 2021, which provided certainty for suppliers/installers on whether it is worth investing in this transition, building up experience and lowering the costs of installations over time. However, the reliability of subsidies had less of a role from the consumer's point of view, who often replaces their boiler towards the end of its lifespan. Subsidy levels in the five years leading up to the ban for different heat pumps were small relative to the technology and installation costs, representing less than 10% of required investment sum. The effect of such subsidies is therefore limited in motivating households to change their heating system.

However, the most important subsidy for incentivising the change was the grant of NOK 20,000 (EUR 2000) for removing existing oil-fired heating systems, in combination with subsidies for air-to-water and brine-to-water heat pumps. In 2018, Enova issued 14,500 of these grants and 90% of grantees chose some form of heat pump (Agora Energiewende, 2021). This is in comparison to the remaining 80,000 oil boilers in the same year (Enova, 2019). Furthermore, "Ask Enova", the enterprise's help service, received over 61,000 enquiries in 2019. One year later, after the grant to phase out oil boilers had been discontinued, enquiries fell by 43% to just over 35,000 in 2020. These figures support the finding that the oil boiler replacement subsidy was popular among households.

Overall, the strongest taxation drivers of the phase-out were the excise tax (representing approximately 15% of total running costs for an oil boiler), followed by the carbon tax and VAT, corresponding to 13% each. The most important subsidies were the grants for removing existing oil-fired heating systems, and the subsidies for heat pumps, in the years leading up to the ban. However, overall subsidy levels were low in comparison to total installation costs and taxation, therefore, played a much larger role in altering relative prices to leverage private investment.

Building up installation capacity through reskilling and upskilling

To build up supply capacities to facilitate the growing number of heat pumps installed each year, the Norwegian Water Resources and Energy Directorate and industry organisations introduced the Heat Pump Ordinance scheme, *Varmepumpeanordningen*, in 2000. The scheme was operated by the Norwegian Heat Pump Association (NOVAP) and consisted of a three-day training course, accreditation for installers, as well as setting standards for service and installation.

The training course was based on a Swedish system. After a few years, the initial interest declined, and it was replaced by other training courses during the 2000s. Such training courses represent a best practice in many aspects, as a lack of skilled labour and, therefore, a lack of confidence in labour skills, can become a major barrier for increasing investment. In that way, the combination of standardised training and certification is key to building skills and competences.

NOVAP developed new training courses that combined theory and practice related to the correct dimensioning and operation of heat pumps. Since 2003, the year when heat pump subsidies were introduced, NOVAP provided training courses for the installation of air-to-air heat pumps, and, from 2010, separate training courses for heat pumps became available for the optimal design of other heat pump systems for both large and small buildings.

Additional courses currently offered by NOVAP include those that cover laws and regulations for the heat pump industry, project management, and dealing with flammable refrigerants and with F-gases. The scheme was a success to the extent that shortages of skilled installers did not prove to be a significant bottleneck. Part of the scheme's success may be due to workers already having considerable experience with multiple types of electric heating technologies (in particular, direct electric resistance heaters), as well as district heating systems which had been in use long before the ban was implemented.

The role of local governments has also been very important for building up supply chains, due to the context specificity of the heating sector. While it was for the government to announce the mineral oil ban, it was through cooperation with local cities that the required infrastructure was planned and built up over time, such as for district heating facilities (Interview 1).

Joining forces through information campaigns

Throughout Norway's transition away from mineral oil heating, different interest groups came together on several instances with the common goal of achieving the phase-out. Partnerships often emerged through information campaigns. For example, the NOVAP collaborated with the Norwegian District Heating Association (Norsk Fjernvarme) through information campaigns, even though the solutions they advocated were in competition for the substitution away from fossil-based heating systems (Interview 2). Information campaigns helped to raise awareness and educate consumers, policy-makers, installers, and distributors on the available technologies and relative benefits that they provide.

Since 2006, Enova has provided information and advice on the heating transition, by targeting households through two websites: My Energy, and The Rain Makers, which target mostly children and young people, partly through schools and teachers. Enova carries out three or four information campaigns each year, at least half of which targets residential households (Markusson et al., 2009).

Friends of the Earth Norway campaigned for “oil free”, pushing for heat pumps, DH, and biofuels. From 2012 to 2020, Friends of the Earth in cooperation with NOVAP, Norsk Fjernvarme and other organisations informed households on different subsidy schemes, showing the potential savings from replacing inefficient oil boilers. NOVAP often worked with Enova for this, by sharing information and material. Such information campaigns were crucial for overcoming behavioural barriers and encouraging a change to unfamiliar technologies (Interview 2). The phase-out highlights the benefits of sending a coherent message by collaborating with information campaigns between government, NGOs, and clean industry, aiming at all levels (households, children, and society as a whole).

Clear analytical process with long-term planning

When the target of banning the use of oil in existing buildings was first agreed in 2012, the government commissioned the Norwegian Environment Agency to conduct an ex-ante impact assessment (IA). This was done with the goal of improving policy design such that it mitigates energy security risks, and provides the necessary exemptions and variations of bans for different building types or competitively disadvantaged sectors (Norwegian Environment Agency, 2015).

The IA projected emissions savings of 0.34 $MtCO_2e$ per year from 2016 to 2035, 0.5% of the 72 $MtCO_2e$ that Norway currently emits. While these reductions do not represent such a large share of the country’s emissions (given the low prevalence of oil heating to begin with), it highlights that the policy intention was not just to reduce absolute levels of emissions, but to eliminate them.

There is considerable uncertainty associated with these emissions reductions. The policy affects a wide range of facilities and there is a lack of precise information on the current stock of oil-based heating systems and their usage. Despite this uncertainty, the IA concluded that the ban would probably be economically profitable, with a net saving of NOK 2.5 billion (EUR 0.25 billion), mainly because the increased investment costs involved in the transition are more than offset by reductions in annual energy costs, as well as the environmental cost reductions from reducing emissions over the 20 year period (Norwegian Environment Agency, 2015).

Conducting an impact assessment prior to legislating the ban can be considered a good practice that ensures policy decisions are based on long-term forecasts, accounting for lifetime costs of ownership and damage costs of future emissions, rather predominantly evaluating the costs to consumers today. However, providing the option that the ban could be extended if the transition were found not to be economically profitable, damages the signal aimed at triggering industry to invest in the transition. Nevertheless, the Norwegian government provided the signal that fossil-based heating was to be phased out much earlier than the 2012 target announcement — to first phase out oil boilers from new buildings by 2010, to then phasing out all fossil fuel boilers from new buildings by 2017, before mandating that oil cannot be used in existing heating systems by 2020. Having clearly outlined policies made it easier for the government to increase the stringency of the phase-out approach over time, such as the extension to include construction sites from 2022. The government's stepped approach to phasing out all fossil-based boilers over time was both effective and logical.

Norway's phase-out policy was set as part of an economy-wide, integrated plan for achieving emissions reductions targets for 2020 and 2050, based on agreements made in the 2008 and 2012 Climate Settlements. The electrification of home heating was recognised early on as an essential step in the transformation to climate neutrality. In this way, the phase-out of oil heating was embedded in an economy-wide plan for reaching long-term targets. Furthermore, since 2005, the Norwegian Environment Agency has published a biannual report with analyses of climate measures already in place, which also assesses the effect of the heating phase-out (Interview 2). The Climate Change Act in 2017 introduced a system of five-year reviews where the Norwegian government must submit to parliament updated information on the status and progress towards achieving climate targets enshrined in law.

Box 4.2 Impacts of the Policy on investment

The Norwegian case provides an interesting example of how the smart design of taxes and subsidies can leverage private investment — by incentivising the good and disincentivising the bad. Norway successfully altered relative prices to make an investment in a heat pump the economical choice for households. This applied both to the operational costs (costs of electricity and oil / gas), and to the capital cost (through subsidies for new heat pumps as well as a premium for decommissioned oil heating). While the capital costs for heat pumps are often still greater, the total cost of ownership is now lower for a heat pump relative to an oil-fired boiler. In combination with the long-term signal sent by the ban announcement, this sufficed to unleash the necessary investments for the ban to take effect in 2020.

Norway's experience also demonstrates that phase-out timelines can provide confidence to installers to invest in the transition, using training courses which combine standardised teaching and accreditation to build skills and competencies — reducing supply bottlenecks and costs in the long run. The example also shows that such confidence can be strengthened through long-term coherent information campaigns that target all levels of society — collaborating between governments, industry groups, and NGOs to provide a multitude of communication channels.

4.3.5 Discussion

The regulation on the banning of the use of mineral oil for heating of buildings from 2020 has eliminated oil heating from Norwegian households (bar a few exemptions) and has done so in line with the target agreed upon in 2012. In this way, Norway has managed to close one chapter in the transformation to climate neutrality, which most other European countries have only begun to address. The Norwegian heating phase-out is a best practice which demonstrates that if all conditions are met, the phase-out is possible, even in a country with large domestic fossil fuel reserves (and a powerful fossil fuel industry). However, there are limitations on what can be learnt about dealing with the fossil fuel industry from this case study, where the industry's export-oriented business model was not questioned.

The Norwegian experience shows that phase-out dates can also be applied to existing, well-functioning technologies that have not yet reached the end of their lifetime, even while the alternative (in this case heat pumps) is still maturing. Having long lead times in the phase-out discussions, the stranding of assets was avoided as much as possible. The policy has been politically transformative, by executing long-term plans with cross-party support, and interest group constellations between environmental groups and between sectors that may otherwise be competitors in the markets for heat pumps and district heating.

There were four policy drivers that contributed most to the policy's success: leveraging private investment through tax and subsidy design, building up installation capacities through reskilling and upskilling, joining forces through information campaigns, and having a clear analytical process with long-term planning.

Once the ban took effect, the use of taxation on mineral oil, in combination with subsidies for installing heat pumps and for removing oil boilers, helped the running costs of an electrified heating system to become lower than for an oil-fired boiler. The strongest taxation driver of the phase-out was the excise tax (representing approximately 15% of total running costs for an oil boiler), followed by the carbon tax and VAT, corresponding to 13% each. The subsidy that was collected most frequently was the grant for removing existing oil-fired heating systems in the years leading up to the ban. However, overall subsidy levels were low in comparison to total installation costs and taxation therefore played a much larger role in altering relative prices to leverage private investment.

Upfront costs of heat pump installations are still more than for oil-fired boilers and the payback time may be too long to incentivise low-income households to switch. If the household were to take out a bank loan when the ban was implemented, then immediate savings would be made from installing an air-to-air heat pump in combination with an electric-based heating system. However, obtaining loans can be difficult for low-income households, which provides a rationale for making these processes easier and offering low-interest loans to support these clean energy investments. Information campaigns were crucial for overcoming behavioural barriers and encouraging change to unfamiliar technologies. Furthermore, through cooperation between the government and heat pump associations, courses were made available to provide standard settings training courses and accreditation for installers of heat pumps, which helped to reduce supply bottlenecks throughout the phase-out.

There are clear benefits of Norway's approach to conducting an impact assessment prior to legislating the policy — basing decisions on long-term forecasts, accounting for lifetime costs of ownership and damage costs of future emissions, as opposed to short-sighted decisions based predominantly on the costs to consumers today. Moreover, Norway's phase-out policy comes as part of its wider, long-term package of policies and measures that revealed the government's signal that fossil-based heating must come to an end. However, the case raises the issue of credibility by providing the possibility for extending the policy, as many households and industry actors were initially unsure as to whether the policy would be implemented at first, weaking the investment signal for industry to transition. It is important that phase-out timelines are set with as few loopholes as possible, to improve the credibility of long-term target setting.

What is clear from this best practice is that for a phase-out timeline to be successful, the enabling policies must already be in place before the ban takes effect. The ban was really the last measure to come into effect once all conditions had already been met and as the technological alternative was evolving to become both technologically and economically advantageous. Through a combination of fiscal incentives and penalties, the replacement technologies were made economical over a typical lifespan of ownership. The case also highlights the importance of long-term announcements that are necessary to make sure that the conditions are set and that accompanying policies are in place before the ban is enacted.

Since the the transition away from fossil-based heating was already at a very advanced stage when the ban took effect, the benefits of this policy are not so much in terms of absolute emissions reductions, but rather by eliminating entirely one source of emissions so that efforts can be redirected towards the next problem.

4.4 Case study 2: Phasing out fossil fuels in heating – Vancouver, Canada

Vancouver, Canada was selected as the second case study for analysis because it was among the first jurisdictions after Norway to effectively phase-out the use of fossil-based heating systems (both oil and gas) in new buildings since the start of 2022 – via stringent performance standards that regulate boiler efficiencies and usage levels. Whilst the phase-out in Vancouver is still ongoing, of special interest are the accompanying polices and conditions which enabled the policy's implementation. The case study opens with Section 4.4.1 which introduces Vancouver's energy system, its heating sector and policy development – within the larger context of British Columbia. Section 4.4.2 provides a description of the policy under evaluation and discusses how it was received by public and industry. Section 4.4.3 explains the conditions that made the phase-out policy implementation possible. Section 4.4.4 closes with a discussion and extraction of lessons learned from Vancouver's experience.

4.4.1 Context and background

Energy system and overview of building sector in Vancouver

Since Vancouver is a municipality located in the Canadian province British Columbia (BC), much of the history and context for the energy sector can be explained at the provincial level. Since renewable electricity generation in the province is abundant and cheap, it greatly improves the rationale to transition away from fossil fuels, to cleaner alternatives. With over 8000 mountains, BC is endowed with large hydro resources. The electricity mix of BC consists of 87% hydropower, 5% biomass/geothermal, 4% natural gas, 2.6% wind, with the remaining share coming from oil (0.5%) and solar (0.1%) (Canada Energy Regulator, 2022). The Clean Energy Act, passed in 2010 by the British Columbia Government, established several objectives for the province, including a goal to generate at least 93% of electricity from clean or renewable resources. This goal is exceeded annually, with an average renewables generation share exceeding 95% (Canada Energy Regulator, 2022).

All hydropower provided to Vancouver is produced by BC Hydro, a federally owned power company. One study found that out of 22 North American cities (within Canada and the US), Vancouver had the third lowest electricity price for residential customers in 2021 (CAD 0.12/kWh (EUR 0.09/kWh)[15]) (Hydro-Québec, 2021). Low electricity prices provide a rationale for Vancouver to pursue electrification of heating.

[15] 1 CAD = 0.75 EUR

Prior to policy implementation, in 2008, buildings accounted for 55% of GHG emissions in Vancouver (Greenest City Action Team, 2012). Around half Vancouver's homes are heated with electricity and the other half by natural gas (Interview 3). Oil boilers are banned in new buildings and if selling a property, it is necessary to remove the oil tank first. The use of wood-fired stoves is also rare in Vancouver as they are also subject to stringent emissions standards.

Historical context on the decarbonisation of the building sector in Vancouver

Climate policy in Vancouver has become more stringent in the last two decades, in large part aided by changes at the provincial level. In 2009, the BC Green Energy Task Force was formed and the BC Energy Plan was launched later in the year. Also in 2009, the mayor of Vancouver formed the Greenest City Action Team, a group of local experts that researched international best practices from leading green cities, establishing the goal of reducing emissions in existing buildings to 20% below 2007 levels, by 2020 (Greenest City Action Team, 2012). Furthermore, the group generated the target to require all newly constructed buildings from 2020 onwards to be carbon neutral in operations — a precursor to the current phase-out policy.

The Zero Emissions Building (ZEB) plan was introduced and approved by the Vancouver City Council in 2016. The policy sets out the targets of reducing emissions from new buildings by 90% by 2025, and to zero by 2030 (City of Vancouver, 2016). The objectives are to rapidly increase the rate of construction for highly energy-efficient (passive) homes that are heated with renewable energy, and to make older homes more efficient through retrofits. The policy has been amended over time, as was the case in 2020 when the Climate Emergency Action Plan (CEAP) was launched, which merged several standalone initiatives into the ZEB plan. To reach Vancouver's 2025 and 2030 targets for the building sector, one element of the policy is to mandate emissions maxima for different classes of new buildings, which increase in stringency every five years until they have effectively been phased out.

The political conditions in Vancouver shifted in favour of more stringent climate policy after the 2018 election, which saw a socially liberal and progressive party enter the city council (City of Vancouver, 2018). At the provincial level, since 2008, BC has levied a carbon tax, initially set at CAD 10/tCO_2e (EUR 7.5/tCO_2e) for the first year, and subsequently raised in incremental steps until 2012, when it was capped at CAD 30/tCO_2e (EUR 22.5/tCO_2e). For three out of the four years between the announcement of the phase-out policy and it taking effect in 2022, the BC carbon tax increased — to CAD 40/tCO_2e in 2019, to CAD 45/tCO_2e in 2021, and to CAD 50/tCO_2e (EUR 37.5/tCO_2e) in 2022 (Ministry of Environment and Climate Change, 2022). While BC was the first Canadian province to impose a carbon tax, its tax rates must now keep up with the levels imposed by the federal government — otherwise, the federal government will simply impose its own carbon tax, as it has in other provinces. The carbon tax was "revenue neutral" until 2018, where the amounts returned to BC residents through income tax cuts and income tax credits were greater than the amount of carbon tax revenues collected[16].

After a change of government in the May 2017 election in BC, changes were made by formally untying the carbon tax to specific tax cuts and credits. While the previously introduced tax cuts and credits remain in place, the policy has shifted towards a more general commitment of providing carbon tax relief, and to protect affordability, to maintain industrial competitiveness, and to encourage new green initiatives. The tax is now accounted for under regular budgetary procedures, no longer being subject to the "Revenue Neutral Carbon Tax Report", as it was previously. This means that a portion of carbon tax revenues are now spent on climate initiatives, including CleanBC, which provides rebates of up to CAD 6000 (EUR 4500) for substituting a fossil fuel boiler with a heat pump (City of Vancouver, 2022a).

While much of the wider political framework for climate and energy policy, particularly in the initial phases, was set at the provincial level, Vancouver has taken advantage of the autonomy granted to it by its charter. This has allowed Vancouver to advance the decarbonisation of the building sector through its ability to implement ambitious usage and efficiency standards within building codes. In 2020, the Vancouver City Council set emissions efficiency and performance requirements which have, essentially, phased out fossil fuel boilers from new residential buildings — this policy will be evaluated below.

4.4.2 Low emission requirements for space heating 2022

Description of Vancouver's phase-out policy

The low emissions requirements for space heating in 2022 were introduced as an amendment to the ZEB plan, through an agreement made by the City Council in 2020. The regulation requires that all single unit residential buildings below four floors follow one of two pathways set out in the Vancouver Building By-law (City of Vancouver, 2022b). The first (prescriptive) pathway is that boilers must be electric. The alternative (performance) pathway allows the use of a fossil-based heating system, but only if the boiler can maintain a 92% thermal efficiency rating, if the boiler emits no more than 3 $kgCO_2/m^2$ per annum and it meets the energy use intensity requirements outlined in Table 5. To understand how this works, take a 40 m^2 apartment. The maximum amount of mechanical energy that can be consumed in one year is 40 x 125 = 5000 kWh. Likewise for a 200 m^2 house, the maximum energy use is 9000 kWh. As a reference, for those who use natural gas in Canada, the average household consumption is 24,600 kWh (Canada Energy Regulator, 2022).

[16] Source: Email communications with Ministry of Finance, Government of British Columbia, Canada.

Table 4.6: Permitted mechanical energy use intensity for fossil fuel boilers in buildings under four floors

Conditioned Floor Area / m^2	Mechanical Energy Use Intensity (MEUI)
≤ 50	125
≤ 75	108
≤ 120	78
≤ 165	58
≤ 210	48
> 210	45

Source: City of Vancouver (2022b).

The strictness of the energy efficiency and usage requirements, in most cases and for typical energy needs of a household, result in natural gas heating installations becoming cost ineffective, after accumulating the costs for both buying the boiler and all the associated costs involved with installation (including connection to Vancouver's natural gas grid). This results in an implicit ban on the use of fossil fuel heating systems in new homes, as the requirements are stringent enough that for typical energy needs, the usage levels would be exceeded, unless complemented with a cleaner alternative. Oil boilers are already banned from new buildings.

The policy is supported by the measures outlined in the ZEB plan, which includes subsidies in the form of grants for cleaner alternatives, which will be laid out in more detail in the next section. The phase-out of fossil fuel heating is still ongoing in Vancouver — the second class of buildings (residences over four floors, commercial buildings, hotels, and others) do not yet have to adhere to the requirements. Furthermore, the policy does not apply to gas stoves or gas fireplaces.

Acceptance of policy from public industry

The policy was pushed primarily by the Vancouver City Council. However, there was also a robust environment created by different interest groups, including environmental NGOs, practitioners, consultancies, and organisations willing to address decarbonisation together (Interview 3). The policy did not come as much of a surprise to the public, as Vancouver had been strengthening its climate policy in the years leading up to the ban. Affordability of the transition was the greatest concern expressed by the public (Interview 3).

The ban was originally envisaged to take the form of an explicit phase-out policy for all fossil fuel boilers in new buildings. However, the proposed policy was met with significant pushback from BC's strong natural gas industry, particularly from the regulated gas utility FortisBC (Interview 1). They argued that Vancouver's phase-out policy for fossil fuel boilers was simultaneously phasing-out investment in the gas grid, which could be used for transporting renewable gases in the future (Interview 3). As a result of pushback from industry, and from misinformation that was spreading regarding the impacts of the policy on consumers, the city council made a compromise, that natural gas hook-ups could still be permitted, but only if they meet the passive house standard set out in the building code, or if they are only used with very low energy intensity and have high efficiencies.

4.4.3 Enabling conditions

The low emissions requirements in Vancouver since 2022 have made it very difficult for households to install gas boilers in new buildings and have made the household decision for proceeding with a heat pump as a climate-friendly alternative more attractive. Vancouver has been tightening its climate policies in the decade leading up to the ban and its ambitions have notably accelerated within the last six years. Furthermore, Vancouver has produced comprehensive long-term plans which outline how these ambitions will be met in practice. For example, in 2016, the city set out the target of reducing emissions from new buildings by 90% by 2025, and to zero by 2030. Four years later, in 2020 the strategy was released outlining how these targets are going to be achieved. Due to the increased ambition and credibility, the phase-out requirements did not come as an unexpected shock for residents in Vancouver. This example highlights the importance of signalling the jurisdiction's phase-out intentions long in advance — overcoming behavioural barriers, and improving awareness of households on the rationale to switch and on the available technologies.

There are also several relevant initiatives accompanying Vancouver's phase-out strategy, which have aided the implementation of the policy and help to explain how the different elements need to go hand in hand. Three areas were identified as notably relevant for enabling the policy's implementation: financial incentives, reskilling programmes, and social equity programmes.

- **Financial incentives** were introduced to encourage adoption of heat pumps through subsidies in the form of rebates and interest-free loans to address high upfront costs, as well as taxation levied on fossil-based heating systems.
- **Reskilling programmes** were developed to create new skills through training courses on the installation and maintenance of heat pumps, and by providing passive house certification courses for prospective electrician trades.

- **Social policies** have been implemented in Vancouver to offset some of the distributional impacts of the phase-out. Revenues from the BC carbon tax are used to provide relief to low and middle-income households, and the scheme is structured progressively. Moreover, Vancouver has plans to subsidise training for small contractors, to disseminate training in multiple languages, and to subsidise the training of underrepresented groups within the trades.

Financial incentives

The primary forms of financial assistance available for residents of Vancouver to electrify heating are subsidies for heat pumps in the form of rebates. Households are eligible for up to CAD 17,500 (EUR 13,125) for removing a fossil-based heating system and replacing it with an air-to-air heat pump. The average installation cost of such heating systems range from CAD 6,000 to CAD 18,000 (EUR 4,500 to 13,500) (City of Vancouver, 2022a).

Subsidies are offered at all levels of government: up to CAD 6,500 (EUR 4,875) is available at the provincial level through the CleanBC initiative, a municipal top-up of up to CAD 6,000 (EUR 4,500) is offered by Vancouver, while another CAD 5000 (EUR 3,750) is available from the federal government via the Canada Green Homes Initiative (City of Vancouver, 2022a). Subsidy levels are higher for the more efficient, costlier models which cope better in colder climates.

While the provision of financial incentives strongly influences household decisions on the purchase of new heating systems, and reduce the burden of investment onto households, the subsidies provided in Vancouver account for a large proportion of heat pump installation costs (often over 75%). Despite the large subsidies, barriers remain for low-income households to install heat pumps, who often cannot pay for the high upfront cost before claiming the rebate. To address this, the Canadian federal government offers ten-year interest-free loans worth up to CAD 40,000 (EUR 30,000) for switching to energy-efficient heating equipment (Government of Canada, 2022). The loans offered by the federal government extend to other home renovations as well, including building envelope upgrades.

There are cases where, even after accounting for subsidies in Vancouver, the installation costs of a gas boiler can still be lower (Klein, 2021). However, this represents a benefit from mandating the end of a technology — that it forces households to make investment decisions that will be beneficial in the long-run, at the private and public levels, when considering the full lifetime of the technology.

A rising carbon tax from CAD 10/tCO_2e (EUR 7.5/tCO_2e) in 2008, to CAD 50/tCO_2e (EUR 37.5/tCO_2e) in 2022, has had the effect of improving the economics of electric-based heating systems by disincentivising fossil-based heating systems. The carbon tax of CAD 50/tCO_2e accounts for approximately 17% of residential energy bills (EIA, 2022a; FortisBC, 2022)[17]. The provincial sales tax on fossil fuel heating systems was updated in April 2022, which increased from 7% to 12% of technology costs. Furthermore, this reform exempted heat pumps from the tax (Government of British Columbia, 2022c).

Reskilling programmes

Heat pumps and the passive house building techniques for energy efficiency both require relatively novel skillsets. For construction companies and installers, new technologies require a time investment in order to develop the necessary skills, and to implement these technologies efficiently. Contractors may be reluctant to invest in training, preferring instead to continue using the technologies they are familiar with, where the contractor already has a broad knowledge base. This inertia to pick up additional skills resulted in a massive backlog of both heat pumps and passive house certifications (Interview 2).

To address the heat pump knowledge shortage, Vancouver City Council partnered with the BC Institute of Technology, to deliver training courses on the installation and maintenance of heat pumps, and to provide the means for prospective electrician tradesmen to undergo passive house certification. This is done with the logic that enforcing knowledge standards in trade schools should result in a work force that is comfortable and well equipped to work with the new technology, which may be foreign to older workers. However, individual training of new workers will not immediately reshape the workforce in such a way that adequately addresses the knowledge shortage.

The Vancouver City government has implemented reskilling measures and incentives for construction crews in the city. These reskilling measures, through the Province's CleanBC Building Innovation Fund, provide CAD 9.65 million (EUR 7.34 million) worth of training to industry professionals for knowledge building, and are supposed to result in a vastly better-trained and experienced workforce, developing expertise in retrofitting existing buildings, working with new technologies, such that when the ban takes effect workers are able to provide expertise at an affordable cost (Government of British Columbia, 2022b).

Box 4.3 Reskilling initiative: the ZEBx Programme

Another reskilling programme is the ZEBx — a knowledge sharing platform which provides construction companies with incentives to pursue sustainable building practices, and then make public the knowledge and experience they have gained. ZEBx uses some of its funds to pay contractors to build houses to the Passive House Standard in return for conducting a case study on the house. Contractors can receive upwards of CAD 25,000 (EUR 18,900)

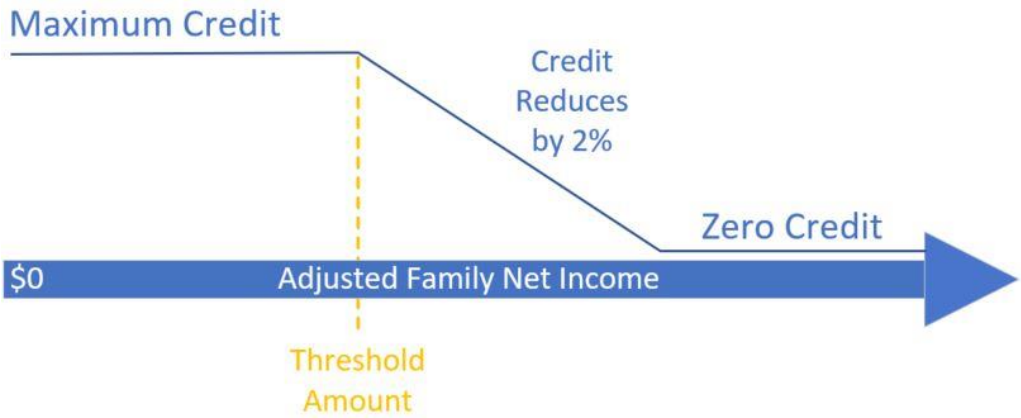
[17] Calculated using emission factor for natural gas – 1 million BTU produces 52.91 $kgCO_2$

for conducting data collection on site, and document outcomes in a case study on the construction of the building. In this way, Vancouver is pre-seeding the contractor market with knowledgeable crews such that when all buildings are required to follow stringent performance standards, the industry leaders can help to prepare the sector for the enactment of the policy when there is a jump in the number of installations.

Social policies

The BC carbon tax has played a role in offsetting the distributional impacts of the fossil fuel phase-out within Vancouver, while, at the same time, disincentivising fossil-based heating systems. Revenues from the carbon tax are used to provide relief to households through the BC Climate Action Tax Credit (BCCATC), the level of which is based on adjusted family net income, and decreases as income levels increase (Government of British Columbia, 2022a). The maximum annual credit that can be received is CAD 193.50 + CAD 56.50 for each child, which is received by all resident families below the threshold.

Figure 4.6: Revenue distribution of BC carbon tax through the BCCATC.



Source: Government of British Columbia (2022a).

Although additional taxes can have an adverse effect on the public's willingness to accept even more environmental regulation and policy, BC's approach to distributing revenues with the BCCATC led to improved public acceptance — polling data suggested that the majority of the BC public opposed the tax when it was implemented in 2008, but three years later the tax was generally supported (B. Murray & Rivers, 2015). However, such compensation schemes tend to increase the lobbying opposition, which is why they are uncommon in the EU context. Furthermore, there is a lack of data to understand how public acceptance for the BC carbon tax has shifted since the carbon tax ceased from being revenue neutral in 2018. Out of the 5 million people who live in B.C., 1.3 million benefit from this credit (Government of British Columbia, 2022a). Progressive approaches to redistributing revenues from carbon taxation may be crucial to improve public acceptance for the tax and to fund the acceleration of phase-out processes for high-carbon technologies.

To address the social inequity which might arise from rapid shifts in building code, the City of Vancouver consulted with different cities on how to best mitigate distributional impacts of decarbonisation. Considerations for equity are written into Vancouver's sustainability policy. Some examples of these equity actions are written into the CEAP, such as identifying methods to engage small business renovators and skilled tradesmen, disseminating training, and technology information in multiple languages, as well as subsidising the training of underrepresented groups within the trades (City of Vancouver, 2020).

Furthermore, by 2023, Vancouver aims to subsidise the training of trades accreditation for small contractors and offer incentives for qualified trades for heat pump retrofits. The training courses will be co-developed with industry (City of Vancouver, 2020). The council is also exploring ways to target training support for groups currently underrepresented in the trades — including women and people living with disabilities or mobility issues.

4.4.4 Discussion

Vancouver's phase-out policy to, effectively, end the installation of fossil-based boilers in new buildings demonstrates how many different elements need to be in place simultaneously — ensuring that the support is there to be able to implement stringent phase-out policies for fossil-based heating. Vancouver has benefitted from its unique circumstances of having low electricity prices due to large hydro capacities, and from its charter, which has allowed Vancouver to set its own building by-laws. However, as the ban only took effect at the start of this year (2022), there is still insufficient evidence to evaluate the level of success of the policy.

In the years leading up to policy implementation, Vancouver had been progressively strengthening its climate policy to the point where the passage of the phase-out measures came as no great surprise to the public, and hence no pushback. The Vancouver experience highlights the importance of signalling the jurisdiction's intentions long in advance — that the old fossil-based technologies must eventually be phased out — providing the time for the necessary skills creation and improved consumer awareness, and to ensure that the enabling policies are set in place.

Furthermore, several accompanying polices that aided implementation of the policy were identified. Financial incentives in the form of rebates encouraged the adoption of heat pumps, while taxation made fossil-intensive heating systems more expensive. Moreover, Vancouver has developed reskilling programmes to train installers on the installation and maintenance of heat pumps, and on how to make homes more efficient through retrofitting and passive house certifications.

The Vancouver experience demonstrates that the implementation of stringent phase-out policies is possible and provides examples of how to get the public on board by using policy to partially mitigate the resulting distributional impacts from the transition — through the use of carbon tax revenues to provide relief for low and middle-income households, and by targeting vulnerable groups for the training of heat pump certifications. Furthermore, to ensure that the property owner does not have to take the initial risk of capital investment involved with heat pump installation, zero-interest loans are provided by the government, which represent another successful element of the wider policy package to ensure that the political support is available for policy implementation.

4.5 Case study 3: Norway internal combustion engine vehicle phase-out

Norway was chosen for the third case study as it is the once again the frontrunner for transport decarbonisation. In 2017, Norway set a target for the phase-out of passenger Internal Combustion Engine Vehicle (ICEV) sales, such that all new cars sold by 2025 shall be zero-emissions (electric or hydrogen) – the earliest target of any country globally. The case study opens with Section 4.5.1 which provides the context and background on Norway's energy system, its transport sector and development of its phase-out policy. Section 4.5.2 provides a description of the policy under evaluation and discusses how it was received by public and industry. The policy is then evaluated in Section 4.5.3 before closing with a discussion and extraction of lessons learned in Section 4.5.4.

4.5.1 Context and background

Overview of transport sector in Norway

Norway has been endowed with large reserves of both fossil fuels (oil and gas), and renewables. The country is a significant exporter of fossil fuels, estimated at over NOK 800 billion (EUR 80 billion) in 2021 for a population of only 5.4 million. Consequently, Norway is the third largest exporter of natural gas globally (IEA, 2022b). Norway has a mountainous landscape with meteorological conditions that provide large hydroelectric power potential. Hydropower accounts for 92% of the country's electricity mix. A further 7% of Norway's electricity mix comes from wind power, resulting in an almost fully decarbonised grid, with a renewables share of 99% (Ritchie & Roser, 2021).

Norway has over 1500 hydroelectricity plants providing its power and, consequently, Norway's electricity prices for both business and households are among the lowest in the world, and are lower than all IEA member countries (comprising of mostly developed countries, including 20 EU members) (IEA, 2022b).

Energy demand in Norway's transport sector accounted for 22% of its total final consumption (TFC) in 2020, which represents almost 33% of the country's GHG emissions (IEA, 2022b). Oil products make up 86% of Norway's transport demand, followed by biofuels (9%) and electricity (3.2%). Hence, Norway's transport sector is still far away from full electrification, including the road transport sector, where electricity provided only 2.9% of road transport demand in 2020 (IEA, 2022b).

Norway's passenger vehicle fleet has a total volume of 2.9 million vehicles (Statistics Norway, 2022c), made up mostly of petrol and diesel cars (ICEVs) (72.9%). Battery electric vehicles (BEVs) make up 16% of the vehicle fleet, followed by plug-in hybrids 6.4% (PHEVs) and non-chargeable hybrid ICEVs (4.8%). Plug-in vehicles (EVs), represent 23% of Norway's total passenger vehicle fleet, which has grown by 5% on the year before (Holland, 2022; Statistics Norway, 2022c). New EV purchases in Norway are therefore likely to be mainly increasing the total vehicle stock rather than replacing old ICEs. Norway does not mass-produce any of its own vehicles anymore, after the last remaining large-scale EV manufacturer, Think Motors, declared bankruptcy in 2011. In 2020, Norway imported USD 5.3 billion (EUR 5.3 billion) worth of vehicles — primarily from Germany (38.9%), Japan (7.8%), China (6.8%), Sweden (6.3%), and the US (5.9%) (OEC, 2022a).

In 2021, a record 64.5% of new car sales in Norway were fully electric — an impressive 86% share when including plug-in hybrids (NEVA, 2021b). The transition away from ICEVs in Norway is progressing at a spectacular rate and trends suggest that the 2025 target for ICEVs may even be achieved before schedule. Norway has the most advanced EV market and the most ambitious phase-out policy for ICEVs of any country in the world. The country is therefore an excellent candidate for study.

Historical context of ICEV phase-out in Norway

Support for the ICEV phase-out in Norway began in response to the oil crisis and the associated high energy prices in 1973, by investing in the production and sale of EVs, through the provision of direct support via research and development (R&D) programmes. As concerns over climate change rose throughout the 1980s and 1990s, decarbonising transport became a higher priority for the Norwegian government. Cheap hydroelectricity and its associated low electricity prices were considered as a vehicle for powering the EV transition in Norway. In addition to the climate change impacts resulting from vehicle emissions, ICEVs also contribute to air pollution and other environmental impacts in Norway, particularly in urban areas, which provides further rationale for transitioning to cleaner mobility alternatives.

Although not a member of the EU, Norway is a member of the European Economic Area (EEA) and has been since 1994. The country has access to the single EU market and aligns many of its climate policies with those of the EU, including participation in the EU Emissions Trading System (ETS), and the Effort Sharing Regulation. Norway follows the EU Regulation 2019/631, which sets limit values for new passenger cars and light-duty vehicles; however, since 2012, Norway has enforced more stringent targets on vehicle efficiencies than the EU regulation (Kristensen et al., 2018). The Norwegian government has suggested that the EU increases the stringency of these standards to implicitly phase out the sale of new passenger cars and light-duty vehicles by 2030, five years earlier than the current EU proposal of phasing out ICEVs by 2035 (European Commission, 2021b).

Before announcing the ICEV phase-out policy, Norway's transport sector accounted for approximately 50% of emissions outside of the EU ETS (Fridstrøm et al., 2022). In addition to meeting Norway's ambitious goals, the country needed to implement accompanying policies to lower emissions from these uncovered sectors, and did so through increases in taxation for ICEVs, exemptions from taxation for EVs, behavioural incentives as well as direct government support for R&D, and the roll-out of the charging infrastructure.

The first exemptions to registration taxes and import taxes were granted for EVs in the 1990s, including a removal of the annual road tax in 1996. A reduced road tax for EVs was reintroduced in 2021 and has been increased to full level since 2022. A company car tax reduction of 50% was introduced in 2000, which has since been reduced to 40% in 2018, and 20% in 2022. Since 2001, EVs have been exempt from the 25% value added tax (VAT) on purchase. Norway became one of the first countries globally to introduce a carbon tax, in 1991, which has increased to around NOK 771/tCO_2e (EUR 77.1) for diesel and NOK 777/tCO_2e (EUR 77.7) for petrol in 2022 (Government of Norway, 2022). Furthermore, it was announced in the Climate Action Plan 2021 to 2030 that the total carbon price (EU ETS price and domestic carbon tax) would gradually triple, to approximately NOK 2000/tCO_2e (200 EUR/tCO_2e) by 2030 (Government of Norway, 2021). Even stronger than the carbon taxes are the excise taxes levied on both diesel and oil, worth NOK 1323/tCO_2e (EUR 132/tCO_2e) for diesel, and NOK 2162/tCO_2e (EUR 216/tCO_2e) for petrol.

Behavioural incentives for EV deployment in Norway began in 1997, by introducing an exemption for EVs from fees on Norwegian toll roads. Since 2017, fees have been reintroduced but represent only a 50% maximum reduction from the standard ICEV rate (NEVA, 2022). These exemptions will remain until the end of 2022, at which time they will be reviewed and revised to be in parallel with market developments. From 2009 to 2017, EVs were even exempted from ferry charges.

In 1999, EVs were granted free parking in public areas by using "EL" license plates to make identification easier. Allowances for EVs to use bus lanes were introduced in Oslo in 2003, before being rolled out nationwide in 2005. It has been claimed that the provision of bus lanes for EVs had a noticeably positive impact on the demand for EVs, by reducing commuting times (Kristensen et al., 2018). Since 2016, access to bus lanes is only permitted for EVs that carry one or more passengers.

The toll road exemption, along with the bus lane and free parking privileges, provided strong non-fiscal incentives for individual consumers to switch to EVs, explicitly targeting the everyday convenience of using an EV, rather than only providing upfront financial support (Mersky et al., 2016). In this way, these policies countered the inconveniences of electric car usage, such as shorter driving ranges or longer charging breaks (Mersky et al., 2016).

The government agency, Enova, helped to accelerate EV development through research by working with the Research Council of Norway and commercialising Innovation Norway, providing support for the deployment of EV charging stations (Enova, 2021). Public investment in EV charging began in the 2000s. The deployment of public EV chargers is handled by Enova, which is controlled by the Ministry of Climate and Environment (NEVA, 2022). Research and innovation projects on electro-mobility are funded by the Research Council of Norway.

In 2008, plans were made for both national and municipal investment in charging stations. Oslo launched a charging infrastructure programme with the goal of installing 400 EV charging points in the city, which was followed in 2009 by the Norwegian Government's commission of Transnova, which has since been absorbed by Enova, to accelerate the roll-out of public charging points across the country. For example, as part of a larger crisis package to counteract the financial crisis, Enova introduced a support programme for public charging points with a limit of NOK 50 million (EUR 5 million), which provided municipalities with up to NOK 30,000 (EUR 3,000) for every charging point installed (Kristensen et al., 2018). The programme resulted in a total of 1800 charging points and required slightly less than the per unit funding available. The number of charging points in Norway has increased from 1.4 chargers per 1000 population in 2016, to over 3.4 chargers by 2021, in comparison to the EU average of 0.5 (Green Car, 2016; IEA, 2022b; Werwitzke, 2021). The Norwegian government has also initiated a programme aiming to finance the installation of at least two fast charging points on every 50 km of all main roads.

Discussions around the banning of petrol and diesel car sales had been going on for several years, but intensified in 2016, when, despite differences in political views, Norway's four main political parties reached agreement on a 2025 end date (The Week, 2016). However, as was, and continues to be, falsely reported — there was no agreement on a ban, rather a compromise was reached on setting a target (Hanley, 2022; Roadmaps for Energy, 2016).

After reaching bilateral agreements across parties, the Norwegian Ministry of Transport and Communications presented its white paper to parliament in 2017, where it was agreed that the 2025 phase-out target for passenger ICEVs would be enshrined into law. The law stipulates the target of only selling zero-emissions vehicles, but there is no formalised interdiction for sellers to do so.

4.5.2 The 2025 ICEV phase-out target

Description of the policy

The Norway National Transport Plan 2018-2029, released in 2017, provided a comprehensive plan to achieve the overall objective of creating "a transport system that is safe, enhances value creation, and contributes to a low-carbon society" (Norwegian Ministry of Transport and Communications, 2017). The main climate and environmental objective of the plan was for decarbonising the country's transport sector, in line with its previous target of reducing greenhouse gas emissions by 40% by 2030, relative to 1990 levels (Norwegian Ministry of Transport and Communications, 2017). The document is the main strategic instrument and politically agreed roadmap for Norway's transport sector.

The plan sets out that, by the end of 2025, all new cars, city buses, and light vans sold in Norway shall be zero-emissions vehicles. The policy applies to EVs (BEVs), hybrids (PHEVs), as well as hydrogen vehicles. Between target announcement and when the date is set to pass, eight years are provided for the transition. By 2030, the plan also states that all new heavy-duty vehicles, 75% of long-distance buses, and 50% of new lorries shall be zero-emissions (Norwegian Ministry of Transport and Communications, 2017). The phase-out targets have not yet been enshrined into law. Within the plan, NOK 16.6 billion (EUR 1.7 billion) has been set aside for tax and other EV incentives over the 12 year period (Kristensen et al., 2018).

Acceptance of policy from public and industry

Although Norway's political landscape has changed over the decades, since the early 1990s there has been a strong and bipartisan support for environmental issues in Norway within the Norwegian parliament and the Norwegian people, which has aided the ICE phase-out (Kristensen et al., 2018). The transition to EVs is not just premised on environmental objectives. In a survey conducted in 2017, 41% of respondents said that their primary reason for buying an EV was "to save money" (Lorentzen et al., 2017). This highlights the importance of reducing the costs for EVs relative to ICEVs before any policy announcement, to ensure that public acceptance is high enough.

Several reservations were expressed by the Norwegian public when the agreement was reached, as the setting of the target was a top-down process, with no formal public consultation. The number of reservations made increased because the agreed 2025 target was, and is still, very often interpreted by popular media outlets as a ban. Government spokespeople have tried to correct any false claims, but it is still misreported in the media (Zeniewski, 2017). This highlights the limitations of only setting the target, rather than legislating the policy, and of burying the target in long-term transport plans, rather than being displayed on its own page on the government's website.

Furthermore, concerns were raised over driving ranges, transition costs, affordability, and job losses from the Norwegian automotive industry (Petro, 2016). The government improved affordability by taxing heavily the purchase of new ICEVs, targeting those buying new cars rather than from the secondary market, where most purchases are made. The domestic automotive production industry had already collapsed and, as a result, had little influence in blocking the phase-out strategy.

Municipalities were facing difficulties and voiced their concerns about revenue shortfalls resulting from 'free-riding' BEVs that did not pay for road or ferry tolls. In response, the National Transport Plan 2018-2029, included proposals to reinstate toll fees for EVs at a reduced rate (Zeniewski, 2017). It has also been suggested that EV access to bus lanes should become conditional on local traffic developments.

There have also been perceptions that the incentives are regressive, benefitting wealthier classes of society, as luxury models from automakers such as Tesla and BMW increase in the market share (Zeniewski, 2017). On the other hand, taxing larger vehicles more, and targeting the purchase of ICEVs has been received well by the public. Public acceptance was further improved by well-known leaders and celebrities promoting the policy (Interview 1). As an example, Norway's crown prince Haakonn supported the policy and was a royal advocate for electrifying transport (Kireeva & Digges, 2019). For a country with such a large domestic oil industry, there was surprisingly little pushback against the announcement of a 2025 ICEV phase-out. Several things account for this, the first of which is the fact that Norway consumes only about 10% of the oil it produces, the rest is either stored in a reserve or exported internationally (British Petroleum, 2022; Worldometer, 2022).

The Norwegian Electric Vehicle Association (NEVA), an industry association, has played a significant role in improving acceptance and influencing Norway's EV policy. The association works to ensure that the 2025 target can be achieved through advocacy work, knowledge sharing, and direct lobbying with government. For example, in 2021, NEVA has held 18 meetings at national level, responded to 11 public hearings, and participated in five parliamentary hearings (NEVA, 2021a). NEVA also organised a debate on how Norway can achieve the 2025 goal, and on how to make charging accessible throughout Norway.

4.5.3 Policy evaluation

The EV transition in Norway is advancing at a rapid rate, with EV shares in total car sales rising from 3% in 2012, to 86% in 2021 (NEVA, 2021b). Much of this rise has been facilitated through global EV market developments and cost reductions. In addition, Norway's bonus-malus system of providing incentives for EVs and by taxing ICEVs heavily has had a huge impact on making EVs more economical over their lifetimes. Furthermore, Norway's ICEV policies appear to be having a domino effect across the automotive industry, as many firms have announced revised targets and strive to move ahead of the curve. For example, recently, the CEO of Harald A. Møller (the importer of Volkwagen vehicles into Norway) announced that the company will not import Volkswagen ICEVs after the beginning of 2024 (Hanley, 2022). This is noteworthy as Volkswagen is Norway's best-selling car brand (Statista, 2022).

Value of Economic Incentives

The retail price of EVs is now, in many cases, cheaper than their ICEV equivalents, after accounting for added taxes placed on ICEVs. When a vehicle is imported to Norway it is not just the 25% VAT which must be paid, but also a scrap deposit tax, a greenhouse gas tax, and a one-off registration tax. For example, NEVA compared the price in the first year of purchasing a Volkswagen e-Golf to its ICEV equivalent Volkswagen Golf, accounting for taxation, to find that the e-Golf was almost EUR 1000 cheaper (NEVA, 2022).

Table 4.7: First year cost comparison of Volkswagen Golf and Volkswagen e-Golf after accounting for taxation.

	Volkswagen Golf	Volkswagen e-Golf
Import price	22,046	33,037
Carbon tax (113 g/km)	4348	-
NOx tax	206	-
Weight tax	1715	-
Scrapping fee	249	249
25% VAT	5512	-
Retail price	34,076	33,286

Source: NEVA (2022)[18].

The calculations displayed in **Table 4.7** do not even consider the lifetime cost savings of an EV from reducing energy use by substituting to electricity and through free parking initiatives,

[18] Values expressed in Euros

as well as reductions on ferries and road tolls. In terms of running costs, VAT has remained constant at 25% of wholesale diesel and petrol costs. Carbon taxes have risen annually from 2018 to 2022. Excise taxes have fluctuated for both fuels but have declined on average. However, the combined equivalent carbon tax has been growing, and is nearly triple the level of the carbon tax alone. For diesel, this is worth NOK 2094/tCO_2e (EUR 209/tCO_2e) in 2022, and for petrol, NOK 2939/tCO_2e (EUR 293/tCO_2e).

Table 4.8: Carbon taxes and excise taxes on diesel in Norway from 2018 to 2022

Year	Carbon tax (NOK/l)	Carbon tax (NOK/tCO_2e)	Excise tax (NOK/l)	Excise tax (NOK/ tCO_2e)	Combined tax (NOK/l)	Combined equivalent carbon tax (NOK/tCO_2e)
2018	1.33	500	3.75	1410	5.08	1910
2019	1.35	508	3.81	1432	5.16	1940
2020	1.45	545	3.62	1361	5.07	1906
2021	1.58	594	3.58	1346	5.16	1940
2022	2.05	771	3.52	1323	5.57	2094

Source: Government of Norway (2022).

Table 4.9: Carbon taxes and excise taxes for petrol in Norway from 2018 to 2022

Year	Carbon tax (NOK/l)	Carbon tax (NOK/tCO_2e)	Excise tax (NOK/l)	Excise tax (NOK/ tCO_2e)	Combined tax (NOK/l)	Combined equivalent carbon tax (NOK/tCO_2e)
2018	1.16	507	5.17	2258	6.33	2764
2019	1.18	515	5.25	2293	6.43	2808
2020	1.26	550	4.91	2144	6.17	2694
2021	1.37	598	5.01	2188	6.38	2786
2022	1.78	777	4.95	2162	6.73	2939

Source: Government of Norway (2022).

When filling up a small car with a 50-litre tank, the equivalent carbon costs from these two taxes equate to NOK 279 (EUR 27.9) for diesel, and NOK 319 (EUR 31.9) for petrol. This represents 33% of total prices for diesel (NOK 17.54/l (EUR 1.75/l)) and 34% of total fuel prices for petrol (NOK 18.64/l (EUR 1.86/l)) (Statistics Norway, 2022b). To refill a 50-litre tank, it therefore costs NOK 877 (EUR 87.7) for diesel, and NOK 932 (EUR 93.2) for petrol.

If the average 50-litre tank of fuel provides 625 km, and if the average EV requires 30 kWh to travel 100 km, then an EV requires 187.5 kWh of electricity, which costs 187.5 x 0.803 = NOK 151 (EUR 15.1) (Statistics Norway, 2022a). A typical EV therefore has running costs roughly four times lower than an ICEV.

However, even if running costs are low due to taxes, rebates on charges (road tolls, ferries, parking etc), and low electricity prices, there is still the high investment at the beginning, which is a barrier for low-income households. The upfront investment of an EV is still, in many cases, greater than an ICEV, but low running costs and other incentives make EVs the logical investment decision. A comprehensive study on the cost of ownership, comparing EVs and ICEVs, was carried out by Figenbaum (2022), and estimated that BEVs became economic in 2012, when the total cost of ownership of an EV was already lower than for three-year old gasoline vehicles.

Enabling conditions

Several conditions enabled the current successful trajectory of the transition away from ICEVs to EVs by 2025. Norway has benefitted from access to cheap and abundant renewable energy sources, as well as revenues from fossil fuel exports, which have both contributed to making EVs the more advantageous choice for buying a new passenger vehicle.

Norway's bonus-malus system for vehicles has been the cornerstone of the government's approach to the ICEV phase-out and is the most important enabler of the 2025 goal, providing incentives for EVs and disincentives for ICEVs. EV tax exemptions in 2017 were worth NOK 100,000 (EUR 10,000) per car on average (Kristensen et al., 2018). EVs are exempt from most taxes (apart from a 20% electricity tax) which has significantly improved the relative economics against ICEVs (IEA, 2022b). For example, one study found that the price of carbon characterising the trade-off between ICEVs and BEVs in Norway exceeds EUR 1370 per tonne of CO_2 — several orders of magnitude higher than current or previous EU ETS prices (Fridstrøm, 2021).

Another crucial element of the government's taxation design was targeting the purchase of ICEVs, rather than targeting oil prices at the pump. This is a less regressive means of implementing climate policy as it is aimed at those buying a new car, rather than indiscriminate taxes on users refilling their vehicles. Furthermore, taxation for ICEVs is structured progressively, meaning that larger ICEVs, which produce more emissions, are taxed more heavily (NEVA, 2022). Taxing new and larger ICEVs will affect the wealthier consumers greater but will also create less resistance to the phase-out policy from low-income households if taxes are reduced for second-hand vehicles and petrol prices. On the other hand, the incentives have placed a huge burden on public finances and spending on transport infrastructure. The 2017 National Budget calculated that the VAT exemption for EVs reduced the average per-vehicle tax take by around NOK 15,000 (EUR 1500), amounting to forgone tax receipts of NOK 2.75 billion (EUR 257 million) in 2017 (Government of Norway, 2017). Furthermore, the incentives laid out in the transition were not all planned far in advance and were, in large parts, down to the approach of trial and error (Interview 1). There was very little communication between ministries when setting the policy instruments required to achieve the 2025 target (Interview 1). It would be beneficial to have more coordination with other ministries or sectors to ensure that the grid can manage increased electrification from the transition.

Behavioural incentives have also played a key role in the Norway vehicle transition, by using discounts and exemptions from ferries, road tolls, and parking fees, but most significantly access to bus lanes, which, after the announcement in 2005, resulted in an explosion in demand (Kristensen et al., 2018). It is important to get consumers on board such that EVs are made the most economical, and the most convenient, choice.

Consistent lobbying from NEVA and other stakeholders to maintain VAT exemptions for EVs (NEVA, 2021a). NEVA's advocacy work has resulted in the continuation and strengthening of Norway's EV policy, particularly VAT as the largest tax component on EV purchase. Together with Enova and an ever-expanding host of BEV owners, a strong lobby has been created against any rollbacks in state support for EVs (Zeniewski, 2017). However, while the incentives implemented in Norway have been successful in encouraging EV adoption, they may also contradict Norway's wider goal that future growth in travel demand should be absorbed by public transport, cycling, or walking rather than private vehicle ownership.

The final enabling factors have been the external global market developments and technological improvements, that have helped to produce a competitive EV market — with broader choice, lower cost, and more convenient vehicles available on the market. Most major car manufacturers now produce at least one line of EVs, and several have declared their intention to become fully electric. External influences have shaped the ICEV phase-out in Norway, such as cost reductions in EV production in other countries. However, one negative aspect of Norway's transport strategy is that it has not managed to develop a domestic EV production sector. This outcome has contributed to the growth of foreign manufacturers, who benefit from the tax incentives funded by Norway (Kristensen et al., 2018).

Box 4.4 Impacts of the policy on investment

The Norwegian experience demonstrates how to use taxation incentives to leverage private investment — through tax breaks for EVs and by heavily taxing ICEVs. After accounting for VAT and registration taxes, the upfront costs of EVs are now very similar to the costs of their ICEV equivalents. The VAT exemption (25%) for an EV purchase represents the largest tax component that has made EVs cost competitive to ICEVs. Furthermore, in terms of running costs, the taxation through VAT, carbon tax, and excise tax on petrol and diesel, represent over half of ICEV fuel prices (58% and 59% respectively). As a result, a typical EV has running costs roughly four times lower than that of an ICEV. Norway successfully made EVs the economical option to purchase for consumers in most cases. A study earlier this year found that, after comparing different models, the total cost of ownership for EVs in Norway was lower than ICEVs in 85% of cases (LeasePlan, 2022). Reducing the costs of the low-carbon alternative is paramount for ensuring that consumers invest in the switch. This statement is reinforced by a public opinion survey, where 41% of respondents felt that their primary reason for buying an EV was "to save money" (Lorentzen et al., 2017).

4.5.4 Discussion

While several countries have announced a phase-out timeline for ICEVs, the transition in Norway is more advanced than in any other country. The first policy mechanisms, infrastructure programmes and financial incentives, put in place to encourage rapid growth of the EV sector have allowed for the setting of an ambitious 2025 target for the phase-out of ICEVs — and trends suggest that even this target is likely to be achieved early. The setting of the phase-out target in this case is not the strongest driver to explain the current sales trends, but it helps to ensure that the necessary incentives are designed and implemented in due course. Furthermore, without any accompanying policies, the target would not be credible and would therefore be insufficient to redirect finance to the extent necessary.

Possibly the most important aspect of the policy package has been the bonus-malus scheme to improve the relative prices of EVs to ICEVs. The Norway example also provides a best practice example of how to improve public acceptance for the policy through progressive taxation – by taxing larger (heavier) ICEVs that produce more emissions, but also targeting the purchase of new ICEVs through the registration tax, rather than applying these taxes to oil prices at the pump. These are both examples of less regressive means of implementing climate policy, as they affect wealthier consumers the greatest.

Furthermore, behavioural incentives played a key role in enabling the phase-out policy, most notably through the provision of bus lanes for EV drivers since 2005, but also through reductions in both parking and ferry charges as well as road tolls. Lastly, Cooperation between NEVA and other stakeholders resulted in a strong pushback to any rollbacks in state support for EVs — most notably to maintain VAT exemptions for EVs.

Norway provides a successful example of how to implement a bonus-malus system with progressive elements, and on how to combine these incentives with a long-term phase-out target that provides certainty and enables better planning on the design of the required policies for transitioning from ICEVs to EVs.

4.6 Lessons for the European Union

The three case studies of policy-driven heating and transport phase-outs in Norway and Vancouver provide several lessons that the EU can learn from. While Norwegian policy is suited to function within its specific context, the broad strokes of the heating and transport phase-outs can provide insights for other countries, especially within the EU, that share many environmental and climate regulations. The heating transition in Vancouver is still ongoing, but the case nevertheless highlights the accompanying policies and conditions which enabled the implementation of its phase-out policy at the start of 2022 – providing relevance for EU countries that are considering implementation of related policies.

The experiences from all three phase-outs reveal that to gather sufficient support for implementing and achieving phase-out timelines, it is crucial that adoption of the new, immature technology is made economically attractive. Through both penalising the fossil-based technology and incentivising the cleaner alternative, Norway and Vancouver used a mix of taxation incentives and subsidies to encourage adoption of heat pumps and EVs. In the EU context, it raises the importance of aligning energy taxation and carbon prices with EU climate goals — but also underlines that sticks alone will only do half the job, as the rest needs to be done carrots, such as subsidies to accelerate the deployment of alternatives.

Even if the total cost of ownership is lower, heat pumps and EVs often have greater upfront capital costs than their fossil-based counterparts, despite having lower running costs. It is crucial that low-income households can finance the upfront costs involved with immature technologies, particularly if the transition is at an earlier stage, as in the EU case. The Vancouver experience, while far from perfect, provides lessons on how to improve public acceptance and deal with these upfront costs by redistributing revenues from carbon taxation and by providing zero-interest loans for building retrofits.

Another lesson from the experiences in Norway and Vancouver is that to phase out fossil-fuel-based technologies and value chains, information campaigns should lead different actors to collaborate — government, civil society, industry, households, and education. It is important that these collaborations are long term, helping to send a coherent message using a multitude of communication channels. In the cases studied, information campaigns were crucial for overcoming behavioural barriers and encouraging change to unfamiliar technologies.

Both Norway and Vancouver have made great progress transitioning away from fossil-based heating and transport, despite being tied to domestic fossil fuel industries – as are many EU countries. The Vancouver example highlights that when proposing a phase-out policy, significant compromises often need to be made with the incumbent industry to ensure policy implementation. However, it is important that by compromising (on the use of performance standards rather than an outright ban), that it does not significantly impact the signal being sent to households on which heating technology to install, or place at risk the jurisdiction's ability to meet its climate ambitions. It may therefore be beneficial to perform an impact assessment to ensure that these compromises are aligned with ambitions and that they do not incur significantly greater transition costs.

The case studies also raise important governance issues that are relevant for implementing phase-out policies in the EU. The problem is that decisions are often taken at the EU or national levels but need to be implemented at the local level. Coordination and ensuring that the local level has the human and financial resources available to implement national decisions is key.

A final lesson from the experiences in both Norway and Vancouver is that plans for phasing out fossil fuels should be announced as early as possible, as this long-term clarity helps to ensure that the enabling conditions are set (with the necessary accompanying policies) well before the target date. The best practices analysed in this archetype demonstrate that, once these conditions are in place, change can happen relatively quickly — and even more rapidly than expected.

4.7 Conclusion

The Russian attack on Ukraine and the resulting turmoil in energy markets has revealed the extent of the EU's dependence on imported fossil fuels, its implications, and the benefits of eliminating these fuels. This situation sheds light on the need to deliberately phase out the EU's fossil-intensive systems to reduce this reliance. Buildings and transport are at the centre of this challenge. Norway and Vancouver, Canada have made great progress in decarbonising these sectors, which is why they have been selected for analysis in this report.

Norway has successfully phased out the use of oil for heating in existing buildings since 2020. In this way, Norway has managed to close one chapter in the transformation to climate neutrality, which most other European countries have only begun to address. The case study provides useful insights on how to leverage private investment through tax and subsidy design, on the need for building up installation capacities through reskilling and upskilling, and on the importance of information campaigns to drive behavioural change. Norway's long announcement times and sequential order of its heating phase-out policies helped existing systems run until their natural end of life, reducing the number of supply bottlenecks occurring with heat pump installations. However, it is debatable to what extent the EU can replicate this approach, given the increased urgency to wean itself off fossil gas imports, and the need for drastic emission cuts.

The phase-out process for fossil fuel heating in Vancouver is still ongoing and because the ban only took effect at the start of this year (2022), there is still insufficient evidence to evaluate the level of success of the policy. However, the case study provides insights on how to ensure the political support is available for implementing stringent phase-out policies, by providing financial incentives and zero-interest loans to deal with high upfront costs, and by redistributing carbon tax revenues back to low- and middle-income households. Furthermore, the Vancouver experience provides lessons on how to upscale skills creation programs by partnering with universities.

The Norwegian ICEV phase-out provides a successful example of how to implement a bonus-malus system with progressive elements, and to combine these incentives and penalties with a long-term phase-out target. This provides the certainty necessary for designing, planning and implementing the required policies for achieving the 2025 goal. However, there are limitations on the replicability of some key policy levers identified in this case study to the EU context, including changes to vehicle taxation. Nevertheless, the example provides useful lessons on how to disincentivise ICEVs without penalising low-income households as strongly – by taxing heavier ICEVs that produce more emissions, and by targeting the purchase of new ICEVs - where both approaches affect wealthier consumers the greatest.

The experiences across the different best practices show that the successful roll-out of a new technology is not only a matter of creating economic incentives and providing a total cost of ownership advantage, but requires a whole array of supporting interventions — building up the domestic (installation) industry and skill base, rolling out the needed (charging) infrastructure, and ensuring the support is there for the policy to be implemented.

The case studies and findings presented in this report warrant some caution and highlight areas for future research. First, whilst there are several qualitative benefits that can be explained by the setting of phase-out timelines and the accompanying policy packages, the study was limited in its ability to measure the impacts of policy implementation at the quantitative level. Both the heating and transport transitions are complex and irreducible to a single cause. Future research would benefit from econometric or energy-economy modelling approaches to measure the causal effects of the phase-out policies on the jurisdictions being studied.

Lastly, the Norwegian case studies provide limited insights on how to deal with the incumbent fossil fuel industry. In these cases, the fossil fuel industry being focused on export was only marginally impacted by the phase-out - the problem was not addressed, but only transferred to other countries. This is a key limitation of what we can learn from this example. Future research could investigate how the fossil fuel industry can become more serious about decarbonisation, by looking at methods of transitioning the industry to generating solely non-fossil-based income.

List of Interviews

Norway heating phase-out

Interview 1, Trygve Mellvang Tomren-Berg, Managing Director, Norwegian District Heating Association (Norsk Fjernvarme). 28/06/2022, via videocall

Interview 2, Marit Hepsø, Policy Officer, Norwegian Environment Agency, 30/06/2022, via phonecall

Interview 3, Rolf Iver Mytting Hagemoen, Secretary General, Norwegian Heat Pump Association (NOVAP), 01/08/2022, via videocall

Vancouver heating phase-out

Interview 1, Patrick Enright, Senior Green Building Engineer, Sustainability Group, Planning, Urban Design, and Sustainability, City of Vancouver, 28/06/2022, via videocall

Interview 2, Doug Smith, Director, Sustainability Group, Planning, Urban Design, and Sustainability, City of Vancouver, 14/07/2022, via videocall

Interview 3, Tyler Bryant, Public Policy Manager, FortisBC, 16/09/2022, via phone call

Norway transport phase-out

Interview 1, Sture Portvik, Project Leader, Oslo Municipality's electric vehicle initiative, Agency for Urban Environment, City of Oslo, 30/06/2022, via videocall

Interview 2, Erik Lorentzen, Head of Analysis and Advisory Services, Norwegian Electric Vehicle Association (NEVA), 03/08/2022, via videocall

5. Archetype 4: Driving storage

5.1 Introduction

The share of renewables in electricity generation will rise exponentially in the coming decades, with wind and solar photovoltaics (PV) expected to become the dominant electricity sources (IEA, 2022c). Despite the myriad benefits that come with decarbonising the energy sector, such a transition also brings challenges. More specifically, imbalances exist between supply and demand. Such imbalances are known as variabilities, whereby there tends to be an oversupply of energy when the sun shines or the wind blows, and a shortage when the sun sets or there is no wind. Solving this variability problem, then, is critical to ensuring a consistent supply of energy in a carbon-free grid.

Energy Storage Systems (ESSs) have emerged as being effective in bridging gaps between supply and demand. An ESS can store energy for later use, meaning that energy produced by the sun or wind can be stored until it is needed to be consumed. ESSs can come in a variety of forms, though the most popular technology is lithium-ion batteries (LiB). As has been the case with wind and solar technologies, a LiB ESS has seen a dramatic drop in costs, reporting an 85% decrease between 2010 and 2019 (IPCC, 2022). This is due in part to the electric vehicle industry, which has promoted manufacturing economies of scale, as well as government support for the clean-energy transition, which has guaranteed demand for ESSs and driven innovation (Deloitte Center for Energy Solutions, 2018).

As a LiB ESS can discharge at full power for between four and six hours, it is well suited to managing the daily fluctuations associated with wind and solar energy. Storage systems are displacing fossil fuels — for example, on days with insufficient wind and sun, fossil gas peakers would have been the obvious choice to stabilise the power system (Argonne National Laboratory, 2021). There is a range of emerging technologies in this regard, including (but not limited to) pumped hydro, flywheel, liquid air, and compressed air. In order to fully decarbonise the energy sector and ensure consistent access to power for consumers, a combination of short and long-term ESSs is needed to resolve renewable variabilities.

Various factors dictate which storage technology is favoured. For instance, round-trip efficiency (the percentage of electricity put into storage that can later be used), and the lifespan of a technology before it needs to be replaced, offer more value and are thus important aspects when deciding which technology is used (Ruby, 2018). Technological developments and associated price decreases, combined with increased volatility of electricity prices due to the variability of production, will inevitably accelerate deployment of ESSs into both national and regional grids. The role of policy, however, is just as important in developing these technologies. Just as tax credits for renewable energy sources helped to decrease costs (ibid), economic incentives and government mandates can provide market certainty and stimulate growth.

Alongside managing variabilities, ESSs can assist the grid in other ways. They can improve resiliency by acting as a source of emergency backup power, particularly in the aftermath of events such as storms (Al Shaqsi et al., 2020). The ability of ESSs to load shift, i.e., move electricity consumption from one time to another, can reduce demand at peak times. This has multiple benefits, including less need for reserve capacity, improved efficiency, and significant cost savings for end users due to different costs of electricity between peak and off-peak periods (Märkle-Huß et al., 2018). ESSs can improve the economic value of renewable energy by storing surplus power to participate in the energy trading market and through substituting the need to upgrade old distribution and substation facilities (Jo & Jang, 2019). ESSs are also used to adjust the power frequency, which is essential to maintaining high-quality power. If the amount of electricity being used is not matched by generation, the frequency of electricity can be affected (World Bank, 2021; You et al., 2019).

Considering the European Union's (EU's) commitment to reduce its emissions by at least 55% below 1990 levels by 2030 and reach carbon neutrality by 2050, decarbonising the power grid will play an essential part of meeting these targets. The EU already intends to increase the share of renewables in the overall energy mix to 40% by 2030, and a proposal to increase this target to 45% by 2030 has recently been announced (European Commission, 2022f). This translates to a 69% share of renewables in the electricity sector by 2030.

Such an increase in the deployment of renewables will also require an increase in ESSs. The Commission recognises the importance of storage to the clean-energy transition, labelling batteries a strategic value chain which requires increased investment and innovation (European Commission, 2022a). Yet the EU has been slower than countries such as the US and China in terms of scaling up storage capacity. In 2021, the EU had a similar level of installed storage capacity as a single US state, i.e., California, despite the Union's population being 11 times larger (Taylor, 2022). If storage is indeed deemed a strategic value chain, a ratcheting up of both effort and capacity will be needed.

In order to assess the most effective way to procure storage and to maintain a stable and efficient energy supply to European consumers, this chapter will analyse the storage procurement mandate in California and the Renewable Energy Certificate in South Korea. Both California and South Korea have achieved considerable success in terms of increasing their ESS capacity, providing valuable learning lessons for the European effort in achieving its renewable energy goals.

The case studies presented here are based on desk-research and expert interviews. We identified important explanatory factors with the help of grey literature and academic publications. In addition, we analysed official policy documents as well as media reports.

These helped to identify the relevant actors, institutions, policies, and processes. We conducted an interview with two South Korean energy storage experts and an energy expert from California. The collected information was presented and discussed in a workshop with European stakeholders. The collected information was then used to develop a comprehensive narrative that describes and explains California's procurement mandate and South Korea's RECs. Based on the case studies and expert interviews, general lessons for the EU were then drawn.

The report proceeds as follows. The next section (Section 5.2) discusses the importance of increasing storage capacity in the EU. Section 5.3 presents the case study of California's storage procurement mandate. Section 5.4 presents the case study of South Korea's Renewable Energy Certificates. Section 5.5 draws learning lessons for EU policy-making based on these case studies, while the final section concludes.

5.2 Why consider procurement mandates and Renewable Energy Certificates?

It is hard to overstate the importance of energy storage to the EU's clean-energy transition. Its ability to better integrate renewables onto the grid by smoothing supply and demand imbalances will be critical to ensuring a consistent supply of electricity to European consumers. At the same time, its capacity to improve grid resiliency and flexibility, load shift, and adjust power frequency carries an array of benefits for the grid and end users.

Gas peaker plants are the main alternative of storage to balance renewable variabilities. These are polluting and stand as an obstacle to the EU meeting its GHG reduction targets. As the recent energy crisis has shown, reliance on gas also represents a strategic threat to European energy security. Yet the RePowerEU plan still relies on gas into the medium term, with a particular emphasis on gas peaker plants to stabilise the grid (European Commission, 2022i). This is despite a core aim of the plan being to reduce the reliance on Russian gas at the same time as renewables are currently being curtailed, i.e., when output is reduced during periods of oversupply (Clerens, as in Colthorpe, 2022b). If gas peaker plants are to remain, future generations of this technology may be fuelled by hydrogen, as they may still be needed to operate side by side with ESS.

The EU's relatively slow uptake of ESSs stands in contrast with its swifter deployment of renewables, which accounted for 37% of electricity consumption in 2020 (Eurostat, 2022f). This has begun to change, with the rate of storage installations experiencing significant year-on-year growth (Darmani, 2022). However, far more needs to be done. Modelling carried out by the European Association for Storage of Energy (EASE) forecasts a need for up to 200 GW of storage by 2030 to integrate the renewable targets that the EU plans to achieve (EASE, 2022). This would entail the installation of 14 GW of storage per year until 2030, a huge increase on the historical deployment of 1 GW per year. Wood Mackenzie forecasts the European market for energy storage to grow considerably by the end of the decade as investor confidence increases, especially due to decreases in cost. However, this growth is hampered by challenges around valuing storage and the absence of a coherent storage strategy (Clerens, as in Colthorpe, 2022b; Darmani, 2022). Furthermore, some legislative barriers may also exist at member state level, for example, linked to taxation and restrictions due to contracts as is the case in the Netherlands. Just as a clear strategy has enabled the growth of renewables in the EU's power system, there is also a need to develop a comprehensive storage strategy. Such a strategy will inevitably need to be integrated with the EU's renewable energy strategy, as the success of renewables depends on a corresponding increase in storage capacity.

The case studies of California and South Korea present different examples of strong policy intervention designed to increase storage capacity. While California initiated mandated targets for utilities, South Korea developed financial incentives that successfully stimulated growth in the storage market. Neither policy existed in a vacuum, with other areas of each respective regulatory environment contributing to the success of the two case studies. As EU policy-makers work towards integrating more and more variable renewables onto the grid, creating a framework which allows the storage market to grow in line with the growing share of renewables is crucial.

Box 5.1. Why is storage relevant for Infrastructure and Integration?

Storage development determines the way in which a high share of variable renewables will be integrated into the electricity grid. It can also facilitate better integration between different sectors.

Five main ways of integrating variable renewables can be identified: (1) grid development, especially between regions with different wind conditions and solar radiation, (2) demand management, adapting demand to variable supply, (3) taking advantage of the flexibility offered by other renewables, especially hydroenergy and bioenergy, (4) storage in different forms and timescales, (5) hydrogen as a replacement to natural gas. The balance between the utilisation of these options depends on the specific geographic, technology, and economics, as well as social acceptance. Increasing the role of storage will reduce the need for investments for other ways of balancing the grid. While itself part of the infrastructure, storage also reduced the need for other infrastructural projects, especially grid or the need to build peaking power plants.

Sectoral integration may often require storage to better integrate high shares of renewable energy sources. Electricity needed for heating in the evening and at night-time can be stored from the periods of high solar radiation. Storage can also facilitate electrification of the car fleet by storing electricity from high solar/wind periods until there is a need and possibility to recharge the vehicle.

5.3 Case study 1: Storage procurement mandate (California)

California's venture into energy storage has led it to develop the most successful framework for energy storage procurement in the US, thus warranting investigation into their experience. The case study presented here starts with Section 5.3.1, on the background to the situation faced in California around the need for storage to accommodate the expansion of renewable energy generation, and ultimately the development of legislation AB 2514 to promote and incorporate energy storage into the grid. Section 5.3.2 explains further the mandate set in California through this bill and other means for energy storage and how the sector started developing, while section 5.3.3 details the implementation of AB 2514 and the impacts it has had. Section 5.3.4 outlines the updates to the legislation following the AB 2514 bill at state and federal level. Section 5.3.5 briefly evaluates the effectiveness of California's efforts in energy storage procurement. Lastly, Section 5.3.6 offers a discussion of the lessons learnt from California's experience with energy storage.

5.3.1 Context and background

As a global leader in clean energy, California has set a target of generating 73% of its electricity from renewables by 2032 (Decision Adopting 2021 Preferred System Plan, 2021). This target, in conjunction with the state's Renewables Portfolio Standard (RPS), provides certainty to investors and has led to an exponential growth in the share of renewables in the mix. California's total electricity mix in 2021 accounted for a share of 14.2%[19] from solar, and 11.4% from wind; however, a considerable amount of wind energy is imported from nearby states (California Energy Commission, 2022a). Such a high proportion of renewables places California among the leading states in the US in terms of total renewable electricity generation, second only to Texas (U.S. Energy Information Administration, 2022a).

After a series of rolling blackouts hit California in 2000 and 2001, there was widespread anger at the state government's perceived failure to keep the power on. The electricity crisis motivated the Californian government to establish the RPS in 2002, which initially required California to generate 20% of its electricity from renewables by no later than 2017. There

[19] Reporting requirements are limited to facilities with a capacity of 1 MW or higher. Most residential and commercial solar PV installations are below 1 MW, meaning that the share of solar PV is higher than the figure reported by the California Energy Commission.

have since been numerous updates to the initial RPS target, with the most recent one, SB 100, increasing the RPS to 60% by 2030 (SB 100, 2018). The RPS has contributed to a significant drop in electricity sector emissions. In 2019, only 14% of California's emissions came from the electricity sector (California Air Resources Board, 2022b), whereas nationwide, the electricity sector accounted for 25% of emissions (U.S. Environmental Protection Agency, 2021). To avoid shifting emissions to other states, Senate Bill (SB) 100 requires that the achievement of emissions reductions in California does not increase carbon emissions elsewhere in the western grid (SB 100, 2018). In this way, the bill forbids California from reporting lower emissions simply by importing carbon-intensive energy from nearby states.

Although solar and wind accounted for 96% of renewable growth between 2007 and 2017 (56% and 40%, respectively) (Strategen, 2020), hydroelectric power remains an essential component of the grid. Together, these three sources are expected to form the backbone of California's future carbon-free grid. Though both are seasonal, the state has strong potential for both wind and solar. Solar production is maximised during the summer months while maximum wind output occurs in the second and third quarters of the year (Wärtsilä Energy, 2020).

Californian hydropower is dependent on weather patterns. The state is prone to droughts, and extended periods without rainfall can decrease production and cause hydro plants to shut down. While droughts are nothing new to California, their length and severity are worsening due to climate change. This was demonstrated by the ceasing of hydroelectric generation from the Edward Hyatt Power Plant at Lake Oroville in 2021, the first time this occurred since its construction in 1967 (Tarroja, 2021). When hydroelectric generation needs to stop because of droughts exacerbated by climate change, Californian utilities compensate for the loss by burning fossil gas, thus emitting more CO_2. During the 2011 to 2017 California drought, replacing hydroelectric generation with fossil gas caused a 33% increase in annual CO_2 emissions between 2012 and 2014 (Tarroja, 2021). The role of hydropower as a balancing source of electricity will further decrease as global warming worsens and droughts become more severe. This is not an issue for wind and solar, though their variable generation means that energy storage is essential in order to maximise their potential.

The need for more energy storage arose out of California's success in growing the share of renewables in its electricity mix. The increase in solar and wind capacity due to the RPS highlighted the need to manage renewable variability. In general, these variabilities were counterbalanced by ageing gas-fired peaker power plants, which were expensive, inefficient, and polluting (Mainzer, 2021). Indeed, utilities were spending billions of dollars to build new peaker plants that would only operate some hours per year to avoid blackouts during large spikes in demand. Energy storage was thus proposed as a cost-effective and environmental alternative to these peaker plants (Mainzer, 2021).

Storage advocates argued that, despite the technology being available, deployment was stalled by a lack of regulatory focus (Woody, 2010). Nancy Skinner, a member of the California State Assembly at the time, advocated for a policy framework that would encourage the development of energy storage in California. The proposed procurement mandate put forward called for setting targets to public utility companies for energy storage so as to facilitate the uptake and incorporation of renewable energy into the grid and provide market stability for investors. Although Skinner recognised the importance of procuring ESSs when she proposed a procurement mandate in 2010, managing variabilities was often framed as a future problem and a procurement mandate was much too extreme (Skinner, 2013).

Skinner initially only had limited support outside of energy storage companies and the Attorney General (and soon to be governor), Jerry Brown. The California Public Utilities Commission (CPUC), the state body in charge of regulating privately owned public utilities, opposed the idea of any storage mandate at the beginning, as did the utilities themselves. This scepticism began to subside, however, when Skinner was accompanied by utility executives, energy experts and legislators to several locations that had attempted to integrate renewables onto the grid. According to Skinner, experts at many of the sites they visited repeated a similar mantra, emphasising the necessity of storage for integrating renewables (Skinner, 2013).

As a result, the idea of developing a policy that prioritised the procurement of ESSs began to take hold. Although an ESS was viewed as an ideal solution, its use was considered out of reach due to high costs. Nevertheless, its potential benefits for the grid held the interest of energy experts and members of the Californian legislature. There were, however, signs that an energy storage market could be developed. Interest from investors and storage companies existed, signalling to legislators that, with the right policy framework, there was room for growth. (Skinner, 2013). As a result, a core motivation of Skinner and others who worked on drafting the procurement mandate was to send the right market signals. If the state was to move towards decarbonising its grid, providing explicit support for ESSs would create the space for the technology to be developed, allowing it to become more economically viable (Mainzer, 2021).

Numerous stakeholders who had initially opposed or been on the fence about energy storage legislation took a more proactive stance, including the CPUC. Despite the overt support of Nancy Skinner and Jerry Brown, both members of the Democratic Party, the bill did not get bogged down over partisan lines. At the time, Arnold Schwarzenegger, a Republican, was the governor of California. Known for reaching across the aisle (Ruby, 2018), Schwarzenegger in power provided an opening for bipartisan support that may not have been possible in many other US states, particularly given the increasing Republican hostility to the Obama presidency (Weiss, 2010). Similarly, the generally progressive leaning of Californian voters compared to other US states provided an opening for forward-thinking environmental legislation to be passed. For instance, opinion polls showed that most Californian citizens considered it very important for the state to be a world leader in fighting climate change and support policy efforts that address global warming (Baldassare et al., 2018).

The timing of the procurement mandate's first draft was also highly relevant to its content. Given that it was proposed in 2010, in the aftermath of the Great Recession, cost-effectiveness was central to any potential policy. During the recession, legislators were acutely aware that any bill must be economically justifiable. To that end, energy and environmental policies were seen as potentially effective ways to stimulate the economy. At the national level, the Obama administration viewed clean-energy legislation as a valuable means to stimulate economic recovery while hitting the policy goal of reducing emissions at the same time. Obama proposed the American Clean Energy and Security Act, which aimed to establish an emissions trading scheme like the one implemented in the European Union. This proposal faced stiff opposition from oil and coal companies, who invested heavily to block a clean-energy bill in the US Senate (Weiss, 2010). They ultimately succeeded, and the bill failed to pass the Senate.

Nancy Skinner's bill, known as Assembly Bill (AB) 2514, was proposed within this national context. In many ways, it mirrored President Obama's bill at the national level in terms of its emphasis on cost-effectiveness and economic stimulus. However, the progressive leaning of Californian politics and Governor Schwarzenegger's willingness to cooperate, provided fertile ground for such a bill to pass successfully. Indeed, California has consistently been a national leader in terms of passing environmental legislation, with a science-based approach guiding government policy (Barnes et al., 2021).

That is not to suggest, however, that AB 2514 faced no resistance. The California Manufacturers and Technology Association (CMTA) — a manufacturing industry lobbying group — remained committed to opposing the bill, even in its final form (AB 2514 Energy Storage Systems, 2010). This was in line with the CMTA's general opposition to environmental legislation, which it often portrayed as detrimental to the economy. Analysis of CMTA-sponsored studies has shown cherry-picked data, such as emphasising costs to carbon-intensive industry while ignoring impacts on clean products and services (Fine & Lee, 2012). However, other groups who opposed it at the start tended to drop their opposition once cost-effectiveness concerns were adequately addressed. Conversely, the Attorney General, energy storage and renewable energy companies, the California Energy Storage Alliance (CESA), and environmental groups effectively lobbied for the bill (Ruby, 2018).

AB 2514 was nested within a suite of energy initiatives intended to complement each other. Although California's emissions reductions and renewable targets have garnered greater media attention, the storage target represents a critical tool to successfully achieving these headline targets. Thus, AB 2514 was not created in a vacuum but was designed to complement these already existing policies. As mentioned previously, the existence of the

RPS drove the proposal of AB 2514 as a central need for storage to manage the variabilities arising from the growing share of renewables in the mix. Alongside the RPS, the AB 32 Global Warming Solutions Act of 2006 aimed to reduce emissions to 1990 levels by 2020. A range of other environmental policies also existed to cut emissions, such as the Low Carbon Fuel Standard. It was within this policy context that Nancy Skinner proposed the storage procurement mandate.

5.3.2 The early days of California's storage procurement mandate

AB 2514 became law in September 2010. The overarching goals of the legislation were to transform the storage market and to support the integration of the state's expanding portfolio of wind and solar resources as procured under the RPS, while achieving the mandated reduction in carbon emissions under AB 32. Storage was also expected to support general grid operations and assist long-term reliability requirements (Eichman et al., 2015).

However, policy-makers had stripped the bill of its more stringent measures by the time it was finalised. Initially, it had required the state's three big investor-owned utilities (IOUs) — Pacific Gas & Electric (PG&E), Southern California Edison (SCE), and San Diego Gas & Electric (SDG&E) — to procure ESSs capable of providing at least 2.25% of average peak electrical demand by 2014, rising to 5% by 2020 (Woody, 2010). This mandate was dropped to get the bill passed, with the compromise being that the CPUC could make the decisions regarding the appropriate ESS targets itself (Skinner, 2013). In essence, the bill's first iteration directed the CPUC to evaluate the feasibility of storage and determine suitable procurement targets, if any, for the state's electricity providers.

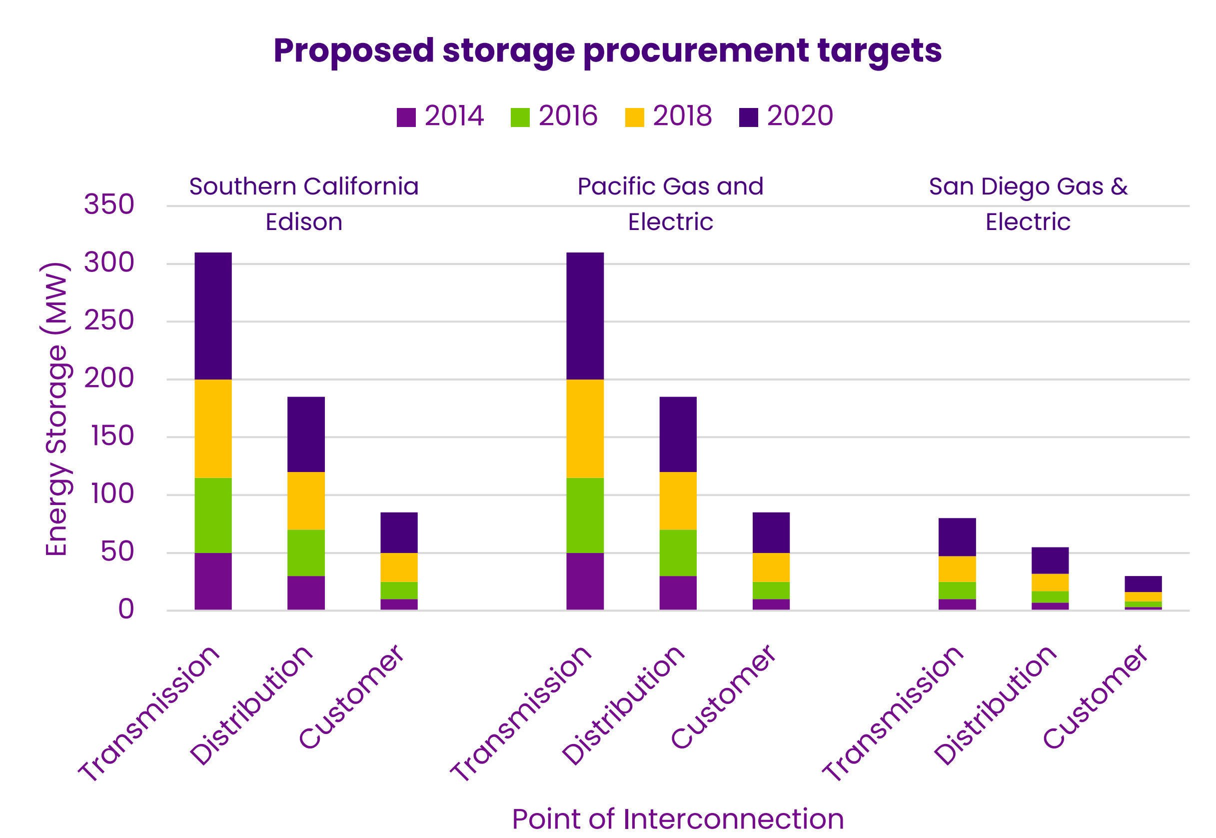
However, the concept of a target was never eliminated and remained an essential part of the bill going forward, even if there was no specific target set in stone with the passing of AB 2514. As far as the CPUC was concerned, the primary consideration was whether a procurement mandate was appropriate and, if so, how much should be procured (Skinner, 2013). There were also questions from the CPUC as to whether storage should be treated as a favoured/preferred resource, i.e., resources given preference due to their reliability and ability to reduce GHG emissions, to signal its benefits. Skinner argued that this should be the case due to its ability to help meet system needs and ancillary services, and ultimately to utilise generation capacity without adding extra capacity (Skinner, 2013). The CPUC agreed, designating storage as akin to a preferred resource when AB 2514 was eventually implemented (Decision Adopting Energy Storage Procurement Framework and Design Program, 2013).

Although the bill was only eight pages long, considerable care went into its drafting after engagement with a wide range of stakeholders, including representatives from renewable energy companies, the CPUC, utilities, national labs, consulting firms, and advocacy groups (Ruby, 2018). The flexibility of AB 2514 was a critical part of how it was drafted. Rather than committing to specific targets and narrowly prescribing the means to get there, such as the extent to which particular technologies should be used, the bill allowed affected parties more control over how they would meet the targets. This was an intentional aspect of the bill's design as Skinner considered that, while it is helpful for the legislature to push for goals or mandates, it should be for the appropriate bodies to evaluate the best way to get there. Bodies such as the CPUC can adjust their strategy more quickly than the legislature if the first approach proves to be suboptimal (Skinner, 2013).

As a result, the CPUC was directed to determine appropriate targets, if any, by March 1 2012, and if a target was deemed appropriate to then adopt it by October 1 2013. Moreover, it was obliged to re-evaluate its decisions every three years and update them accordingly (AB 2514 Energy Storage Systems, 2010). Between 2010 and 2013, the CPUC analysed the ESS market and the extent to which Californian utilities should be mandated to procure them. The first draft of its research, published in August 2012, disappointed many energy storage advocates as there was no recommendation for the adoption of a target. The lack of a target was a result of the CPUC not knowing the future needs of the grid or how to deal with cost recovery projects due to difficulties with storage valuation (Skinner, 2013). These issues were dealt with throughout a series of public workshops, as well as soliciting comments from stakeholders, which were incorporated into the CPUC's final decision (Stiftung Mercator, 2017).

After further evaluation and input from stakeholders, the CPUC published its programme in October 2013 (Decision Adopting Energy Storage Procurement Framework and Design Program, 2013). Unlike the first draft, this did contain a storage procurement target. The three IOUs that own 70% of the state's transmission system (the remaining 30% is owned by publicly owned utilities and other public agencies) (Higgins, 2014) were instructed to procure 1325 MW of energy storage by 2020, with installations to be completed by no later than the end of 2024 (Decision Adopting Energy Storage Procurement Framework and Design Program, 2013). The target was divided between transmission connected, distribution level, and customer-sited storage (Stiftung Mercator, 2017), as shown in **Figure 5.1**. The mandate was the first of its kind worldwide and, despite worries among storage advocates that the CPUC would not impose a procurement mandate on the utilities, the set target was instead quite ambitious.

Figure 5.1: Proposed energy storage procurement targets (in MW) across California.



Source: *Decision Adopting Energy Storage Procurement Framework and Design Program* (2013).

The mandate stated that the procurement of ESS projects was to be financed by the utilities, which resulted in resistance from the three large IOUs. SCE, for instance, warned that the targets were too aggressive, while SDG&E argued that the targets should be delayed as storage technology was still too immature (Decision Adopting Energy Storage Procurement Framework and Design Program, 2013). In essence, the utilities felt they were being forced to invest in energy storage projects even if it did not make economic sense for them to do so.

Once again, flexibility soothed these concerns. Firstly, by allowing the utilities to select which energy storage projects they wished to invest in through a competitive bid, they could choose their preferred projects at a competitive price (Ruby, 2018). Secondly, if an IOU could show that it was unable to "procure enough operationally or economically viable projects to meet the targets within a given period", then it could seek to defer up to 80% of the capacity to later procurement periods (Decision Adopting Energy Storage Procurement Framework and Design Program, 2013). So, while the final target remained the same, the IOUs were given flexibility in case energy storage remained unaffordable in the first years that the mandate was in effect. That flexibility was limited, however, as the absolute installation deadline of 2024 had to be met. In addition, various cost-recovery mechanisms were included, such as distribution and transmission rates, generation charges, and the CPUC's cost allocation mechanism (Stiftung Mercator, 2017).

Along with the three IOUs, Community Choice Aggregators (CCAs) and Electric Service Providers (ESPs) were mandated to procure energy storage. In this way, AB 2514 applied to all load-serving entities. Core differences exist between CCAs, ESPs and the three IOUs, however. While the IOUs are private, for-profit electricity providers, CCAs are publicly owned at the local level. CCAs thus allow cities and counties to make energy procurement decisions while the affiliate IOUs continue to provide transmission and distribution services. ESPs, on the other hand, are non-utility entities that offer electric services to customers within the service territory of an electric utility (Trumbull et al., 2020).

Although AB 2514 did not recommend a specific target for CCAs and ESPs, the CPUC proposed that these load-serving entities procure 1% of their 2020 annual peak load from energy storage projects, with these projects to be installed by no later than 2024 (Decision Adopting Energy Storage Procurement Framework and Design Program, 2013). The requirements for these smaller load-serving entities were somewhat more straightforward than for the IOUs. Instead of allocating interim targets before the final deadline of 2024, as was done for the IOUs, the CCAs and ESPs were given only the final deadline to meet. Despite the lack of interim deadlines, the CPUC required progress reports every two years to prevent the procurement process from being delayed until later in the decade (Decision Adopting Energy Storage Procurement Framework and Design Program, 2013). Additionally, the target set for the CCAs and ESPs was lower than that of the IOUs. This was justified on the grounds that all customers, including those of CCAs and ESPs, would be required to pay certain charges that the IOUs may use to develop storage. Customers of CCAs and ESPs would also be expected to pay, through distribution charges, for storage procured for the IOU's distribution system (Decision Adopting Energy Storage Procurement Framework and Design Program, 2013).

As the CPUC drafted the procurement mandate, a critical issue that arose was how to value storage. Although the CPUC recognised that storage could improve grid efficiency in multiple ways, concerns existed regarding how to monetise the value that storage created. Monetisation was core to the success of AB 2514, as investors needed a realistic chance of making a return on their investment. At the time, justifying the financial risks of storage was difficult. Many of the benefits of storage, e.g., decreased likelihood of blackouts, are public goods. Due to the deregulated nature of the Californian electricity market, such benefits were deemed difficult to monetise (Higgins, 2014).

As one of the goals of AB 2514 was to develop the energy storage market, the CPUC decided to exclude large-scale pumped storage projects from counting towards the procurement target (Twitchell, 2019). The cut-off point was 50 MW, after which such a project would not be eligible to bid into solicitations. Opponents argued that as AB 2514 did not specify any size limitations and large-scale pumped storage met the eligibility criteria, the CPUC was improperly favouring other technologies at the expense of pumped hydro. However, due to the sheer size of the majority of pumped storage projects, most of which were over 500 MW when AB 2514 was first passed, they would crowd out other emerging technologies and prevent the fulfilment of market transformation goals (Decision Adopting Energy Storage Procurement Framework and Design Program, 2013).

5.3.3 Implementation of AB 2514

Impacts to date

Although the CPUC ordered its energy division to evaluate the storage procurement mandate's progress by no later than 2016 and at least once every three years after that, this process was delayed. This was due to the CPUC wishing to wait until more storage was installed — as opposed to only procured — that could then be analysed. By 2020, the CPUC determined that enough energy storage had been installed in the system to warrant conducting the study (State of California Public Utilities Commission, 2021). The delayed report does not suggest that the utilities were behind schedule in procuring ESSs in line with their interim targets. On the contrary, the three major IOUs procured more energy storage than was necessary under the law (Energy Storage Association, 2017). Earlier concerns from the utilities regarding storage valuation and fears that the procurement mandate was too extreme proved unfounded. Instead, once the regulatory framework was adjusted to favour energy storage, the value and cost-effectiveness of these technologies to the grid were highlighted.

As of May 2022, almost 2650 MW was installed on the Californian grid (California Energy Storage Alliance, 2022b), considerably more than was initially required by AB 2514. Yet even this figure does not represent the amount of storage that has been procured. CESA tracks all projects that have been actively procured but are yet to pass all approval stages. When these projects are considered, there have been 10,675 MW of active storage procurements since 2010.

Table 5.1: Energy storage capacity procured by load serving entity (LSE) as of May 2022.

Energy storage capacity procured by LSE (MW)

LSE	MW
Pacific Gas & Electric	3,321.70
Southern California Edison	3,165.34
Clean Power Alliance	1,195.50
San Diego Gas & Electric	717.16
Los Angeles Department of Water & Power	431.01
East Bay Community Energy	229.13
San Diego Community Power	220.00
Clean Power SF	140.00
Valley Clean Energy Alliance & Redwood Coast Energy Authority	125.50
California Community Power	119.00
Silicon Valley Clean Energy & Monterey Bay Community Power	105.00
Silicon Valley Clean Energy	96.63
Sonoma Clean Power	80.00
Desert Community Energy	50.00
Redwood Coast Energy Authority	38.75
California Choice Energy Authority	15.00
San Jose Clean Energy	10.00
Riverside Public Utilities	7.85
Sacramento Municipal Utilities District	4.87
Redding Electric Utility	3.60
Glendale Water & Power	3.50
City of Santa Clara Utilities	3.25
City of Anaheim Public Utilities	3.15
Pasadena Water & Power	0.74
Moreno Valley Utilities	0.08
Lancaster Choice Energy	0.03
Colton Public Utilities	0.02
Alameda Municipal Power	0.01
Marin Clean Energy	-
Burbank Water & Power	-
Imperial Irrigation District	-

Source: California Energy Storage Alliance (2022b).

As CCAs are publicly owned at the local level, they enable local citizens to exert greater control over decisions regarding their energy. Significant demand for a decarbonised grid exists among Californian citizens, which is something borne out by the numbers. The vast majority of CCAs outperform the three major IOUs in deploying renewables as a share of their overall load, with CCAs delivering an average of 25% more renewable energy than IOUs in the same regions (Einstein, 2021). This has necessitated increases in storage capacity, which CCAs have invested in accordingly.

Due to their local nature, CCAs tend to reflect their customers' preferences and are proactively involved in responding to natural disasters and crises within their communities. To this end, storage plays an important role. For instance, two CCAs in Northern California created Advanced Energy Rebuild programmes in conjunction with PG&E for customers affected by wildfires in 2017 and 2019. These programmes incentivised technologies such as battery storage for customers who were rebuilding their homes in the aftermath of devastating wildfires (Trumbull et al., 2020).

The Californian storage mandate has given certainty to the ESS market and has, as a result, driven innovation. It has also had indirect effects on the market by providing a template that other US states have used to establish their own procurement mandates (Twitchell, 2019). The more states that commit to procurement mandates, the greater the confidence that the storage market will provide a return on investments, therefore increasing investments in storage technologies. Since AB 2514 was implemented, ESS costs have dropped significantly. For instance, the cost of Li-ion batteries in the US plunged between 2010 and 2018 since AB 2514 and other procurement mandates and incentives. Prices have continued to fall, with a Li-ion battery pack costing USD 132/kWh in 2021 (Henze, 2021). While state-level policies undoubtedly played a role in this price drop, with AB 2514 particularly influential as it was the first one, they are not the only reasons behind the reduction in Li-ion battery costs. Other factors include the market transformation driven by electric vehicle (EV) demand, and federal R&D programmes (Henze, 2021).

Some of the largest battery storage systems in the US are in California, signalling the impact of AB 2514 in helping to establish extensive, utility-scale facilities. These include the Moss Landing Energy Storage Facility which, at 400 MW, is one of the largest storage facilities in the world. An expansion of 350 MW is planned which, if authorised by the CPUC, would make Moss Landing the largest storage facility in the world (Vistra Corp., 2022). Yet Moss Landing also highlights an area of concern regarding Li-ion batteries, i.e., the issue of fires. The facility has faced two separate fire incidents, something which is not uncommon to Li-ion storage facilities. Although deemed a 'growing pain' for the technology as innovation develops, it is nonetheless a point of concern that must be addressed. In particular, thermal runaway, when internal cell defects or external stresses trigger fires, has been responsible for fires at multiple storage facilities (Hering & Sweeny, 2022). While these fires have not been significant enough to slow down market growth in California, they remain an expensive complication to rolling out Li-ion storage facilities.

As well as Moss Landing, a range of other large projects have been announced since 2020, including a 100 MW project in Ventura County and a 200 MW project in Pittsburg, California (REGlobal, 2021). California accounts for 31% of installed utility-scale storage capacity in the US. This share is even higher for small-scale battery storage (nameplate power capacity of 1 MW or less), with California making up 83% of the US total (U.S. Energy Information Administration, 2021a).

The need for long-duration storage

As more renewables are added to the mix, a noticeable issue is the need for long-duration storage. Most of the storage capacity in California has a duration of four hours or less. This is partly due to the low cost of Li-ion batteries, which tend to have durations of up to four hours, and partly because the regulatory framework has incentivised the procurement of four-hour assets to the detriment of long-duration technologies. As a resource that discharges power for four or more hours meets the standards set by the CPUC, companies lack incentives to develop long-duration technologies (Strategen, 2020).

Four-hour assets are helpful in managing the daily variabilities that come with renewables. They are not prepared, however, to deal with occasions when there is insufficient wind and sunshine for over a day. As this tends to occur in the winter, the main challenges for a decarbonised Californian grid will likely shift from managing peak loads in the summer to dealing with multi-day periods of low wind and solar availability (Balaraman, 2021). Yet coping with peak demand during summer heatwaves remains a critical issue that climate change will only exacerbate. Rolling blackouts in the summer of 2020 highlighted the need for California to be more aggressive in installing energy storage. At the time, only 200 to 300 MW of storage capacity was installed. By the following summer, 1500 MW was installed (Balaraman, 2022). It was largely because of this additional storage capacity that the Californian grid managed highly stressed conditions in the summer of 2021, driven by high temperatures and forest fires (California ISO, 2022).

Although most of this additional capacity was Li-ion batteries, in mid-2021, the CPUC ordered the procurement of 1 GW of long-duration storage. USD 380 million was earmarked to advance the commercialisation of non-Li-ion long-duration energy storage technologies (Balaraman, 2021). A range of technologies can be used as long-duration ESSs, and the CPUC remains flexible in terms of which technologies can be used to meet this target. For instance, two large compressed air storage projects are underway near Los Angeles and San Luis Obispo, with maximum capacities of 500 MW and 400 MW, respectively (Mulder, 2021). These projects use excess generation to compress and store air, which can later be used to generate electricity during high demand, for at least eight hours at full capacity.

There exist points of contention regarding how to address California's need for long-duration storage. Pumped hydro, for instance, represents an effective way in which the state can meet its long-duration storage target. One project currently seeking permission to begin construction is the Eagle Mountain Pumped Storage Project. The intention is to fill an abandoned mining pit with water, which can then use electricity generated at a nearby solar farm to pump water uphill to a higher pit. When there is not enough solar power on the grid to meet demand, the water can be released back to the lower pit, generating electricity. The planned project has met opposition from environmentalists, who argue that the facility — which is in a desert — would pull too much water from the ground, endangering the surrounding ecosystem in the process (Roth, 2020). Although the companies involved in this project argue that it will create minimal damage, the debate highlights a common thread surrounding pumped hydro facilities, where contention exists between their proven efficiency and their potential threat to local ecosystems. Other than public opposition and water issues, other barriers to pumped hydro include high capital costs and a complicated planning permission process, the latter being connected to the aforementioned environmental and biodiversity issues (Ali et al., 2021; Willson, 2022).

5.3.4 Updates to the regulatory environment since AB 2514

State-level policies

Since AB 2514 transformed the energy storage market, legislators and the CPUC have become increasingly aware of its benefits to the grid. This has led to numerous other bills intended to update the regulatory environment. This includes AB 2514's 'sequel bill', AB 2868. This required the three IOUs to propose programmes and investments to accelerate the deployment of up to 500 MW of distributed energy storage systems. Distributed energy storage systems were defined as ESSs "with a useful life of at least ten years connected to the distribution system or located on the customer side of the meter" (AB 2868 Energy Storage, 2016). Unlike the share of the headline 1325 MW target from AB 2514, which was divided according to the size of each IOU's market share, the 500 MW from AB 2868 would be divided equally among the three utilities (AB 2868 Energy Storage, 2016). These programmes and investments were then to be adopted into each IOU's 2018 AB 2514 energy storage procurement plans.

A stipulation of AB 2868 was that behind-the-meter systems could provide no more than 25% of the capacity for distributed ESSs. Behind-the-meter ESS refers to energy storage that is connected to the distribution system on the customer's side of the utility's service meter (National Renewable Energy Laboratory, 2021). Permission for utilities to own behind-the-meter storage was given if it did not unreasonably limit or impair the ability of non-utility enterprises to market or deploy ESSs (AB 2868 Energy Storage, 2016). This element of competition was a point of contention and required some amendments. As representatives of the non-utility storage industry expressed concern that they would not be able to compete with the IOUs' programmes and investments fairly, the bill was amended to guarantee such competition. This would be ensured by the CPUC, which was directed to approve IOU programmes and investments if they did not unreasonably impede non-utility enterprises from installing distributed ESSs (California Legislative Information, 2016).

In 2017, another bill was passed that ordered the procurement of more energy storage. SB 801 was proposed in response to a gas leak in 2015 in the Aliso Canyon Natural Gas Storage Facility near Los Angeles. The facility was one of the country's most extensive natural gas storage facilities, with the capacity to hold 86 billion cubic feet of gas (SB 801 Aliso Canyon Natural Gas Storage Facility, 2017). The leak's extent was severe, leading to the evacuation of 8000 families from the surrounding area (Energy Storage Association, 2017). The leak prompted the California State Legislature to prohibit more gas from being injected into Aliso

Canyon until a comprehensive evaluation deemed it safe. At the same time, the CPUC was directed to determine whether it was possible to minimise or even eliminate the use of Aliso Canyon while maintaining energy and electric reliability in the area (SB 801 Aliso Canyon Natural Gas Storage Facility, 2017).

Due to the prohibition of gas injections in Aliso Canyon, the CPUC ordered the installation of 120 MW of energy storage to manage reliability concerns linked to anticipated peak demand shortfalls in the coming summer. This was achieved in record time, with 70 MW brought online within six months (Energy Storage Association, 2017). Like AB 2514, there was an emphasis on cost-effectiveness. By the time the leak at Aliso Canyon occurred, the effectiveness of ESSs in maintaining the reliability of the grid was well established. Indeed, the legislative response and the rapid installation of energy storage to ensure the grid could withstand expected peak demand could only have come about due to AB 2514. In instances like these, the prioritisation of market transformation proved valuable. If large-scale pumped storage projects had been allowed to count towards the 1325 MW target, the development of other storage technologies may well have been impeded. This benefitted the citizens near to Aliso Canyon, who gained from the rapid installation of ESSs in under six months.

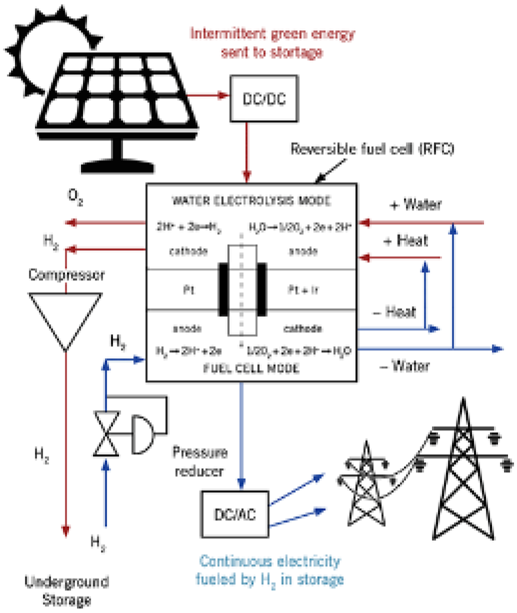
Besides mandates, the State of California also provides financial incentives to encourage the installation of energy storage and other forms of renewable energy generation. For instance, the Self-Generation Incentive Program (SGIP) focuses specifically on customer-side technologies. Between 2001, when it was established, and 2020, the SGIP provided USD 1.2 billion in incentives to support the development of over 750 MW of distributed generation and 620 MWh of energy storage (Order Instituting Rulemaking Regarding Policies, Procedures and Rules for the Self-Generation Incentive Program and Related Issues, 2020). The SGIP has been revised several times over the years, including the decision to allocate 88% of its budget to energy storage projects and setting GHG emissions reduction requirements for ESSs (Fero & Ferguson, 2020). Other significant reforms to the SGIP that related to the energy storage market include the 'equity resiliency' budget, which promotes the installation of energy storage for vulnerable customers, and 'critical facilities' that assist communities which are affected by public safety power shutoffs or wildfires (Fero and Ferguson, 2020).

The success of AB 2514 was partly due to the broader legislative framework addressing the need for energy storage. This included AB 1637, which emphasises the intent of the SGIP to increase the deployment of ESSs; SB 1136, which aims to expand the range of projects (including energy storage) that qualify for a focused environmental impact report, thus speeding up the process by which they can be improved, a necessary step in achieving California's climate goals in time (SB-1136 California Environmental Quality Act, 2018); and SB 1339, which facilitates the commercialisation of microgrids (independent local energy systems) and can include storage technologies (Sb 1339, 2018). Instrumental in the adoption of these bills was CESA, which has engaged directly with the policy process, with many of its positions resulting from its member-driven Legislative Working Group (California Energy Storage Alliance, 2022a).

Partly because of the lobbying of CESA and the growing awareness of the need for long-duration storage, AB 33 was passed. This bill was designed to evaluate and analyse the potential for all types of long-duration bulk energy storage resources to assist the integration of renewables into the grid. Examples of these resources include pumped hydro and compressed air storage. Another goal of AB 33 was to assess the potential costs and benefits of long-duration bulk storage. The CPUC was directed to conduct an evaluation to achieve this latter objective (AB 33, 2016). Recognition of the importance of long-duration storage to the grid has been further emphasised by its inclusion as one of the five pillars of California's future energy system.

Another important piece of legislation influenced by AB 2514 is SB 1369. This bill specifies green hydrogen as a technology that should be targeted for increased use as a storage option. Hydrogen has characteristics that make it well suited as a storage technology (**Figure 5.2**), namely that energy stored as hydrogen does not degrade over time and can be stored with a greater energy density than Li-ion batteries (SB 1369, 2018).

Figure 5.2: Using hydrogen for energy storage.



Source: Weaver (2022).

Federal-level policies

Although the State of California has been proactive in improving the regulatory environment for energy storage, changes at the federal level have also contributed to the Californian storage boom. The first came with the enactment of Federal Energy Regulatory Commission

(FERC) Order 755 in 2011. This established a compensation methodology for the procurement of frequency regulation. FERC Order 755 aimed to remedy discrimination against faster-responding resources by aligning incentives and performance so that more efficient resources received better pay (Order No. 755: Frequency Regulation Compensation in the Organized Wholesale Power Markets, 2011). The Order also allows for the recovery of inter-temporal opportunity costs, defined as "the foregone value when a resource must operate at one time, and therefore must either forego a profit from selling energy at a later time or incur costs due to consuming at a later time" (Order No. 755: Frequency Regulation Compensation in the Organized Wholesale Power Markets, 2011). Regarding ESSs, it is more profitable to charge during low-price periods. However, if required to provide frequency regulation during a part of the day when costs are low and then charge when costs are higher, an inter-temporal opportunity cost is incurred. The recovery of these costs was significant for the storage industry as it removed barriers to their deployment by providing remuneration for their flexibility.

Additionally, FERC Order 784 was developed to improve competition and transparency in ancillary service markets. The order had several objectives. These were to eliminate certain restrictions on third-party ancillary-service sales at market-based rates to transmission providers, make the speed and accuracy of ancillary services a consideration for utilities in their assessments, and apply new accounting practices to track the use of energy storage, thus helping utilities achieve rate recovery for storage (Order No. 784: Third-Party Provision of Ancillary Services; Accounting and Financial Reporting for New Electric Storage Technologies, 2013; Stinson LLP, 2013). By developing proper pricing for ancillary services, the FERC indicated its support for energy storage, which directly benefitted from the new criteria.

A particularly significant FERC ruling was Order 841, whereby the FERC removed barriers to storage participation in wholesale markets. Regional grid operators were directed to revise their regulatory framework so that storage resources would be compensated for all the services they provide (Order No. 841: Electric Storage Participation in Markets Operated by Regional Transmission Organizations and Independent System Operators, 2018). The new revenue stream for services provided by storage was aimed at levelling the playing field for storage technologies to enable their development further. Although regional grid operators were provided flexibility in implementing Order 841, the FERC did set out minimum requirements that each operator was required to meet. For example, storage assets must be allowed to participate in the market as supply and demand resources.

The ruling was challenged in court as it was argued that the FERC's involvement in the distribution system, which is typically controlled by local utilities, was a breach of state rights. However, this line of argument was unsuccessful, and the ruling was upheld. The attorneys general of California and several other states defended the FERC's decision, contending that the order would produce billions of dollars in health, economic, and environmental benefits for their states (Bandyk, 2020). While this victory was hailed as a pivotal moment in the transition to a carbon-free grid, it is relevant to note that market access does not necessarily lead to more storage projects.

Following Order 841, was Order 2222. This required regional grid operators to create financial mechanisms for distributed energy resources (DERs) so that they could fairly compete to provide services usually reserved for large-scale systems. Like the impetus behind Order 841, the FERC deemed existing market rules to act unreasonably as barriers to the participation of DERs in the markets (Order No. 2222: Participation of Distributed Energy Resource Aggregations in Markets Operated by Regional Transmission Organizations and Independent System Operators, 2020). DERs, which storage resources are a form of, are small-scale systems located close to the power grid. They are generally connected to the distribution network and help to reduce the load on the transmission grid (U.S. Energy Information Administration, 2021b).

Order Nos. 841 and 2222 have the potential to go a long way towards increasing storage capacity, not just in California but across the US. However, the major challenge is the high upfront cost, which may be difficult to finance, especially with increasing interest rates. A solution could be offered by fixed revenue contracts, i.e., long-term agreements to pay a fixed price for a project's output instead of generating revenue that fluctuates with changes in market prices. Regulating such contracts constitutes an issue for states with little experience managing DER programmes. Due to California's experience with handling the storage market, it has been able to implement the FERC's Order Nos. 841 and 2222. California also benefits from the California Independent System Operator (CAISO) being a single-state ISO. This allows federal orders to be integrated into the existing regulatory framework more easily as there are fewer state laws and policies and fewer stakeholders to engage with when designing and executing compliance plans (J. Bell & Macbeth, 2021).

Alongside the orders, the Federal Government provides the Investment Tax Credit. This tax credit can be claimed on federal income taxes proportional to the capital expenditures intended for certain renewable technologies. ESSs installed at a solar or wind farm and charged by renewables more than 75% of the time can qualify for this tax credit (U.S. Energy Information Administration, 2021b). The Modified Accelerated Cost Recovery System also provides tax breaks based on capital costs. For example, a storage system charged by renewables more than 75% of the time qualifies for around a 21% reduction in capital costs (Elggvist et al., 2018).

Despite the ever-growing partisan divide in US politics, energy storage provides a relatively rare source of agreement. Both the Trump and Biden administrations have rolled out R&D initiatives to position the US as a global market leader. Hostility to clean-energy legislation from the Trump administration was common (Gentile & Kelly, 2020). Still, the administration continued to provide financial support for storage, such as through the Energy Storage Grand Challenge Program (U.S. Department of Energy, 2020a). Likewise, the Biden administration has advanced R&D plans of its own. The Long Duration Energy Storage for Everyone, Everywhere Initiative aims to lower the costs and enhance the duration of storage technologies (U.S. Department of Energy, 2022d).

5.3.5 Evaluating California's storage procurement mandate

Twelve years since the introduction of California's storage procurement mandate — and two years before the 2024 deadline — the energy storage market looks significantly different to how it did in 2010. AB 2514's headline 1325 MW target has already been surpassed — as of May 2022, the three major IOUs have procured 7204.2 MW (California Energy Storage Alliance, 2022b). That alone is testament to the procurement mandate's impact on the market. By almost any measure, California is the leading state in the US regarding its installed and procured storage capacity. To this end, AB 2514 has effectively achieved its core target. The IOUs have not been alone in procuring energy storage. CCAs have led the way, reflecting the preferences of the communities they represent who want their electricity supply to be sourced from renewables. When all Load Serving Entities are accounted for, there has been 10,675 MW of active energy storage procurements since 2010 (California Energy Storage Alliance, 2022b).

Adding storage capacity to the grid was not the only objective of AB 2514. Also important was transforming the market and providing regulatory support to companies with new, innovative technologies. To achieve this, the CPUC excluded large-scale pumped storage projects from counting towards the procurement target. Though a controversial decision at the time, it has allowed other technologies to develop to maturity that may otherwise have been crowded out by large-scale pumped storage. Twelve years since the passing of AB 2514, the energy storage market is in a considerably better place, with the costs and efficiency of a variety of technologies improving rapidly.

However, there are caveats. While pumped hydro may not have dominated California's storage market, there has been a heavy emphasis on Li-ion batteries. Due to significant drops in their prices, it makes sense that Li-ion batteries have been relied on to meet the state's storage needs. Due to the lack of incentives for companies to procure ESSs with a duration of longer than four hours, there has been an undersupply of long-duration storage technologies. That said, recent regulatory support for these technologies will likely rectify that. While the Californian grid can currently manage with little, long-duration storage due to the ability of fossil fuels to meet peak loads, as it further decarbonises, the need for long-duration storage will become increasingly evident.

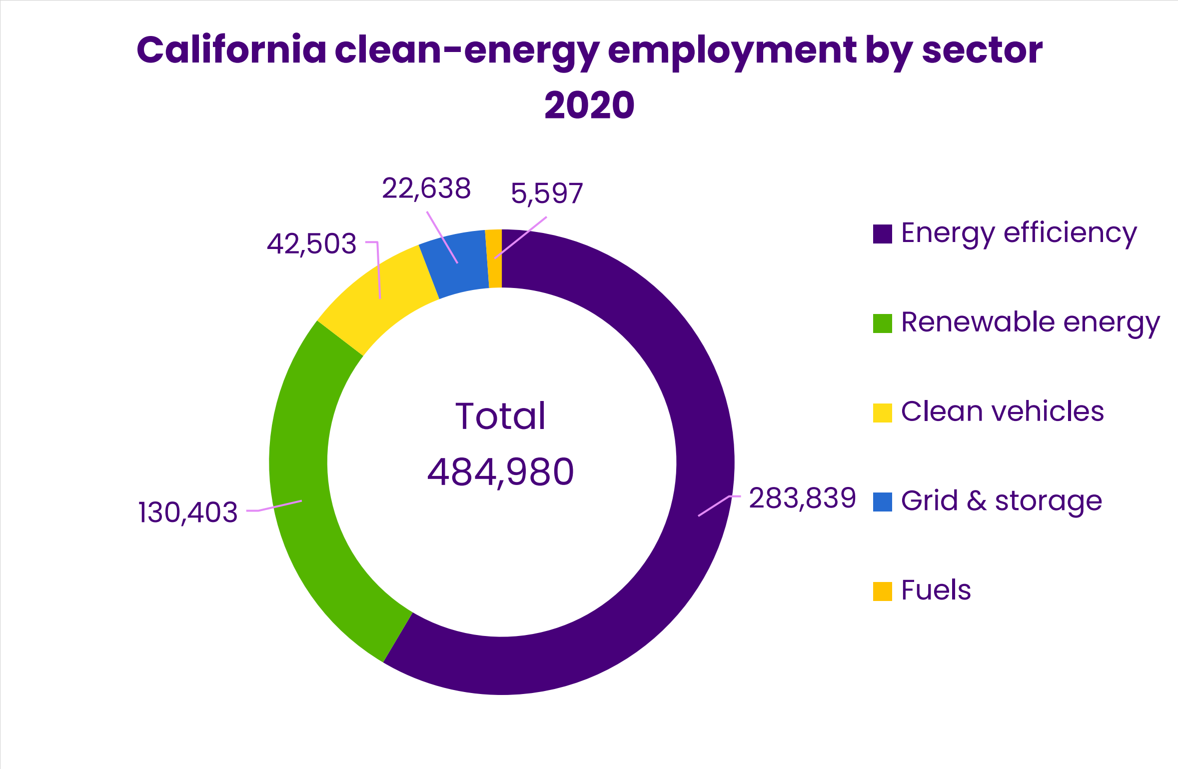
A rapidly growing demand for lithium, both for ESSs and EVs, means that competition for the resource will only increase throughout the decade. This demand will inevitably lead to more quantities being mined, but recent shocks to the market demonstrate the importance of diversifying storage technologies (Denning, 2022). While lithium has been the backbone of the Californian storage boom, investing in alternatives can safeguard the industry from possible market shocks in the future.

The transformative effect of AB 2514 on the storage market has made a tangible difference to how the Californian grid responds to crises. The increasing severity of heatwaves and wildfires due to global warming means that the grid will come under more significant pressure in the future. The increased storage capacity can largely be thanked for preventing rolling blackouts during the summer of 2021 (California ISO, 2022). It has also shown its benefits in handling infrastructure failures at fossil fuel facilities. The 2015 gas leak at Aliso Canyon spelt immediate danger for the thousands of families in its vicinity but also meant that the grid would be unreliable the following summer. Storage was rapidly installed and can be credited for maintaining grid reliability in the aftermath of the Aliso Canyon gas leak.

AB 2514 was not a standalone policy, but was the beginning of a chain of legislation focusing specifically on storage. As regulators have become more aware of the benefits of energy storage to the grid, they have made corresponding updates to the regulatory environment when deemed necessary. For instance, greater awareness of the need for long-duration storage led to AB 33. This is indicative of one of AB 2514's greatest strengths, i.e., the legislature's willingness to pass progressive legislation while providing flexibility to the CPUC to oversee implementation. The legislature backs goals or mandates while the CPUC evaluates how best to achieve them. This division of labour has been effective in implementing AB 2514's plans. Changes at the federal level have complemented those at the state level, helping to allow storage technologies to be properly compensated for the myriad benefits they provide to the grid.

The growth of California's storage market has had significant co-benefits for the economy and has supported the accelerated development of variable renewables, especially wind and solar energy. The clean-energy economy now represents 3% of California's overall employment. **Figure 5.3** highlights how employment is divided between clean-energy sectors. As a subsection of grid and storage, storage directly employs over 16,800 people (E2, 2021). Due to COVID-19, this represents a drop from the previous year, but employment in the clean-energy sector bounced back twice as fast as the state's overall economy.

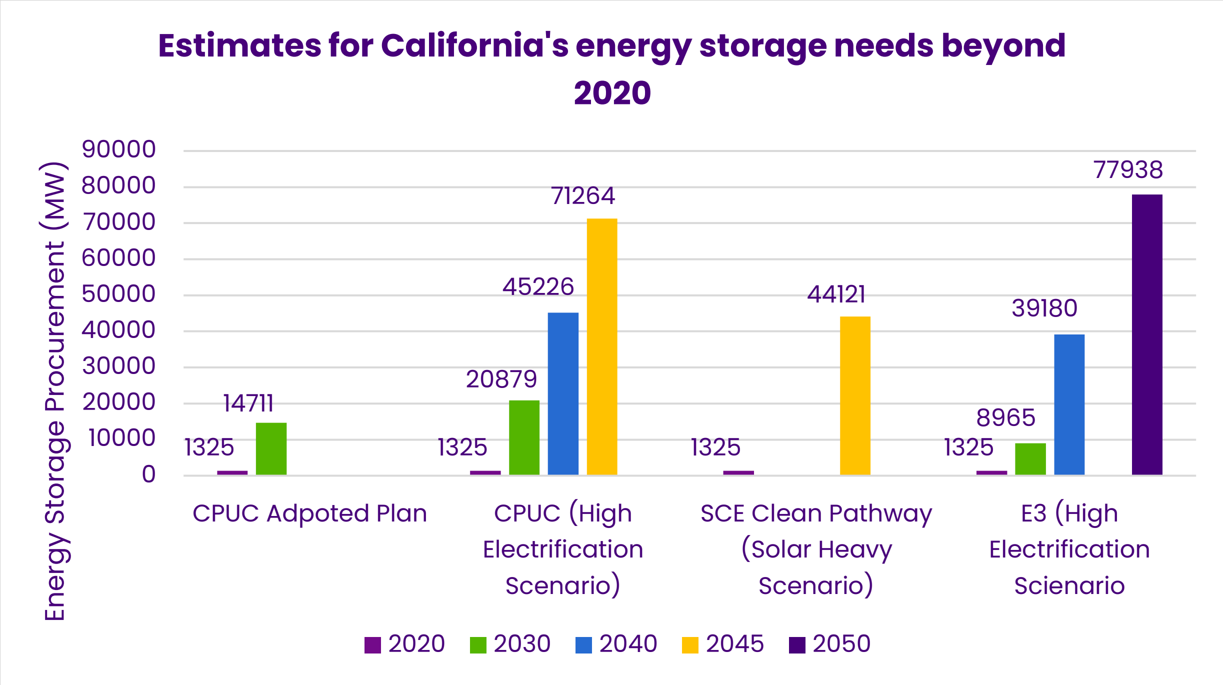
Figure 5.3: California clean-energy employment by sector 2020.



Source: E2 (2021).

The achievement, in May 2022, of powering the grid entirely with renewables was a historic milestone and a glimpse into California's future. AB 2514 will remain a critical tool in successfully decarbonising the grid. Despite the considerable progress so far, more needs to be done. There is no definitive answer regarding how much storage will be required as this will depend on state policy decisions and how the technologies evolve. Nevertheless, meeting the goals of the RPS will require a significant scaling up of capacity. Most estimates suggest that between 10,000 and 20,000 MW will need to be installed by 2030 (**Figure 5.4**). By 2050, this figure will need to be quadrupled (Union of Concerned Scientists, 2020). The CPUC's decision to invest USD 49 billion in a range of clean-energy technologies, including almost 15,000 MW of battery storage, is a strong message that the state is prepared to scale up capacity (Decision Adopting 2021 Preferred System Plan, 2021).

Figure 5.4: Estimates for California's energy storage needs beyond 2020 for different scenarios.



Source: Union of Concerned Scientists (2020).

Achieving these targets is a sizeable task. However, due to the groundwork laid by AB 2514 and the policies that followed it, California is in a strong position to stabilise the grid with enough storage capacity to integrate the high shares of variable renewables needed to decarbonise the grid.

5.3.6 Discussion

California's storage boom has been a direct result of decisive action by the state government. Despite many observers deeming storage technologies unready for widespread deployment at the time AB 2514 was passed, the amount of storage procured and deployed is already well in excess of what is required by law. The flexibility of the initial bill, most notably in terms of which technologies could be used to meet the targets, was an important part of its success. Despite this flexibility, however, the state has relied heavily on Li-ion batteries. Recent fluctuations in the market and the destructive mining practices associated with the resource mean that an overreliance on Li-ion batteries is not recommended. Going forward, diversification to other forms of storage, particularly long-duration technologies, will be crucial.

Three aspects of the Californian case that were central to its success are:

1. Binding targets for electricity utilities.

2. Flexibility for which technologies are used to meet the targets.
3. Rewarding utilities for additional services and characteristics provided by storage.

The Californian case study highlights the importance of ESSs outside of integrating renewables onto the grid. Storage has already improved grid resiliency by preventing rolling blackouts and guaranteeing access to electricity for citizens affected by the Aliso Canyon gas leak. To this end, the Californian case study demonstrates multiple benefits of storage for consumers and network operators.

5.4 Case study 2: Renewable Energy Certificates (South Korea)

While not a global leader in terms of their share of renewable energy generation, South Korea's experience is of interest due to the rate of growth in renewables due to policy changes to promote not just generation but, subsequently, energy storage. Section 5.4.1 opens with the background to South Korea's history in dealing with its energy challenges and the potential it has for renewable energy, thus setting the pretext for the country to look to energy storage as part of its long-term decarbonisation goals. Section 5.4.2 highlights the opportunities South Korea has had to facilitate changes in policy for renewables and energy storage, and Section 5.4.3 details the policy development to promote the expansion and promotion of renewable energy and storage. Section 5.4.4 evaluates the successful outcomes the country faced in light of its policy changes. Lastly, Section 5.4.5 briefly discusses the core lessons from South Korea's policy experience around renewables and storage.

5.4.1 Context and background

In 2020, South Korea was the world's tenth largest energy consumer, using 11.79 billion kWh of electricity (World Population Review, 2022). However, South Korea's electricity generating capacity continues to be a fraction of a percent of its consumption (Chung & Kim, 2018). South Korea has a power reserve margin of only around 10%, exacerbating its dependence on energy imports, mostly in the form of fossil fuels (U.S. Energy Information Administration, 2020).

The South Korean energy mix is predominantly based on fossil fuels. In 2015, petroleum and other liquids made up 41% of the energy mix, coal made up 31%, and fossil gas represented 14% (U.S. Energy Information Administration, 2020). The remaining energy mix was 14% fossil gas, 13% nuclear, and 1% renewable energy sources. Despite heavy reliance on fossil fuels for energy, South Korea is not home to large fossil fuel deposits and instead must import almost all of its energy (U.S. Energy Information Administration, 2020).

South Korea is an islanded grid due to its relationship with North Korea and its southern location on the Korean Peninsula. This grid isolation requires South Korea to import its energy by using ships. The additional hurdle contributes to higher energy prices (Yun & Jung, 2017). Energy prices in South Korea have fluctuated substantially annually, ranging from a low of USD 111.51 per MWh in 2009 to USD 144.42 per MWh in 2013 (OECD, 2020a). In 2020, compared to the OECD average of about USD 100 per MWh, South Korea's household electricity prices of USD 125.95 per MWh are very high, likely due to import costs (OECD, 2020a).

South Korea imports energy from several countries, with the majority of its crude oil coming from Saudi Arabia, Russia, Kuwait, the United States, the United Arab Emirates, and Iraq (OEC, 2022b). Some of these countries have faced, or continue to face, political turmoil and human rights concerns, which make these large-scale imports a political concern for South Korea. This has recently been exemplified by the cooling of diplomatic relations between Russia and South Korea in the aftermath of Russia's invasion of Ukraine. One potential method to reduce energy imports is to support local renewable infrastructure development, which enables domestic energy production.

The heavy reliance on fossil fuels and the associated import methods make energy a national security interest. South Korea's lack of energy independence makes it susceptible to energy market fluctuations. In the 1970s, back-to-back oil crises stressed the need to diversify energy sources in order to provide more energy security. After the crises, South Korea enacted the Act on the Promotion of the Development of Alternative Energy (1987) and established the Basic Plan for the Development of Alternative Energy Technologies (1987 to 2001) (H. Kim, 2019). This anticipation for future crises highlights the domestic understanding of the changes needed to cope with global fluctuations.

Part of the current strategy to increase energy security includes the promotion of renewable energy sources. South Korea has significant potential for renewable energy production, especially through offshore wind and solar PV (Hassan & Polito, 2020). The government aims to generate 12 GW of offshore wind by 2030. As of 2022 it had installed 124.5 MW (Energy Tracker Asia, 2022). South Korea has also set a target of 34 GW of solar PV energy by 2030, compared to the 22 GW currently installed (Bellini, 2022; GlobalData Healthcare, 2022). Despite the potential, renewables have not flourished in South Korea due to the high initial costs (R.-G. Park & Koo, 2018). An additional challenge for renewable development is a complicated system of restrictions and regulations that slow down the permitting process. As a result, by 2020, the share of renewables in the energy mix had grown to only 7.2% (Feffer, 2022).

Furthermore, renewables provide a cost-effective strategy to deal with air pollution. South Korea's 12 active coal-fired power plants are estimated to emit 45.4 kt of SO_2, 48.1 kt of NOx, 3 kt of particulate matter, 600 kg of mercury deposits, and 1200 tonne of fly ash annually

(Myllyvirta et al., 2021). Reducing the country's dependence on coal has been impeded by fossil fuel industries, who constitute a powerful lobby in South Korea and have remained influential in directing government energy policy. However, awareness of the extent to which the country is affected by air pollution and the objective of reducing emissions has encouraged a shift to cleaner energy sources (Feffer, 2022).

Islanded grids with relatively low power system inertia, like South Korea, can be particularly affected by renewable variabilities. Inertia means the tendency of an object in motion to remain in motion. As it relates to the grid, energy stored in large rotating generators gives them the tendency to remain rotating. This has historically been critical to grid reliability because when a large power plant fails, inertia can maintain power for a few seconds. This is usually all it takes before the systems that control most power plants detect and resolve the failure. As renewable technologies do not use conventional generators, they do not inherently provide inertia. Renewables reduce the amount of inertia that is needed, while ESSs can quickly detect frequency deviations and respond to system imbalances and further integrate renewables into the grid (Denholm et al., 2020).

5.4.2 Window of opportunity

The South Korean push for the development of renewables originated in 2008 under President Lee Myung-Bak (2008 to 2013). Following the 2008 recession, South Korea implemented its "Green New Deal" to support economic recovery, following a 4.5% contraction in the final quarter of 2008 (Energy Tracker Asia, 2020). The stimulus package, worth USD 38.1 billion or approximately 4% of South Korea's GDP, would be spent between 2009 and 2012. Almost 80% of the package's funding was allocated to environmentally friendly measures such as renewable energies (USD 1.8 billion), energy-efficient buildings (USD 6.19 billion), low-carbon vehicles (USD 1.8 billion), railways (USD 7.01 billion), and water and waste management (USD 13.89 billion). The swift government action helped the economy stabilise during the first half of 2009 (Energy Tracker Asia, 2020).

In 2009, South Korea introduced its National Strategy for Green Growth (OECD, 2020b). This strategy intended to promote eco-friendly new growth engines, enhance quality of life, and contribute to efforts to fight climate change (OECD, 2020b). In the framework of the Green Growth programme, South Korea passed the Framework on Low Carbon, Green Growth, as well as the Act on the Allocation and Trading of Greenhouse Gas Emissions Allowances. These laws aimed to develop renewables and establish a carbon trading system, of which the latter started functioning in 2015 (J. Kim, 2013). Nuclear was also deemed important in reducing emissions — something which was especially promoted under the subsequent administration led by President Park Geun-Hye, who considered renewables and nuclear as an effective way to reduce emissions and bolster national security (Yun & Jung, 2017). Despite those statements, South Korea's intended Nationally Determined Contribution, submitted in June

2015, was not ambitious. Instead, the government set a goal of reducing emissions by 37% in 2030 compared to business as usual, which de facto meant increasing emissions by 81% in comparison to 1990 (Climate Action Tracker, 2022b; Republic of Korea, 2022).

While the government showed a decreasing level of ambition for climate action, the situation looked much better for storage technology. ESSs were considered a new economic growth engine for the South Korean economy, especially because South Korea already had a large domestic battery industry making Li-ion batteries, mostly for smartphones. Companies like Samsung and LG strived to be self-sufficient LiB producers to reduce costs in smartphone manufacturing (Hwang & Jung, 2020). As a result, the South Korean industry was aptly situated to have a head start in developing storage technology globally. From the beginnings of ESS development, South Korean companies quickly established the technical capacity to produce the three main components of LiBs: a battery management system (BMS), power conditioning system (PCS), and energy management system (EMS). The BMS stores and charges the energy that the LiB imports from its power source and allows the users to monitor voltage. The PCS converts energy stored in the battery into power with a standard voltage and frequency. The EMS, also called a power management system, monitors and regulates energy consumption (Hwang & Jung, 2020).

To facilitate the development of this technology, in 2011, the South Korean Government created the Korea Energy Storage Technology Development and Industrialisation Strategy (K-ESS) as part of the Third National Energy Development Plan. The strategy set a goal of 1.7 GW of deployed ESSs by 2020, and to make up 30% of the global market by 2020. The strategy also supported the efficiency of ESSs, specifically domestically produced LiBs. It also set the ambitious goals of reducing the battery cell price to USD 180 per kWh, increasing the cell life to 20 years, and increasing the manufacturing capacity in South Korea to hundreds of megawatts by 2020 (Hwang & Jung, 2020). The main institution responsible for the implementation of the strategy was the Ministry of Trade, Industry, and Energy (MOTIE), which is tasked to ensure that the commerce, industry, and energy sectors support economic growth (Ministry of Trade, Industry and Energy (MOTIE), 2022).

However, the deployment of ESS capabilities in South Korea was mostly hindered by the initially high upfront costs and small operation revenues (Hwang & Jung, 2020). The opportunity to boost the economy through government subsidies and increasing technological feasibility was alluring to politicians and industry stakeholders. The existence of the Renewable Portfolio Standards (RPSs) and the weighting system for the Renewable Energy Certificates (RECs) provided an adequate framework for supporting ESS deployment.

5.4.3 Policy development

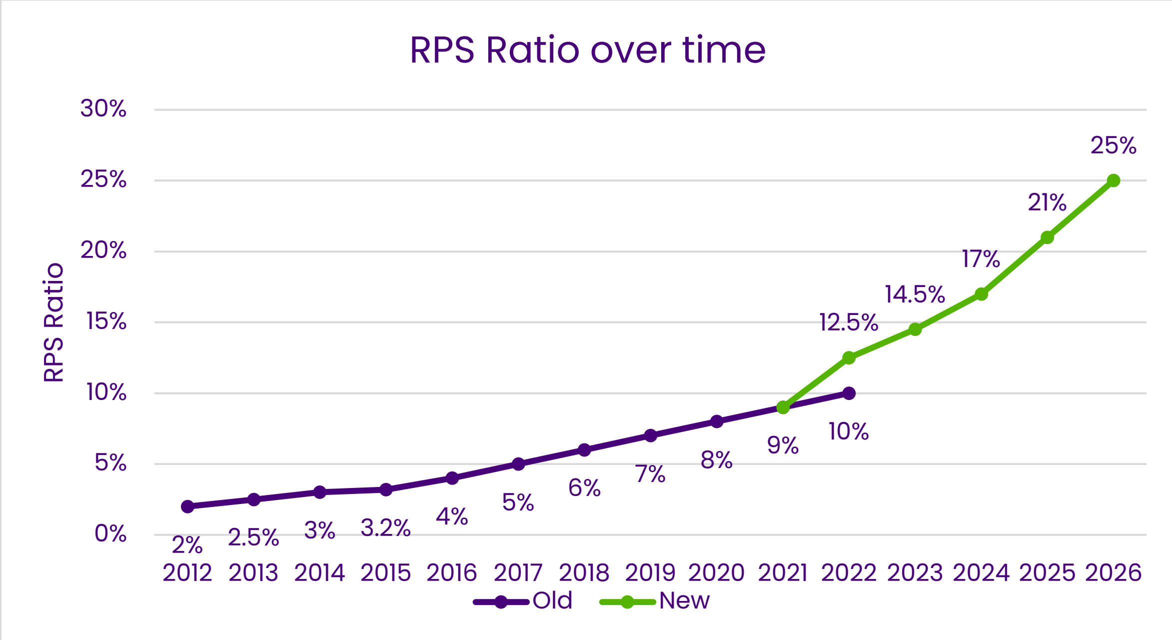
The RPS for renewable energy

The stated goal of the Act of the Promotion of the Deployment, Use, and Diffusion of New and Renewable Energy (2004) was to protect the environment while promoting sustainable development and economic growth. For this purpose, it aimed to support the diversification of energy sources through the promotion and deployment of new and renewable energy sources (Korea Energy Agency, 2015). Based on the 2004 renewable energy act, in January 2012, South Korea introduced the RPS to replace the previous feed-in tariff system (IEA, 2020b). The RPS required South Korean power companies with more than 500 MW of installed capacity to increase their renewable energy mix over time. Each year, beginning in 2012, companies had to generate a certain share of electricity from renewables. Power companies that could not meet the renewable energy targets were expected to buy RECs, i.e., proof that energy has been generated from renewable sources, to offset whatever renewable energy they were unable to produce. If they did not purchase any RECs and were still below the requirement, then the Minister of Trade, Industry, and Energy would fine the company up to 1.5 times the average cost of an REC (Act on the Promotion of the Development, Use and Diffusion of New and Renewable Energy, 2004).

The renewable energy share started with 2%, to be steadily increased to 10% by 2023, with no planned increases thereafter (Act on the Promotion of the Development, Use and Diffusion of New and Renewable Energy, 2004). Due to the numerous multipliers, this share does not necessarily correspond to the share of renewables, which could be lower than that. After the election of President Moon Jae-In in 2017, there were some expectations of strengthening South Korean renewable energy policy framework (Paik, 2018). As a member of the Democratic Party, President Moon campaigned and acted on promises for more environmentally friendly government policies. He also pledged to initiate zero-nuclear and zero-fossil fuel initiatives, a dramatic shift compared to the policies enacted under previous conservative administrations (Wilson et al., 2021) (Feffer, 2022).

However, it took President Moon almost four years to increase the RPS targets in the framework of the zero-fossil fuel policy developed. As a result, the RPS minimum quota was increased from 10% in 2022 to 25% in 2026, marking the first change to the RPS requirement (D’Ambrogio, 2021; Jeong, 2021; B.-W. Kim, 2021). The 15% increase in the RPS requirement, scheduled to reach its maximum only five years after the announcement, emphasised the Moon administration’s commitment to increasing renewable energy capacity. The RPS changes will create additional demand for RECs as the big energy companies are likely to be unable to make such rapid changes to their energy sourcing (Jeong, 2021). The RPS ratio development is shown in **Figure 5.5**.

Figure 5.5: Renewable Portfolio Standards ratio over time.



Note: Author's representation adapted based on D'Ambrogio (2021); Jeong (2021); B.W. Kim (2021).

In 2022, South Korea elected conservative President Yoon Suk-Yeol, who also understands the need for South Korea to zero out its emissions (H. Lee, 2022). While President Yoon has repeatedly stressed the importance of increasing the share of renewable energy, contrary to his predecessor he also sees nuclear energy as a method to decrease South Korea's fossil fuel dependency. According to him, relying exclusively on renewables — as opposed to a mix with nuclear — will slow the transition to a zero-carbon economy (Koons, 2022; H. Lee, 2022). Despite targeting zero emissions by 2050, President Yoon intends to revise carbon neutrality transition goals (Ko, 2022).

Renewable Energy Certificates (RECs)

MOTIE is responsible for certifying new and renewable energy generating companies, so they can trade RECs. Once the generation of a certain amount of energy from renewable sources is certified, the companies are issued with the corresponding number of RECs by the Korean Energy Agency (KEA). The KEA was created in the Energy Use Rationalisation Act to support the work of the Ministry of Knowledge Economy, now MOTIE, to efficiently manage energy consumption in South Korea (Chang et al., 2021). Companies who overachieve their targets in terms of the share of renewables in the electricity mix can sell the oversupply of RECs in the corresponding market, which provides them with an additional income aside from the proceeds from selling electricity. This increases the competitiveness of different sources of energy (S. Youn & K. Kwon, personal communication, July 21, 2022).

There are four REC markets: the spot market, the competitive bidding and long-term fixed price system for solar power market (targeted towards small and medium-sized enterprises, or SMEs), the Power Purchase Agreement (PPA) market, and the Feed-in Tariff (FIT) market. These are illustrated in **Figure 5.6**.

Figure 5.6: Illustration of the four Renewable Energy Certificate (REC) markets.

The different markets were created to ensure that the varying needs of different types of renewable energy were being met. The government also recognised that SMEs were more at risk of failing or being taken advantage of because of their relatively new and tenuous emergence on the domestic market. Conversely, large solar companies need much less government support because they have already established themselves and probably have the needed in-house support to understand the systems (S. Youn & K. Kwon, personal communication, July 21, 2022).

The spot market represents 25% of the REC market and opens twice a year for trading. Supply and demand determine the price for the spot market. The competitive bidding and long-term fixed price system for the solar power market is for small and medium-sized solar power enterprises. The government determines the price by setting a price cap in the SME market. The SME solar market and PPA market together represent about 75% of the REC market. The PPA market is for large-scale solar projects and the government determines the final price after the producer and consumer set initial prices during negotiation. The final market is the FIT market, which is negligible in terms of volume compared to the other markets. In the FIT market, the government determines the price (S. Youn & K. Kwon, personal communication, July 21, 2022).

Depending on the type of renewable energy, the certificate has additional weight to it. Solar, by-product gas, waste/landfill gas, hydropower, wind, tidal power, wood and biomass, and fuel cell-produced energy are all eligible for additional REC weights (Korea Energy Agency, 2015). Weights range from no additional weight to 5.0. If a renewable energy producer generates 1 MWh of renewable energy with a 5.0 weight, then the 1 MWh is treated as 5 MWh of renewable energy generation (**Table 5.2**). MOTIE determines the REC weighting in consideration with capital expenditure and carbon footprint (S. Youn & K. Kwon, personal communication, July 21, 2022). The goal of the REC is to even out the costs of renewable and non-renewable energy production by effectively subsidising renewable energy production and mandating an RPS. Every three years, MOTIE assesses the multipliers to determine their future values, considering changing costs of technology and the potential for market disruption (Chang et al., 2021; S. Youn & K. Kwon, personal communication, July 21, 2022). It anticipates that the multiplier weight would decrease over time as investment costs fall and a higher weight is no longer necessary to compensate the high initial costs (Y. H. Lee et al., 2021).

In accordance with the guidelines, the weighting of renewable energy varies. Depending on the facility type and installed capacity, solar PV can have a weighting from 0.7 to 1.5. Offshore wind can see a weight between 1.0 and 2.5 depending on if it is fixed or variable (Korea Energy Agency, 2015).

Table 5.2: Renewable Energy Certificate weighting scheme without Energy Storage System.

REC weighting scheme

Category	REC weighting	Energy source and criteria	
		Facility type	Criteria
Solar PV	1.2	Facility installed on general site	Less than 100kW
	1.0		More than 100kW
	0.7		More than 3,000kW
	1.5	Facility installed on existing buildings	Less than 3,000kW
	1.0		More than 3,00kW
	1.5	Facilities floating on the water	
Offshore Wind	2.0	Offshore wind (grid connection longer than 5km)	Fixed
	1.0-2.5		Variable

Source: Korea Energy Agency (2015).

Applying the RPS to energy storage

In 2016, the government introduced a specific weighting for wind and solar energy installations equipped with storage: for each MWh of electricity generated in this way, manufacturers could receive 5 RECs (Ministry of Trade, Industry and Energy (MOTIE), 2016). For instance, to earn an REC from renewable energy with an ESS component, solar PV systems must store some power generated between 10:00 and 16:00 and transmit energy to the grid during other times (Jo & Jang, 2019). ESSs in combination with wind or solar energy have had the highest multipliers offered. MOTIE rationalised these multipliers citing that the ESS component of the renewable energy will boost efficiency and economic feasibility. MOTIE projected that the new multipliers would create an ESS market of over USD 330 million and 800 MWh of storage capacity, in addition to creating a competitive export industry (Ministry of Trade, Industry and Energy (MOTIE), 2016).

Solar and wind energy in combination with ESS have had significant multiplier fluctuations over time, as illustrated in **Table 5.3** (Korea Energy Agency, 2015). Both started with the highest multiplier, 5.0, and have since seen a decline in the multiplier, at first slowly and then more suddenly. This sudden change was driven by safety issues; between 2019 and 2022, there were over 30 fires related to ESS batteries (Son, 2022). To mitigate the issue, in 2021, MOTIE temporarily reduced the multipliers given to ESS and renewable energy combinations from 4.0 to 0.

Table 5.3: Renewable Energy Certificate multipliers for 'wind and ESS' and 'solar and ESS' over time.

Technology	2016	2017	2018	2019	2020	2021
Wind + ESS	5.0	4.5	4.5	4.5	4.0	0
Solar + ESS	5.0	5.0	5.0	5.0	4.0	0

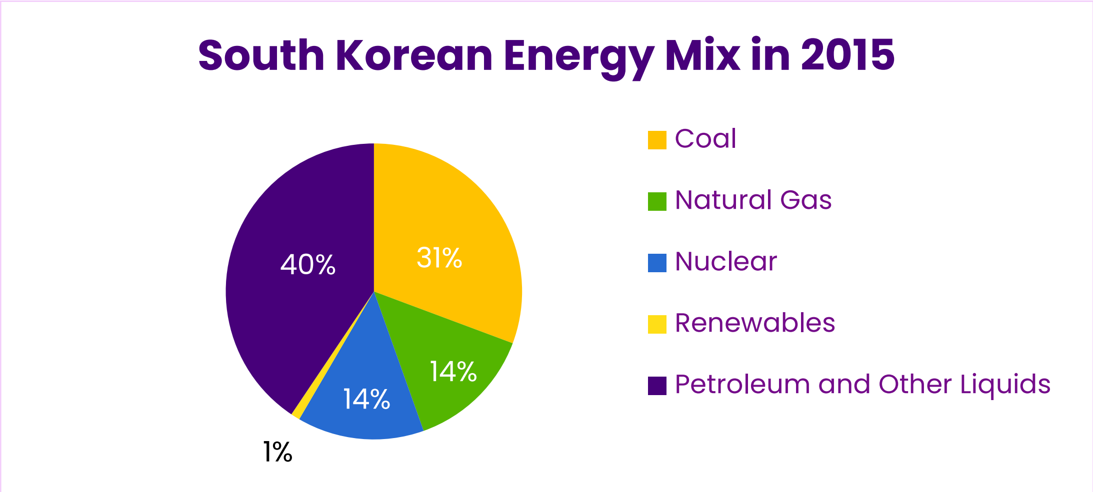
Source: Korea Energy Agency (2015).

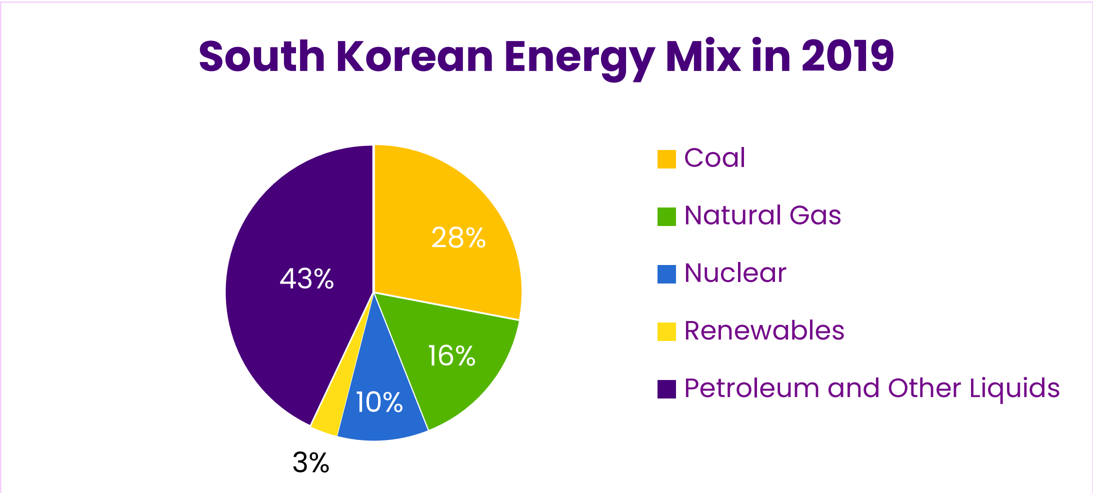
5.4.4 Policy evaluation

Under President Moon, South Korea slowly started reducing its fossil fuel consumption. Between 2011 and 2021, South Korea's share of energy derived from fossil fuels decreased from 88% to 82.5% (Koons, 2022; U.S. Energy Information Administration, 2013). At the same time, South Korea doubled its renewable energy consumption. The RPS has supported significant changes to the South Korean electricity market since its introduction. In 2011, before the RPS was introduced, renewable energy made up less than 1% of South Korea's total primary energy consumption (U.S. Energy Information Administration, 2013). Ten years later, the energy mix is comprised of 7.5% renewable energy sources, making for a total of 43,085 GWh of renewable energy. The year 2021 marked the first time renewable energy made up more than 7% of South Korea's energy mix (Yonhap News Agency, 2022). While progress has been made, large strides are still necessary to achieve President Moon's goal of a 30% share of renewable energy by 2030, as illustrated in **Figure 5.7** (H. Lee, 2021; U.S. Energy Information Administration, 2020). When President Yoon took office, he announced that the renewable energy targets for 2030 would be lowered to below 30% (H. Lee, 2022).

In 2012, South Korea had an installed solar PV capacity of 1024 MW. As of 2019, the installed capacity had increased to 11,767 MW (C. Park et al., 2021). The dramatic increase in capacity highlights the successful efforts of renewable energy targets, the RPS, and subsidy programmes. Wind energy has also seen a similar growth in installed capacity. In 2012, South Korea had 485 MW of installed wind energy capacity (Statista, 2020). By 2019, wind energy capacity had increased to 1490 MW (Statista, 2020). Despite advances, South Korean wind energy is considered underdeveloped because it only generates 1% of the country's electricity demand (Energy Tracker Asia, 2022).

Figure 5.7: Proportions of South Korean energy mix in 2015 and 2019.

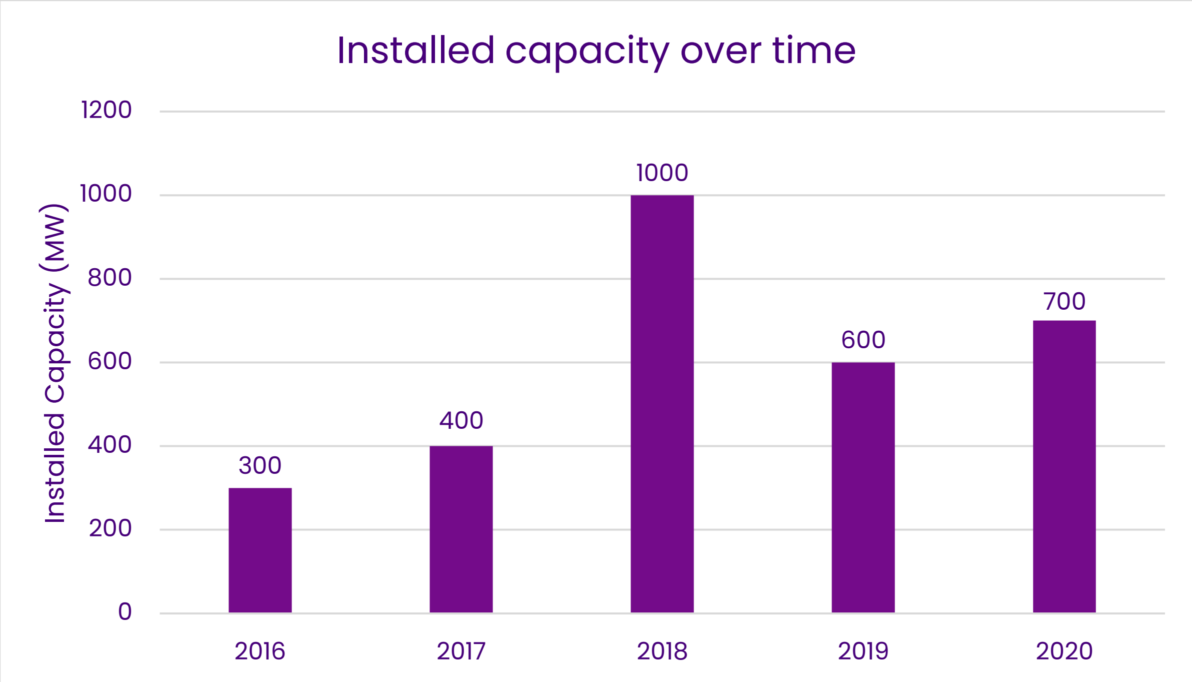




Source: U.S. Energy Information Administration (2020).

Expanding the programme to energy storage had a clear impact on the installed storage capacity in the country. Despite initial concerns that ESS was not economically viable on a large scale, the technology has become widely adopted by energy producers. In 2013, the installed ESS capacity was only at 28 MWh (Korea Energy Agency, 2016). By 2020, installed capacity reached 700 MWh (IEA, 2021a). In terms of installed capacity, South Korea only lags behind the US and China. South Korea deployed 1284 units between 2016 and 2019 — shown in **Figure 5.8** (Hwang & Jung, 2020; IEA, 2021a).

Figure 5.8: Installed energy storage capacity over time.



Source: Hwang & Jung (2020), IEA (2021a).

The programme also exceeded government expectations. In 2013, the ESS market was about USD 69 million (Hwang & Jung, 2020). At the time of the expansion of the RPS to include ESSs, the government projected the market to increase to USD 392 million between 2016 and 2020 (Deign, 2016). However, by 2018 the domestic market had already grown to be USD 1.5 billion (Hwang & Jung, 2020). This growth has largely been due to the decreasing costs of ESSs, driven by the economies of scale made possible, among others, by the RPS scheme. In 2014, the volume weighted average cost of LiBs was USD 592. By 2020, the cost had fallen to USD 137 (Roeper, 2020). While this reflects global average prices, because South Korea represents such a large fraction of the global market, the country has been a significant player in driving down ESS prices.

South Korea's ESS growth is demonstrated by its global position in manufacturing ESS technology. Samsung SDI and LG Chem, two South Korean chaebols, are major players in the global ESS market. ESSs do not have standardised battery components, which could complicate further market expansion (Hwang & Jung, 2020). The lack of international compatibility may be an issue for international market expansion, but this applies to all actors, not just South Korean ones. South Korea, China, and the United States represent the three main players in the global ESS market. China and South Korea have the advantage of larger domestic battery industries that can support the newer ESS manufacturing through shared materials and establish processes (Hwang & Jung, 2020). Furthermore, the ESS market is prominently based in the Asia Pacific region, reducing distances between manufacturers and consumers, given the Chinese and South Korean market shares (U.S. Department of Energy, 2020b).

The rapid expansion of the ESS industry in South Korea is not without drawbacks. Critics of the programme highlight the fact that it simply focuses on ESS capacity, not on safety measures or efficacy (S. Lee, 2019a). Starting in 2018, and continuing in the following years, many ESS facilities suffered fire accidents. LiBs are especially prone to fires because they have high energy density, meaning shocks, overheating, and overcurrent can cause them to ignite (S. Lee, 2019b). The repeated fires stoked concerns over ESS usage and the market represented those concerns, when it was almost halted (Publicover, 2019). The lack of safety, maintenance, and standards — both domestic and international — allowed ESS facilities to continue operating without the necessary precautions (Hwang & Jung, 2020). As fires continued, investigations found that their main causes were poor monitoring and protection systems (S. Lee, 2019a). It was hoped that the government's investigation into, and addressing of, the causes would help the ESS market rebound after a rough couple of years (C. Park et al., 2020).

Another point of critique is the complicated nature of the scheme. There are four different markets for different renewable energy certificates, which makes it more challenging for smaller energy producers to navigate the market. It also reduces transparency and external oversight over the programme. Information on which companies are purchasing and selling which RECs is private information, not publicly released. While it protects company privacy, it fails to publicly call out companies that rely heavily on RECs to compensate for their non-renewable energy production, or to laud the companies growing their renewable energy base and selling their certificates (S. Youn & K. Kwon, personal communication, July 21, 2022).

Finally, the aim of increasing the competitiveness of renewable energy systems equipped with storage is countervailed by the stringent zoning regulations, which lengthen the process of the investment and increase the regulatory and construction costs of navigating the complicated process. These strict and complicated regulations could be streamlined, which would reduce the cost of renewable energy and the time required to build up the renewable energy infrastructure (S. Youn & K. Kwon, personal communication, July 21, 2022). While the REC multipliers aim to make the investment costs more surmountable by increasing the worth of ESSs and renewable energy, they do not counter the fact that government regulations cause the high investment costs.

5.4.5 Discussion

The South Korean government's strategy to grow its domestic storage market has led South Korea to become one of the most successful countries in the world in deploying energy storage. By directing generous subsidies towards ESSs, the early-stage risks linked to high upfront costs were avoided, making ESSs more attractive to investors. Rather than being a permanent subsidy, the REC multipliers were designed to reduce over time as investment costs fell. The government's storage strategy also focused on increasing domestic manufacturing and improving battery cell life. To this end, storage benefitted from strong government support and the South Korean economy received a range of co-benefits due to the growth in its domestic LiB market.

South Korea's RPS scheme was not created solely for storage. It has also benefitted a range of other renewable technologies and helped them to gain a foothold in the market. However, the strong preference shown towards ESSs and the rapid growth in capacity compared to other countries makes this aspect of the policy particularly noteworthy.

Despite the significant increase in storage capacity, the lack of appropriate monitoring and protection systems have meant that fires have been an issue for South Korea's storage market. It is hoped that the resulting drop in deployed ESSs will be resolved by the government's investigations into safety standards. However, the numerous fires indicate the importance of safety standards, particularly for LiBs. The government's strategy to promote ESSs focused heavily on Li-ion batteries. Given the destructive mining practices associated with lithium extraction, strengthening support for other technologies to help them compete with LiBs would enhance the overall policy.

The combination of the RPS system with the REC scheme was useful in requiring power companies to procure renewable energy, while attracting private investment. Although complications exist and South Korea is still a long way off meeting its 2030 renewables targets, the RPS scheme provides an effective market mechanism with which to improve the profitability of storage and drive investment towards it.

5.5 Lessons for the European Union

While the EU proceeds with the development of renewables, especially wind and solar, which in 2021 provided 19% of the electricity generated in the EU (Taylor, 2022), it lags behind California and South Korea in terms of storage development. With an 11 times larger population than California, combined battery storage in the EU amounts to 10 GW — around the same capacity as that of the US state (Taylor, 2022). This is expected to increase to around 57 GW by 2030. In contrast, around 200 GW are needed to integrate the high shares of wind and solar PV that the EU aims to deploy (European Commission, 2022h; C. Moore, 2022).

This comparatively small contribution of storage has been determined by focusing on other ways to deal with the variable character of renewables, such as reliance on hydropower (including pumped storage) or interconnections with other countries. However, the primary way of dealing with the relatively small share of variable renewables has been through the flexibility offered by fossil fuels, especially fossil gas.

The role of many of these options will decrease in the future. Russia’s invasion of Ukraine and the curbing of fossil gas exports to the EU severely undermined the strategy of relying on gas to balance the grid. While in the short term the EU and some member states plan to replace it with coal, this a temporary solution due to coal’s high emissions intensity and the plans of almost all EU member states to phase it out by the end of the decade. In addition, the EU, like California, is becoming increasingly affected by droughts, which limit the potential of hydropower to stabilise the grid. Unlike California, many EU member states need to focus more on long-term, seasonal storage. However, short-term, diurnal battery storage would reduce the significant differences between electricity prices that result from variable renewables, especially in the summer (Agora Energiewende, 2022).

Increasing storage capacity could allow EU member states to not only reduce the role of fossil gas as a balancing source of electricity but also help to ensure that the ramp-up of coal-fired power plants is only temporary. Furthermore, as demonstrated in the case of Aliso Canyon, it can be ramped up in a matter of months if needed. The upfront investment can pay for itself relatively quickly, by reducing reliance on expensive gas.

To ensure that the goals are met, at least initially, European countries can follow California’s lead by requiring electricity utilities to install short-term storage. To avoid overburdening new entrants, the storage capacity installed could constitute a certain percentage of the average generation capacity that was managed by the utilities in the previous five years. Keeping in mind the ongoing energy crisis and the need to replace large portions of fossil gas while continuing with the coal phase-out in the short term, the deadline to meet these goals would have to be staged, with annual, steadily increasing targets.

South Korea represents a different method which the EU can use to increase storage capacity. Rather than setting a mandated storage target, the South Korean case focused on a market-based mechanism to stimulate growth. The central aim of the government's policy was to even out the costs of renewable and non-renewable energy production by effectively subsidising renewable energy production. The high upfront investment costs of ESSs were thus balanced out by the generous multipliers assigned to them. Both the government's clear strategy and its assistance in reducing the early-stage risks of storage investment, provided certainty to investors and directly contributed to South Korea's storage boom. Given that European countries spent EUR 56 billion on fossil fuel subsidies in 2019, with 15 countries spending more on fossil fuel than green energy, a restructuring of market mechanisms to prioritise green energy systems is sorely needed (European Court of Auditors, 2022).

The South Korea and California case studies both demonstrate how supporting technologies with high upfront costs eventually contribute to price declines. Storage will play a key part in the EU's clean-energy transition, but unlocking its financial potential for investors is essential if the required capacity is to be met. Although South Korea directly subsidised storage, subsidies played a much smaller part in the Californian storage boom. However, Californian utilities continued to procure storage well in excess of what they were required to by law, showing that storage is already financially viable within a well-adjusted regulatory framework.

One of the major barriers to storage uptake in Europe is that it is not properly valued. The variety of benefits that storage brings to the grid, including flexibility and grid resiliency, load shifting, and adjusting power frequency needs to be adequately valued, not simply to attract investors, but to allow storage to fairly compete in the market. In the US, the updating of federal-level regulations allowed storage to access multiple revenue streams, thus aligning incentives with performance so that more efficient resources could receive better pay. European policy-makers ought to pay attention to this element of California's storage boom. Well-crafted policy will unlock the array of benefits that storage brings to the grid, while translating these benefits into financial rewards for investors.

A challenge experienced in South Korea, that is familiar to European observers, is the expensive and lengthy process of gaining planning permission. Although the South Korean government was proactive in subsidising ESSs, this financial support was counteracted by a complex planning process, which only served to increase costs and slow down uptake. Similar issues exist in Europe, with a complicated permitting process acting as an obstacle to the rapid uptake of storage that will be necessary for Europe to integrate RePowerEU's renewables targets (STEPS, 2021). A streamlining of the permitting processes is thus strongly encouraged.

The ongoing uptake of electromobility and battery storage worldwide has resulted in a lithium deficit that will make achieving the binding storage targets more challenging. There is already competition over the resource between the US and China, and it is important that Europe is not left behind. However, destructive mining practices and local opposition in some countries to lithium extraction mean that diversifying storage technologies will safeguard European energy security into the future. Developing an export market for storage was a core element of South Korea's strategy, which was more successful than initially hoped. In the near term, ensuring consistent access to LiBs will be an important part of the clean-energy transition. This should also include evolving the regulatory framework to improve the competitiveness of second-life batteries, rewarding circular use of the resource.

At the same time, energy utilities should be encouraged to diversify the technologies used to meet Europe's storage targets. European policy-makers should be encouraged to recall the motivations behind California's AB 2514, which expressly intended to foster technologies and help them reach maturity, and South Korea's storage plan, which aimed to increase domestic manufacturing. A wide range of disruptive European start-ups already exist, and if investments and subsidies are well targeted, a European storage boom will also mean a European manufacturing boom.

Another aspect in which flexibility is important concerns the storage location: electricity utilities should be allowed to develop storage assets — or purchase certificates reflecting their installation — in any EU member state. Since it can be assumed that utilities will build storage in places where the diurnal electricity price is the most volatile, such an approach would increase the impact of the policy on grid stability and reduce CO_2 emissions by replacing fossil fuels.

Proactive policy will be necessary for the storage capacity to increase in line with wind and solar PV. The Californian and South Korean examples provide important lessons regarding what works, and what can be improved on, as storage capacity is increased. Given the urgency to reduce emissions in this decade and the high shares of renewables to be deployed by 2030, it is imperative that Europe learns from other best practices in order to develop a comprehensive storage strategy aimed at rapidly increasing deployment.

5.6 Conclusions

The EU's goal of increasing the share of renewables to 45% of the overall energy mix by 2030 will necessitate a large increase in storage capacity. The Commission's recognition of battery storage as holding strategic value demonstrates the technology's importance to the bloc's clean-energy transition. However, the recently released RePowerEU plan contains no energy storage strategy, though the Commission is currently working on a Staff Working Document on storage, which is expected to be released in October 2022.

Both California and South Korea offer different methods, which the EU can look to in its efforts to increase storage capacity. While California focused on procurement mandates that required utilities to obtain set amounts of storage within a given timeframe, South Korea increased capacity through financial incentives. The dividing line between both examples is a greater commitment to either a carrot or stick approach, though a combination of mandates and financial incentives was present in both cases. Ultimately, both case studies represent the importance of government support for increasing storage capacity.

Given the complexity of regulatory frameworks and the way in which different grids operate, what works in one state or country may not be directly transferable to another. Furthermore, different weather patterns require different solutions to manage renewable variabilities. For instance, countries in western Europe which have numerous consecutive days with insufficient sunshine or wind, will require technologies that can meet the grid's needs over days rather than hours.

The Californian and South Korean examples provide valuable lessons for EU policy-makers, but further research is needed to determine exactly how to translate these successes into the European context. Alongside the overarching policies of mandates and RECs, proper valuation of storage and removing barriers to its market access helped to improve storage uptake. Research which focuses on how to most effectively value storage in the EU context and ease its access to the European market will be useful to identify areas which impede deployment. Likewise, identifying long-duration storage technologies particularly suited to the European context will be an essential part of the clean-energy transition. For this, not only research, but investment, will be required.

6. Archetype 5: Railways

6.1 Introduction

With over 28% of the EU's emissions coming from transport sector (cite dashboard), railways can be of great importance to decarbonise transport, especially for short and medium distances. For almost all domestic trips, EU member states can replace air travel with high-speed trains and, in this way, result in emissions reductions. The decrease in emissions from transport in 2020 due to the COVID-19 pandemic belies the development of the transport sector in the EU over several years: while the amount of goods transported by rail between 2012 and 2019 increased by almost 2% for the EU countries for which data are available (Eurostat, 2022b), and the number of passengers increased by almost 14% (Eurostat, 2022d), the same time period saw an 8% increase in the amount of goods transported by road (Eurostat, 2022e), as well as a 40% increase in the number of air passengers carried in the EU (Eurostat, 2022a). Likewise, the impact of the pandemic was unevenly distributed among the different modes, with rail experiencing larger decreases for both freight and passenger travel than road.

Facilitating the modal shift towards rail for both passenger and freight transport would contribute heavily towards the reduction of emissions from the transport sector in the EU. In 2016, railways contributed to just 0.5% of the total transport sector emissions, according to the European Environmental Agency (2019). High-speed rail (HSR) in particular has significant decarbonisation potential, with up to 90% fewer emissions when compared to driving or flying (P. Chen et al., 2021). The Future of Rail report by the IEA highlights the potential benefits of investing heavily in all forms of rail travel, including metros and trams: greenhouse gas (GHG) emissions are 2.1 $GtCO_2e$ lower in 2050 compared to the current baseline, and there are lower particulate matter emissions, less energy demand, and lower levels of congestion (IEA, 2019). And while the required infrastructure investments are substantial, the potential for unlocking the value of land surrounding railroads and stations and for avoiding expenditure in purchasing fuel and expanding road and parking infrastructure, makes rail a worthwhile investment.

Unfortunately, the EU is not fully utilising the potential of railways: not only has the share of railways in inland freight transport decreased from 19% in 2012 to 18% in 2017 (Eurostat, 2022c), the increase in the share of rail in passenger transport in the same time period (from 7.8% to 8%) has come at the expense of buses, and is accompanied by an increase in the share of private vehicles (EEA, 2022b). This is broadly reflected in the financing and infrastructure investments for transport in some EU, and other, countries: between the years 2000 and 2018, the EU, UK, Norway, and Switzerland collectively invested more in road infrastructure (EUR 1341 billion) than in rail (EUR 843 billion) (Schmidt & Curic, 2021). Within in the EU, the development of transport links between member states is financed through the Cohesion Fund (CF) and the European Regional Development Fund (ERDF). For the financing period between 2014 and 2020, EUR 33.7 billion was allocated for roads, and EUR 19 billion was for rail.

The report proceeds as follows: Section 6.2 motivates the case study selection by highlighting the necessity of proper financing mechanisms and coordination in infrastructure investment for all forms of rail. Section 6.3 presents the case study of railway development in Japan. Section 6.4 presents the case study of railway development in Switzerland, and Section 6.5 draws on lessons from the case studies relevant to EU policy-making. Section 6.6 concludes the report.

6.2 Why consider alternatives to current EU railway policy?

While the EU is making some headway towards increasing the share of rail transport, particularly through committing greater funds to infrastructure development, it is not nearly enough to elicit the transformative modal shift in transport that is necessary for the effective decarbonisation of the transport sector. In addition to there being a greater availability of funding for the construction of road infrastructure vis-à-vis rail infrastructure, the EU is facing a decline in rail lines in operation: the total length of serviceable rail lines has decreased by more the 2000 km between 2012 and 2019.

The following deficiencies and challenges can be highlighted in the current state of EU railway policy-making:

1. There is no possibility of a top-down approach to mandate or implement the construction of railway infrastructure nor to design a network of transboundary long-distance trains and bring them in operation (Treber, 2022). The European Railway Agency's (ERA) mandate relates solely to the certification of train safety and the implementation of the European Rail Traffic Management System (ERTMS), but the member states are responsible for the construction of infrastructure, and decisions on how and when to spend European infrastructure funding, leading to the pervasiveness of national interests over international ones (Witlox et al, 2022).
2. This fragmentation of EU railways policy to the national level leads to severe coordination and compatibility issues. The lack of a common language and differing technical train protection and control systems are but one side of the problem of interoperability. EU passengers are unable to book travel that requires multiple connections across various providers, whereas booking a plane ticket across multiple

stops and providers usually requires just one stop. There are also few cross-border connections with a through-train service, requiring passengers to switch trains when crossing borders and reducing the convenience of such a journey, particularly when navigating different rail systems of neighbouring EU member states (Witlox et al, 2022).

3. The amount of public funding available is insufficient to effect the transformative change necessary for decarbonisation. The Connecting Europe Facility (CEF) only has EUR 26 billion available for railways for the period 2021 to 2027, and the EUR 85 billion for railway infrastructure in the framework of the Recovery and Resilience Fund (RRF) has to be spent by 2026, resulting in a focus on short-to-medium-term improvements.
4. EU member states are progressing at varying speeds: Poland makes greater use of the CEF for railway projects than any other member state, at EUR 6.3 billion for the 2014 to 2020 period (Schmidt & Curic, 2021). However, there are no minimum targets set for individual member states.

There is a need for a unified top-down approach in railway governance at the EU level that can set rules and targets for both infrastructure development and harmonisation of the sector from an operability and customer-facing perspective. There is also a need for the provision of requisite public financing for rail infrastructure, to increase the share of rail in the modal mix and decarbonise the transport sector faster.

Box 6.1 Why are railways important for infrastructure?

Railways development is crucial to the carbon neutrality goals of the EU. While indirectly relevant to integration and innovation, investment and more importantly, infrastructure, are the core areas that primarily concern railways.

Railways development is capital intensive. Large-scale, up-front investments are necessary to buy up land, and then construct all the railroad tracks and stations needed for climate neutrality on it. Signalling, railroad management, and booking require large expenditures on both hardware and software to keep railway businesses functioning, particularly across national borders.

Whether or not passengers will engage in a modal shift from road and air transport to the less polluting rail transport is dependent on multiple factors, primarily focused on convenience (including travel time) and price. While high speed trains in the EU already exist, they often cannot achieve their maximum speed due to lack of dedicated tracks and having to share them with regional trains. Direct connections between large urban centres are also lacking, requiring frequent stops and changes (Witlox et al, 2022). To properly shift customer demand to rail, there needs to be adequate infrastructure to lure them away from airlines and cars. While EU member states receive considerable funding for construction and maintenance of rail infrastructure, it still pales in comparison to funding for road transport, and frequently gets directed to domestic routes, rather than improving cross-border travel.

Customers are also deterred by the perceived high price of rail travel (Witlox et al, 2022). Flights are oftentimes cheaper than comparable trips by train, particularly across EU borders, discouraging a modal shift. Multiple reasons lie behind this: government subsidies for airlines and air travel, greater flexibility for airlines to shut or redirect underutilised routes, and airfare not including the full costs of the carbon emissions they are responsible for (Baker, 2021).

Without the proper infrastructure and financing structures, coupled with integration of railways across national boundaries, railways will be unable to compete with and draw passengers away from more carbon-intensive modes of transport.

6.3 Case study 1: Railways in Japan

Japan's railway system is managed by a privatised approach in which companies function on the basis of market-based competition, working towards integration of infrastructure, management and train operation, a system very much different to that of the EU. The case study is opened by Section 6.3.1 which introduces the context of Japan's socio-economic evolution in the 20th century, leading the corresponding need to advance infrastructure as the country developed. Section 6.3.2 then initiates the discussion around the policy development by the government to privatise Japan's railway network, followed by Section 6.3.3 covering the dynamics of private railway companies and government in coordination of certain policy areas around improving efficiency relating to costs, operations, profits and revenues. Section 6.3.4 details what funding approaches have been taken by companies and government in addressing costs linked to operations and infrastructure development. This then leads to Section 6.3.5 detailing infrastructure development. Section 6.3.6 evaluates Japan's approach to management and infrastructure development of its railways and lastly, Section 6.3.7 provides a brief discussion of what lessons can be extracted.

6.3.1 Context and background

After the Second World War, the Japan National Railways (JNR) faced little to no competition from other modes of travel. As a result, the railroads continued to play a key role in transportation. However, their share decreased steadily: while in 1955 over 82% of the passenger-kilometres were travelled by train, ten years later, this share fell to 67%, and 46% by 1975. This decrease in share took place despite an absolute increase in the activity levels: the number of passenger-kilometres travelled by train increased almost 2.5-fold between

1955 and 1975. However, this increase halted in the subsequent decade and the share of railways in passenger transport decreased to 38% in 1985, with cars taking over from trains for the first time (Doherty, 1999).

This shift from rail to road was caused by the structural changes in Japan's economy and motorisation during a period of high economic growth. The same phenomenon was observed in freight transport. JNR was not able to adapt to these social changes in time, which put pressure on its management. The size of the JNR, which spanned the entire country and employed a large number of people, made its budget setting system extremely inflexible. Since management decisions did not keep regional conditions in mind, inefficiency was a predictable outcome. As a result, JNR faced severe public criticism for ineffective management, but the necessary operational reforms could not be pursued, mainly due to strong opposition from politicised labour unions (Taghizadeh-Hesary et al., 2021).

The situation was worsened by the fact that details of fares, employee wages and personnel matters were strongly influenced by the government and the workers unions: any price adjustments often led to a public outcry and so did the standard fares across the nation, which did not take into account the difference in regional costs and requirements. Vested interests were taking precedence over efficiency and effectiveness (Mizutani & Nakamura, 1997). As a result, after a period of profitability driven by the JNR monopolist position, the company went into the red in 1964 (Tomikawa & Goto, 2022), and therefore JNR accumulated long-term debt which, at the time of the JNR reform in 1987, amounted to JPY 37 trillion, equivalent to almost USD 200 billion (Kurosaki & Alexandersson, 2018).

To reform JNR management, the Act on Special Measures to Promote the Management and Reconstruction of Japan's National Railways was enacted in 1980. Under this law, JNR separated its lines into trunk and regional, promoted the replacement of less profitable regional lines to bus services, and transferred these operations to the third sector, with joint public and private investment. In 1982, the Provisional Administrative Investigation Committee issued a report recommending privatisation as the solution to the various problems in the government-owned, centralised organisation.

6.3.2 Policy development

The privatisation of state-owned enterprises has been a global practice, with the goal of improving their performance and profitability, since the 1980s. It was with this background that the pressure to privatise JNR took place. After discussions and deliberations by the Reconstruction Management Committee, the National Railway Reform Bill was submitted to the National Diet (Japanese Parliament) for approval in 1986, the year in which JNR was at the brink of bankruptcy. In April 1987, JNR was privatised, and the passenger section was divested into six regional joint-stock companies. The distribution of roles was made based on the geography and functions, and conducted in a way that would ensure provision of transport services (Tomikawa & Goto, 2022). As opposed to the railway privatisation experiences in Europe, there was no separation of infrastructure and operation, which allowed these different enterprises to use their assets for the diversification of its business lines (C.-J. Kim & Huang, 2019).

The Japanese approach to railway privatisation had six distinguishing features:

1. horizontal separation (or regional subdivision),
2. functional distinction (or passenger-freight distinction),
3. vertical integration (or operation and infrastructure integration),
4. lump-sum subsidies for low-density JRs,
5. the establishment of the JNRSC as an intermediary institution, and
6. allowance of non-rail service (Mizutani & Nakamura, 1997).

Combined, these features allowed for a significant increase in flexibility of the railways, while simultaneously ensuring that all regions continue to benefit from the railways' availability. To get there, in a first step, the government's control was reduced substantially to the level of creating regulations necessary for the railways' operations. This framework was expected to eliminate unnecessary outside interference, establish management autonomy, and clarify management responsibility.

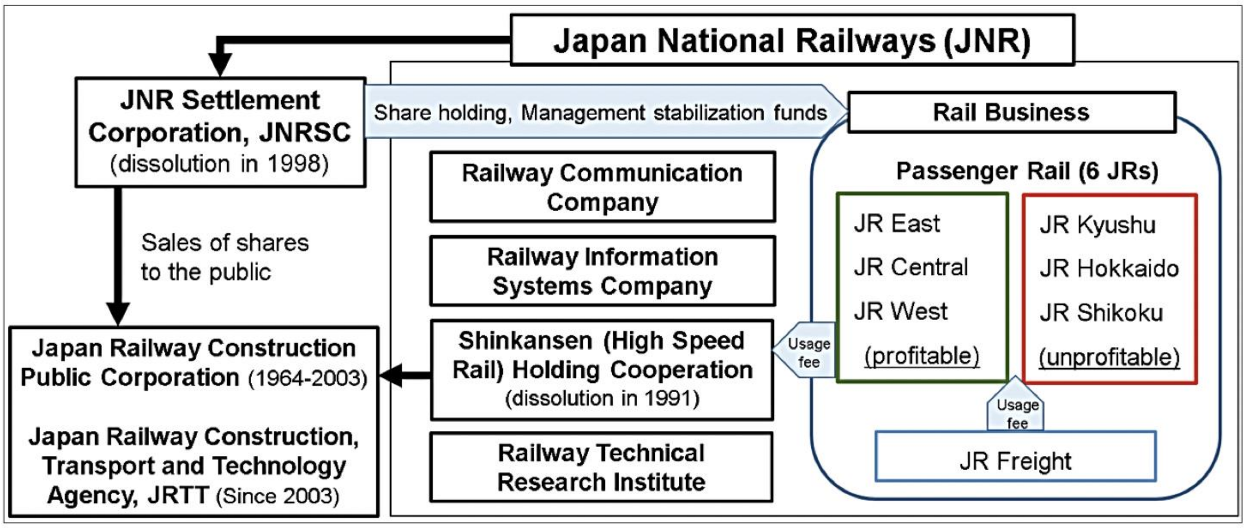
The reform was led by the establishment of the Japan National Railway Settlement Corporation (JNRSC) — a temporary holding company (Taghizadeh-Hesary et al., 2021). The reason why the government established such a company was its deep concern about the JNR's dismal reputation for being deficit-laden and inefficient, which could not attract enough interest from investors, negatively affecting the stock prices of newly created railway companies (Taghizadeh-Hesary et al., 2021).

The JNRSC organisation was converted from a public corporation, which was one government body, to a special corporation in a stock company-style commercial body but still regulated by special laws (Mizutani, 1999). As a result, each of the six companies were expected to become fully private corporations (Ito & Krueger, 2004). JNR ceded liabilities to the new companies only to the extent that they would not hinder sound management in the future. Remaining liabilities were assumed and disposed of by the JNRSC. JNR also ceded the minimum assets necessary to make the new companies viable as railway operators. Assets not ceded to the new companies were sold to the public by the JNRSC to repay the liabilities left by JNR (Taghizadeh-Hesary et al., 2021). The JNRSC began to sell its shares in JR companies in the early 1990s. In 1998, it was dissolved, and the Japan Railway Construction

Public Corporation was formed to settle the remaining obligations of the JNRSC (Milhaupt & Pargendler, 2018).

This horizontal split and the relationship between the companies is evident in the figure below, whereby JR Freight pays usage fees to the remaining JR companies for their tracks, and all of them paying usage fees to the signalling and systems information companies managing track usage coordination.

Figure 6.1: Breakdown of the JNR privatisation.



Source: Taghizadeh-Hesary et al. (2021).

The management was given full capacity and responsibility over managerial decisions, including the labour-management relationship that was envisaged to be resolved independently between trade unions and management. Equally important, railway companies were able to diversify and expand into other fields of business aimed at increasing their corporate revenues.

After consideration of several options for separation, regional subdivision by geographical demand was decided upon with the smaller, subdivided companies expected to meet their users' local needs, and to compete with each other to improve their performance (Mizutani & Nakamura, 1997). Accordingly, the JNR was divided into six vertically integrated regional passenger companies, and a single vertically separated nation-wide freight company, JR Freight — their business areas are reflected in the figure below (Kurosaki & Alexandersson, 2018).

Figure 6.2: Geographical division of Japan railway companies.

Source: Kurosaki & Alexandersson (2018).

Apart from clarifying management responsibility by eliminating external interference and removing inefficient interdependencies, these changes aimed at promoting incentives for competition and strengthening regional management and collaboration. By allowing the independent railway companies to diversify their business fields, they could better satisfy the needs of their customers at more manageable scales (Taghizadeh-Hesary et al., 2021).

The question of loss of employment was a pertinent one that had to be dealt with at that point, considering the fact that JNR employed almost 280,000 people in April 1986, with an estimated 93,000 excess personnel after the JNR reform (Kurosaki, 2016). The government approached this issue by establishing a Surplus Personnel Reemployment Measures Headquarters and by enacting a special law which requested active cooperation from various national sectors to employ them. As a result, the new railway companies reemployed 203,000 workers, while the others changed jobs or retired (Kurosaki, 2016).

6.3.3 After privatisation

As a result of the privatisation, Japanese railway companies owned the infrastructure, rolling stock, and other equipment, and took the primary responsibility of their finance and management, especially with regard to the procurement of new rolling stock. However, the government would also play an important role in providing a master plan for their long-term development and create the necessary policy framework for railway construction by offering subsidies for the construction of new railways, particularly within urban centres and for high-speed rail. It would also make sure that the railway companies ensure safety and security, and create a user-friendly railway system (Ministry of Land, Infrastructure, Transport and Tourism, 2008).

Tomikawa & Goto (2022) carried out the most comprehensive study of the JNR privatisation legacy by implementing data envelopment analysis on various financial and operational inputs and outputs before and after privatisation, covering the period 1965 to 2017. They analysed four main efficiency categories: profit-earning efficiency, cost efficiency, operational efficiency, and revenue-earning efficiency. Each of these is comprised of one input and one output from the following list of characteristics: costs (personnel and non-personnel costs), revenue, operational resources (number of employees and vehicles), and operational output (vehicle kilometres travelled and passengers carried).

Cost efficiency

Cost efficiency uses costs as an input and operational resources as an output. In other words, it demonstrates how much expenditure is used to maintain current levels of employees and vehicles operated, with a higher number of vehicles and employees per unit of expenditure indicating good performance. Starting with a high cost efficiency in 1965, the value plummeted to 0.7 in 1986, recovering slightly after privatisation to 0.13, where it remained to this day.

Operational efficiency

Operational efficiency utilises operational resources as an input and operational outputs as an output. In other words, it evaluates how many employees and vehicles the company uses to achieve its current number of passengers transported and vehicle kilometres travelled. The more passengers and vehicle kilometres travelled per employee and vehicle, the higher and better the efficiency rating. The reform initiated in the 1980s had a positive impact on the operational efficiency. It remained slightly below 0.8 in the 1960s and 1970s before falling to slightly above 0.7 just before the privatisation, after which it continued improving significantly to over 0.9 on average, reaching full efficiency in 2017. The increase is mainly supported by a large volume in passenger traffic carried by the mainland companies combined with corporate efforts to improve performance, and structural reforms to produce higher operational output (vehicle kilometres and number of passengers carried) using fewer operational resource (number of employees and number of railroad vehicles).

Revenue-earning efficiency

Revenue-earning efficiency uses operational outputs as an input and revenue as an output. In other words, it demonstrates how well the company is able to convert the number of passengers carried and vehicle kilometres travelled into revenue. It has been increasing steadily since the 1970s, reaching 0.9 in 1987. After a slight decline in the 1990s, it started increasing again after 2000 and approached 1.0 in 2010.

Profit-earning efficiency

Profit-earning efficiency, on the other hand, depicts how much of a company’s costs, the input, are translated into revenues, the output variable. Profit-earning efficiency decreased from 1965 due to an increase in labour cost and other expenses. This was one of the main drivers of the increasing deficits. While it improved due to increased operational revenue in 1987, it has been hovering since then at around 0.7, making it necessary to reduce expenses.

These improvements in efficiency are consistent with other studies which presented positive impacts of the privatisation on productivity and efficiency (Mizutani & Nakamura, 1997; Sueyoshi et al., 1997). However, there are significant differences between different railway companies. While Tomikawa & Goto (2022) stress that efficiency gains were experienced by all the JNR legacy companies, the positive gains in operational efficiency that are more directly attributable to privatisation are particularly strong in JR East, the only railway company of the six that managed to achieve a rating of one. Considering its overrepresentation of the total number of employees (over 41% of the total for the year ended March 2018) and total number of passengers carried (over 68% of the total in the same period), its operational efficiency score is bringing up the average for the whole group. Other JR companies, such as JR Hokkaido, with an operational efficiency of 0.49, still have room for improvement. The efficiency disparities are far removed from the deregulation policy goal that sought balanced development of JR companies, and highlight the need for further policy debate on effective subsidy for island companies that revitalises the management.

While there are few studies of the 1987 division and privatisation of JNR, there is a good measure of agreement among the ones that do exist (Doherty, 1999). Miztuani & Nakamura (1996, 1997) found improved labour productivity to be associated with lower operating costs, but also with improved service quality, particularly in urban areas. Fukui (1992) and Fukui et. al. (1994) at the World Bank found remarkable performance from 1987 to 1992, with “total performance (transport volume and profits) considerably better than that of JNR”, though that was in a favourable macroeconomic environment. The 1994 World Bank study also showed good results, but with the performance and outlook of JR operators differing with the company, e.g., JR East and JR West showed the best performance in the early period. That study also shows the government as a significant gainer, with the balance between subsidies and taxes changing from a typical annual loss to the government of around JPY 600 billion in the last four or five years of the JNR, changing to a net gain in four of the first five years of the JR companies.

One of the largest and surprising benefits of the privatisation was keeping the train fares steady, which increased the railways' attractiveness and constituted a huge relief to passengers (Yamamoto, 1993). The major private companies have raised fares three times since 1987, each time by more than 10%. The three major JR companies did not raise fares until 1999. The three weaker companies in JR, which were selected to operate the unprofitable island lines, raised fares in January 1996 by only 8%.

Improvements in their operating efficiencies permitted listing the three JRs (East, Central, and West) on the Tokyo Stock Exchange: JR East (2002), JR West (2004), JR Central (2006); they were followed by the listing of JR Kyushu a decade later (2016). It set out the pathway to privatisation, with more flexible management and investments that paved the way for the diversification of their businesses. It was expected to be even more crucial to ensure the profitability of the JR firms, given that a significant increase in passenger transport revenue is not expected in the future due to the nation's population decline (C.-J. Kim & Huang, 2019).

6.3.4 Funding

Operations

The primary source of revenue for the majority of the JR companies is ticket sales, e.g., 62% for JR West (West Japan Railway Company, 2022), 68% for JR East (East Japan Railway Company, 2022), 77% for JR Central (Central Japan Railway Company, 2022), and 32% for JR Kyushu (Kyushu Railway Company, 2022) in 2019. However, it is the vertically integrated nature of the companies that allows them to easily diversify their revenue streams, particularly into real estate; the companies develop the land they own around their stations to build hotels, lease out commercial space, and sell merchandise. This allowed not only for greater revenue for the companies themselves, but also ensured that station openings and development went hand-in-hand. JR companies could then reinvest revenues from other business lines towards the improvement of services and operating new lines.

However, not all the JNR legacy companies were able to profit from this diversification. JR Hokkaido and JR Shikoku cover sparsely populated islands with fewer dense urban centres. The Japanese government, in full realisation that JR East, JR West and JR Central would achieve financial independence quickly due to the presence of dense urban centres on the main island of Honshu, have set up a Management Stabilisation Fund (MSF) for JR Hokkaido, JR Shikoku, and JR Kyushu. The MSF was to augment their revenues and keep them running without much government intervention, in the form of subsidies. JR Kyushu has, in particular, been able to undergo the diversification of revenue streams characteristic of Japanese vertical integration, sourcing 68% of its revenues in 2019 from business activities other than ticket sales (Kyushu Railway Company, 2022). It was this diversification that allowed for its privatisation, weaning it off the MSF.

Nevertheless, the MSF's returns have not been as large as predicted, particularly in years of economic downturn, and therefore JR Hokkaido and JR Shikoku have been dependent not only on supplements to the MSF, but also on additional government subsidies to maintain their operations and still remain in public hands. Given the low population density of Hokkaido and Shikoku, and the proliferation of personal vehicles, unprofitable lines are either jointly maintained by the railway companies and municipal governments with an interest in keeping the lines running, or they are replaced by less expensive bus services where possible. In particular, the Act on Revitalisation and Rehabilitation of Local Public Transport Systems, enacted in 2007 and revised in 2008, made it possible to support unprofitable passenger lines through vertical separation (Kurosaki, 2016). Given that there is no distinct national government budget dedicated to funding the deficit of unprofitable train lines, barring a special law allowing one-off subsidies (as was the case with JR Hokkaido and JR Shikoku), the funding must be provided by local and regional governments.

6.3.5 Infrastructure development

While the Japanese government remains involved in the development of railways, its role in the operation of passenger lines remains relegated to the regulation of fares and approval of companies entering the market on specific lines. Companies have to offer a financial plan, including the maximum fare they intend to charge on newly opened lines. Pending government approval, they are responsible for procuring their own rolling stock and managing day-to-day operations.

With regard to the construction of new railway tracks, the government often subsidises these, given their large capital requirements. These infrastructure development projects are predominantly focused on the construction of the high-speed rail connections, urban rail such as trams and metros, and other regional intercity lines. These funds are managed by the Japan Railway Construction, Transport and Technology Agency (JRTT), which not only helps redirect financing from various levels of government towards rail infrastructure projects, but also assists in procuring additional financing from the private sector (Japan Railway Construction, Transport, and Technology Agency, 2022).

For the high-speed Shinkansen lines, JRTT maintains the infrastructure and charges access fees to the rail operators using them. Parts of these access fees are put towards financing new Shinkansen lines, with the national government and local governments financing the remaining two-thirds and one-third of the costs respectively. JRTT retains ownership of the newly constructed lines and leases them out to rail companies.

The Act on Enhancement of Convenience of Urban Railways, adopted in 2005, stipulates that newly constructed regional and urban rail lines are to use existing infrastructure as much as possible to reduce the need for switching trains, increasing convenience. These projects are financed a third by each of the local government, the national government, and the rail company constructing the line. Once the project is completed, the rail company initiating the construction retains ownership of the newly constructed infrastructure.

6.3.6 Policy evaluation

The JNR privatisation and subsequent reforms resulted in Japanese railways being among the best in the world. This is demonstrated by Japanese railways exhibiting remarkable performance levels by international standards, such as in terms of profitability (Mizutani & Shoji, 1997), punctuality and track capacity usage, and customer-orientation (van de Velde, 2013). This is reflected particularly in terms of the high utilisation rate, density of the railway network, reliability, and state-of-the-art character.

Utilisation rate

The impact of the utilisation rate on railways became visible shortly after the privatisation; by 1995, the mileage increased by 19% compared to 1986 (Doherty, 1999). However, this increase was not enough to counterbalance an increase in the utilisation of private cars, which resulted in a decrease in the share of railways in the modal mix.

This changed in subsequent years. According to Japan Transport and Tourism Research Institute, the 2019 mileage share for railways was 72.7% in Japan, compared to less than 1% in the US, and 8.1% in the EU (Eurostat, 2022d).

Railways carry 49% of all passengers in Japan's three largest metropolitan areas (Tokyo, Osaka, Nagoya), which means that railways and motor vehicles carry almost the same amounts of passengers. There is no other comparable country in the world where the railways are more oriented to mass movements of passengers. The Japanese railway system carried 21 billion passengers in 2001, which shows their enormous commercial success if we compare this to the rest of the world, which carries only 19 billion (Fularz, 2005).

Also, Japanese railways utilise their track capacities to a much higher degree than European counterparts. For example, Japanese railways have twice the frequency of trains than the Netherlands on a comparable, highly utilised infrastructure (van de Velde, 2013).

Punctuality & convenience

Japanese trains are globally renowned for their punctuality, despite tightly packed schedules and greater track utilisation rates than their European counterparts. Over the period of 1997 to 2010, over 95% of journeys on JR trains arrived within five minutes of their scheduled arrival time, on average, compared to a 90% figure for the EU (van de Velde, 2013).

The punctuality of Japanese trains can be attributed, in part, to the specific character of horizontal separation that has taken place since the privatisation of JNR. Unlike the European model of vertical separation, whereby the operator of rolling stock has access to the railways of another company in exchange for a fee, the Japanese model necessitates that each vertically integrated railway is responsible for train operation only within its own network (Kurosaki, 2016). By switching conductors at a border station, this allows for through-train services to cross railway company boundaries without the need to switch trains. More importantly, each company is only responsible for managing trains on its own infrastructure, meaning that conductors are familiar with the tracks on which they are running. Further contributing to the timeliness of Japanese trains is the complete separation of HSR and regional/local rail lines.

This system makes through-train services convenient, a frequent pain point for European travellers, who frequently have to switch trains when crossing borders (Witlox et al., 2022). For example, the Tokyo Metro network is extended by an addition 337 km due to through-train services managed jointly with other vertically integrated companies. HSR trains between major Japanese cities cross these boundaries multiple times a day in either direction. While comparing the boundaries between company service areas in Japan with borders between EU member states with different rail governance structures is impossible, these differing levels of convenience can have a significant impact on cross-border services in the EU, the share of which was only 7% in 2018.

6.3.7 Discussion

The vertical integration that took place in Japan upon the privatisation of JNR in 1987 led to a resurgence of rail transport, despite its share in the modal mix never again achieving the same heights it had before widespread motorisation due to economic growth. While the primary goal of privatisation was to transform the debt-laden and inefficient JNR into a reputable and profitable company, the policies enabling its sale to private investors set up a framework for the development and growth of the entire railway industry in Japan.

The vertical integration and horizontal separation of rail operators in Japan had several positive effects on railway development:

- Rail operators responsible for the management of own infrastructure were able to leverage these assets to diversify their revenue streams. By investing in real estate and commercial property around their tracks and train stations, rail companies contributed not only to urban development in Japan, but also created for themselves a base of customers who would use their services to commute.

- Rail companies became exclusively responsible for the rolling stock operating on their network. Train operators would switch at a border station, meaning that crossing from one JR region into another did not necessitate switching trains but, rather, provided a full through-train service from one region to the next, with enhanced safety that would otherwise be possible since train conductors always managed tracks they were familiar with. This greatly contributed to the convenience and punctuality of intercity train transport, and promoted a resurgence in train usage.
- The JNR legacy companies returned to financial health. No longer part of a monolithic company covering the entirety of the country, the JR companies were better suited to adapt their services to the needs of the region they operated in, be it with the construction of HSR or the discontinuation of underutilised rail lines in favour of more economical alternatives, such as buses. All JR companies experienced growth in various measures of efficiency, and relied less on government subsidies.
- Railway policies establishing the current mandate of the JRTT ensure the planning, financing, and construction of new railway infrastructure and development of new technology. The financing of Shinkansen lines, once approved, is completely covered by the JRTT and the national and local governments, whereas regional and urban lines are financed in equal parts by the national and local government and the company wishing to build the infrastructure, demonstrating the crucial role public finance can play in the expansion of rail networks.
- The financing of unprofitable lines remains difficult. The national government does not provide funds for operational rail expenses, leaving local and regional governments to subsidise underutilised lines, particularly those in less dense, rural areas. Unprofitable rail lines can be supplanted by buses where appropriate. Greater care needs to be taken to align planned infrastructure projects with demographic changes, to avoid investing in areas with a rapidly aging population where other means of transport may suffice.

The case study highlights the need for public funding for the capital-intensive aspects of railways expansion, particularly the cross-border connections that tend not to be prioritised by national governments in the EU. Likewise, the ease of travel across different JR regions in Japan, as exemplified by through-train services from one region into another, at times even integrated with urban transport systems, lends itself to a high level of convenience for passengers and customer satisfaction, obviating the need to switch trains and navigate different ticketing systems as is the case when traveling from one member state to another.

Additionally, the vertically integrated nature of most rail companies allows for diversification to other business lines that can be used subsidise railway expansion and operation.

6.4 Case study 2: Railways in Switzerland

6.4.1 Context and background

One of the main drivers for the development of railways in Switzerland was the road network reaching its limit during the post-war period and the negative environmental impact of increasing road traffic on the Alpine region. Driven by economic growth and increasing car ownership, road traffic increased significantly, leading to significant traffic congestion in the 1970s, especially in the roads through the Alps and Swiss Midlands (SBB, 2004). Goods transportation across the Alps had increased by a factor of six between 1960 and 1988 (Federal Department of Home Affairs FDHA, 2022). To deal with this increasing congestion, the Swiss road network had seen large-scale expansion — a general trend that could also be observed in other European countries (North, 1993). This gave rise to environmental concerns, especially about the local air pollution and the impact on biodiversity, which were linked to the increased automotive traffic through the Alps and the construction of new roads.

Meanwhile, the potential alternative, in the form of railways, remained largely unchanged after almost a century. As the Swiss railway system had not been built to handle an increased mobility demand, its capacity was reaching its limits in the 1980s (Keller et al., 2008). Had such capacity existed, rail could not have competed with roads for freight operations due to the lower upfront costs of road transportation. Even with new planned rail infrastructure, the rapidly growing mobility demand would increase traffic on roads before rail construction could be completed. A policy gap could be identified, in which the effect on the Alpine biodiversity, for example, was not being addressed in the upfront costs of vehicle usage.

While mobility needs and car ownership were increasing throughout Europe, reactions to, and opinions on, busier roads varied. Some believed that the support of greater mobility, especially by car, was of utmost importance, placing pressure on the availability of competitive prices and an expanded road network. For Switzerland, there was also some focus on expanding the railway network. Hugo Gschwind, chairman of the Swiss Federal Railways (SBB) Directorate General, stated "the faster goods in transit can be conveyed through our country, the better our chances of competing successfully with foreign routes" (Federal Department of Home Affairs, 2022e).

In reaction to these challenges and in search for a solution that could reduce road traffic and increase the role of railways (and in this way enhance Switzerland's role as a transit country in the middle of Europe), the Alpine Republic adopted a number of measures which made its railway system one of the best and most reliable in the world. This was achieved despite the challenging terrain and high costs of developing the railways infrastructure.

6.4.2 Policy framework

The development of the Swiss railways system was determined by five main drivers. Firstly, the Rail 2000 programme created a framework that determined the goals and general framework for railway development in the coming decades. It was complemented by the second driver: ambitious infrastructure projects, some of which were not explicitly listed in the initial programme. The necessary funding for the implementation of the Rail 2000 programme and the additional infrastructure projects constituted the third driver. Some of the funding was coming from additional charges on road freight transport, which, along with numerous limits and bans for this mode of transport, constituted the fourth driver. Finally, decentralisation meant that the needs of the local communities are met by rail, instead the road network.

6.4.3 Rail 2000

In 1985, the Federal Department of Environment, Transport, Energy, and Communications presented a draft of the Rail 2000 programme, which aimed at significantly developing the railways infrastructure in Switzerland to make it faster, to increase the frequency of the connections, and to make it more comfortable for the passengers. To achieve these goals, the programme included, among others, the construction of new railway tunnels at the Saint-Gotthard and Lötschberg massifs, connection to the European high-speed network, the complete noise remediation of the trunk line network, and new financing to extend the system. It also suggested a new timetable system for smoother connections, according to which trains would serve stations at the same minute every hour or half hour to allow better accessibility throughout Switzerland. This "clock-face scheduling" would minimise passenger waiting times, provide schedule alignment, and reduce overall travel times, while allowing trains to serve more stations (Swiss Parliament, 1986). With the total investment to modernise the rail system envisaged in Rail 2000 amounting to CHF 30 billion over 20 years, it was the most comprehensive single extension and modernisation project in Swiss rail history at the time (Desmaris, 2014; Keller et al., 2008).

The overall response was very positive and the federal parliament began a vote on the programme in 1986, despite some regional opposition in relation to the loss of arable lands for new route lines (SBB, 2004). It was approved by popular vote in 1987 (Keller et al., 2008). This was one of the first instances in which voters favoured a bill for a transportation policy that support the railways and discouraged road usage (SBB, 2004).

Due to its size, the Rail 2000 programme needed to be split into two stages, with the first one to be completed by 2005. In the course of this stage, 130 infrastructure expansion projects were implemented, double-decker wagons went into utilisation, intercity tilting trains allowing for faster speed were brought in, and the overall train speed was increased through the opening of new stretches of railway (Keller et al., 2008). As a result, railway travel was made more attractive and increased the utilisation of the rail network.

Phase two of Rail 2000 programme had four main goals: (1) entering Swiss rail into the new European railway landscape, (2) enhancing railway efficiency by increasing the productivity and profitability of operation, while improving quality, (3) coping with issues resulting from sustained increases in mobility with a greater share of rail transportation, and (4) improving the cost-benefit ratio of public subsidies (Desmaris, 2014). The changes proposed would have aligned Switzerland more evenly with EU countries (Finger & Holtermann, 2013). However, this proposal was rejected, as a whole, in 2005. Its different components were later proposed and adopted in a piecemeal fashion (Keller et al., 2008). Along with other benefits, it introduced a harmonisation of safety measures, brought operability with the EU standards, initiated the process of Switzerland becoming a member of the European Railway Agency (ERA), and facilitated the liberalisation of the railway market by competitive tendering of transport services (Federal Office of Transport, 2020b).

6.4.4 Infrastructure development

Despite the challenging geographic framework, two infrastructure projects illustrate the Swiss railway's successful development.

The first project was the New Rail Link through the Alps (NRLA) that passed through Gotthard and Lötschberg-Simplon. In the 1960s, Swiss experts reviewed several options for tunnels through the Alps and by 1970 they narrowed it to six key options (Federal Office of Transport, 1974). The Rail Tunnel Through the Alps Commission decided in favour of the Gotthard Base Tunnel and suggested that construction start quickly, given Switzerland's positioning as a key European transit country (Federal Office of Transport, 1974).

In 1988, the Infras research consultancy presented its 401-page report to the Federal Department of Transport, in favour of base tunnel construction through the Alps for faster north to south national connections. The base tunnel construction agreed with policy adoption advocating road to rail transportation shifts. Adolf Ogi, head of the transportation department, was satisfied with, and in support of, the report findings, which would profoundly influence later discussions on railway development (Maibach et al., 2020).

In May 1990, the Federal Council Dispatch on the Construction of the Swiss Rail Line through the Alps agreed with the commission and also recommended pursuing the Gotthard Base Tunnel and the Lötschberg-Simplon options (Federal Department of Home Affairs, 2022b).

The NRLA's construction necessitated an agreement with the EU to increase the capacity of northern and southern access to these routes. Before the construction of the project was approved by the Swiss people by referendum, the Swiss government signed an agreement with the EU in 1992 that would ensure that the Alpine transit could not be limited in other ways. Shortly thereafter, exploratory borings were taking place in the Gotthard and Lötschberg Base Tunnels (Federal Department of Home Affairs, 2022a).

In 1994, during a vote asking the Federal Constitution to protect the Alps from the consequences of traffic and prevent road expansion, 52% of voters supported the Alps Initiative (Federal Department of Home Affairs, 2022f). The next year, the Federal Council incorporated plans for the Gotthard and Lötschberg Base Tunnels in the NRLA as a network option. The Federal Council then asked the Department of Finance to develop a funding model for the tunnels (Federal Department of Home Affairs, 2022c).

Necessary infrastructure development was planned and implemented in a coordinated manner to meet commitments towards infrastructure, rail, and combined transport measures. A legally dependent fund provided financial means for the project, limited to 20 years (Epiney & Heuck, 2012; Maibach et al., 2020). Switzerland also granted financial support to neighbouring countries to use Swiss terminals if their use was associated with goods transported through Switzerland (Jörling, 2018).

Later that same year, Swiss voters approved this project via a mandatory referendum. The electorate voted to invest CHF 30 billion in the NRLA, giving the Gotthard Base Tunnel and other relevant infrastructure the green light (Federal Department of Home Affairs, 2022g). After the funding was granted, in 1998, the construction work began, in 1999. The project was closely intertwined with the Rail 2000 programme as it built a denser network which could offer more frequent trains with more direct connections (Maibach et al., 2020). In 1999, the first blasting took place at the Lötschberg and Gotthard Base Tunnels (Federal Department of Home Affairs, 2022a).

In 2007, the Lötschberg Base Tunnel was completed. The Gotthard Base Tunnel opened in 2016. These tunnels reduced travel time between north and south Switzerland significantly: by approximately 40 minutes for the Gotthard Base Tunnel, and 30 minutes for the Lötschberg Base Tunnel (Fabbri, 2019; Wouter, 2016). The Swiss parliament set aside CHF 990 million to create a '4-metre' corridor on the Gotthard tunnel capable of accommodating trains with a corner height of 4 metres, completed in 2020, between Basel and Ticino (SBB, 2020). The '4-metre' corridor is intended to increase the ease of transport of goods across the Alps (Federal Department of Home Affairs, 2022a).

Another major infrastructure project was the Future Development of Rail Infrastructure programme (ZEB). It was passed in 2009 and began implementation in 2019. With the price tag of CHF 5.4 billion, it aimed to develop a railway grid ready to accommodate an estimated 60% increase in passenger traffic by 2030, especially in densely populated areas. This programme looked to avoid larger and more expensive changes to the system, focusing instead on speed increases, disentangling traffic flows, increasing services, improving power supply, and reducing noise. Projects in areas with the lowest demand that required updates were carried out through public funds, while still accessing updates of greatest benefit to the rail network. It continued the aim of shifting traffic from road to rail and to implement better rail connections in major towns and cities, expanding the capacity of freight and securing capacity for domestic freight on the east-west corridor (Wyss & Halder, 2009).

6.4.5 Funding of railways development

To fund the expensive infrastructure projects, a heavy-duty vehicle levy (LSVA) was put in place that charges freight vehicles by their weight and distance travelled (Jörling, 2018). The rate was fixed by the federal council and the fee could be a maximum of CHF 0.03 per tonne per kilometre (Epiney & Heuck, 2012). A percentage of revenue from the LSVA is rerouted to further fund rail operations and infrastructure development, which makes it different from the heavy-duty levies in neighbouring European countries (Jörling, 2018).

There were initial concerns whether the LSVA in Switzerland was in accordance with the previous transit agreement of 1992 with the EU as it could conflict with the principle of non-discrimination and free choice of mode of transport. The agreement defined the composition of the maximum tax rate, which may be made up according to categories of emission standards, travelling distance, and toll fees for use of specialised Alpine infrastructure, that can make up to 15% of the maximum amount of charges. As long as Switzerland remained within this limit, the heavy-duty vehicle levy was deemed to be in accordance with this agreement (Epiney & Heuck, 2012).

In 1998, the Swiss population, by referendum, supported the Proposal for the Construction and Financing of the Public Transport Infrastructure (FinöV). The FinöV fund would support development of public transportation and infrastructure through revenues from the aforementioned heavy-duty vehicle levy, a tax on petroleum, and value-added tax. These three sources contributed to 64%, 13% and 23% of the overall value of the fund, respectively (Carvalho et al., 2018). This ensured availability of funding for the implementation of the NRLA, Rail 2000, and ZEB, along with later connection extensions and noise mitigation through existing railway routes. 45% of FinöV would be applied to the NRLA, 7% to noise mitigation, 4% to high-speed European network connection links, and 44% to Phase one of Rail 2000 and ZEB (Carvalho et al., 2018).

Federal railway subsidies had been rising during the 1990s, but stabilised between 1999 and 2008 (Keller et al., 2008). A break-even point for ratio between SBB operating income and maintenance costs were therefore expected by the early 2000s (Keller et al., 2008). In 2012, through a legislative initiative discussed in parliament, a new simplified way to finance railway infrastructure through a single fund, the Bahn-Infrastruktur-Fonds (BIF) was introduced as part of a proposed Financing Building of Rail Infrastructure programme (FABI) (Federal Office of Transport, 2020a).

In 2014, the Swiss population voted in a referendum in favour of this simplification, which would cover operations and maintenance, rail expansion, repayments of interest payments, and research (Federal Office of Transport, 2020b). The previous funds available through FinöV were transferred over to FABI and BIF. BIF takes in two-thirds of revenue from the heavy-duty vehicle charge, a percentage of mineral oil tax revenues, and a percentage of revenue from the Value Added Tax (0.1%), as well as funds from regional Cantons and federal government and its own reserves (Federal Office of Transport, 2020a). Real estate holdings of the railways can also contribute to its financing, which is of great importance to SBB which is one of the largest landowners in Switzerland, owning 94.4 km^2. Not all of this real estate is needed for its transport operations (de Kemmeter, 2020). The SBB made a profit of CHF 24 million in 2021 from its real estate interests (SBB, 2022).

Along with FABI, the Development Phase 2025 of the Strategic Development Programme for Rail Infrastructure (STEP) was passed in 2014. CHF 6.4 billion would be allocated to the programme, to get rid of bottlenecks in the SBB network (Railway News, 2019). This would increase capacity and further address growing demand for the rail service.

6.4.6 Reducing road transport

Along with various other rail reforms and policy changes, beginning in the 1980s, support for a modal shift policy in Switzerland emerged in the 1990s with specific focus on freight transportation (Jörling, 2018). The policies were designed to limit freight transportation through the Alps and shift much of this to railway, to be accomplished by encouraging railway use while discouraging road transport. Investments in new rail infrastructure projects were accompanied by measures aimed at reducing road activity. This process was driven mostly by environmental protection measures.

In 1989, the Alpine Initiative association was founded around environmental concerns of the region. The association aimed to protect the region from negative effects of traffic and to preserve the space for humans, animals, and plants. In 1989, to protect the Alpine region from transit traffic, the association launched a popular initiative that would result in an amendment of the constitution, banning an increase in road capacity (Alpine Initiative, 2022).

After a strong referendum campaign, in 1994, the Alpine Initiative for the protection of the Alpine region from transit traffic was passed by a majority of the Swiss population and cantons. As a result, Article 84 BV, a binding mandate was adopted that prohibits an increase in road transit capacities in the Alpine regions, with the only exception being for bypass roads to reduce transit traffic. In this case, increasing road capacity must be a primary interest of preserving and improving traffic security. Four roads were classified as transit roads and affected by a target ceiling of transit road capacity. It further states that border-to-border road freight traffic is to be relocated to rail within ten years. The selected baseline year for this comparison was 1994, which saw 650,000 freight journeys through Switzerland (Epiney & Heuck, 2012).

Another referendum resulted in the introduction of Article 85 of the Swiss federal constitution (Jörling, 2018). Article 85 provides the conditions of charging heavy-duty vehicle tax, as they create public costs which are not covered by other taxes or charges. It states that a cost may be defined for the use of all public roads, calculated on admitted gross load weight and distance travelled, and that kilometres can be differentiated by emission or consumption of the vehicle, but only for national roads and motor highways, not all public roads. In addition, Article 86 introduced a consumption tax on motor fuels and charges for vehicles and trailers outside of the heavy-duty vehicle charge (Epiney & Heuck, 2012).

In addition to the charges, there were also strict rules about road traffic noise, resulting in a travel ban for road freight traffic at night and on holidays (Jörling, 2018). Such policies made road freight transit more difficult to plan and carry out as they required more frequent breaks and thus further decreased the competitiveness of freight rail transport.

6.4.7 Decentralisation

In 1996, a revision of federal law on railways began a decentralisation process in which cantons became entirely responsible for organising their regional commuter services (Desmaris, 2014). Discretionary powers remained with the Federal Office of Transportation (FOT), as the remaining guarantor of traffic coordination at the national level; however, this marked the end of the SBB monopoly for regional railway services. The most innovative of the related clauses opened up competition for regional transport commissions to multiple operators, though notably there has been little to no competition for local and regional transport thus far as cantons do not publish bids for tender.

This 1996 revision created an "ordering principle" which would start the implementation of "net cost" contracts, where public authorities only pay for services agreed upon in advance, related to given routes, durations, or for a specific service, and only pay the amount clearly stated in this contract. Financial compensation amounts were based solely on the running-loss initially projected by operators. Strict adherence is given to financial constraints and Swiss rail must learn to do more with less through these agreements.

6.4.8 European legislation

Although Switzerland is not part of the European Union, it has been strongly affected by the EU legislation and trade relations within the block. Switzerland engaged in many agreements with the EU, such as the aforementioned transit agreement from 1992, which stated principles of non-discrimination and free choice within modes of transport. This primarily concerned freight transportation crossing the Alps (Epiney & Heuck, 2012).

One of the most impactful parts of the EU legislation was Directive 91/440/EEC, which granted member states access to the trans-European Rail Freight Network. In addition, it triggered the process of the railways' liberalisation, aiming at improving the competitiveness of rail transport. The directive also obliged the creation of separate service and infrastructure management accounts, the fair treatment of all railway in-rail infrastructure utilisation, a reduction of railway debt, and the establishment of access rights to railway infrastructure for Community railway undertakings (Council of the European Communities, 1998). Switzerland agreed to acquiesce to these terms to gain European network access.

A new regulatory framework was introduced in keeping with European legislation and transposing principles, laid out in Directive 91/440/CEE, into national law (Desmaris, 2014). Non-discriminatory access was given throughout the railway network (Federal Office of Transport, 2020b). Transport activities were then separated from infrastructure management and catered for more competition, though this was already previously in place for freight transport (Desmaris, 2014). An independent train route allocation body was created, while SBB was moved into the control of a bigger business, and unbundled on accounting levels (Federal Office of Transport, 2020b; Finger & Holtermann, 2013). Thus, SBB gained autonomy over its operations and became independent of political and administrative powers (Desmaris, 2014).

According to previously cited interests of the EU for freedom of transportation mode through Switzerland, heavier vehicles were granted access to Swiss roads. The road weight limit in Switzerland increased from 28 tonne to 40 tonne. Swiss voters approved of this increase in 2000, after the bilateral agreements negotiated with the EU (Hirter & Linder, 2000). The heavy-duty vehicle levy would remain in place, but heavier vehicles could access roads and would need to pay the stipulated amount.

Switzerland sought to improve the financial sustainability and performance of railways, in processes parallel to those in the EU. Proposals to include directive aims in Swiss railways' reform were presented to the Swiss parliament in 1997 (European Conference of Ministers of

Transport, 1998). Independence from the state would be granted to railway operators in stage 1 of the railway reform (Federal Office of Transport, 2020b). The national rail operator, CFF, was transformed into a state-owned stock company (European Conference of Ministers of Transport, 1998). The organisation was separated along the lines of transportation services and infrastructure, such that both held separate financial accounts; greater competition on the railway network was subsequently felt, especially for freight (Federal Office of Transport, 2020b). CFF debts were restructured in 1999 (European Conference of Ministers of Transport, 1998).

Another agreement was reached with the EU in 1999, which aimed at creating a compromise between Swiss priorities and EU legislation. This would allow the road and rail transport markets to better accommodate passengers and goods and form the legal basis for the LSVA in 2001, after the EU recognised the instrument (Jörling, 2018).

In addition, Switzerland implemented most elements of the third EU railway package, which was delivered in 2007, in which the liberalisation of international passenger transport was implemented under review. Also, the fourth EU railway package, in 2016, was gradually implemented (Federal Office of Transport, 2020b).

6.4.9 Policy evaluation

Swiss rail policy has succeeded in shifting more of its overall transportation from roads onto railways since the 1990s and achieved emissions reductions within this period due to the modal policy shift. The same growth would have been unlikely without hundreds of infrastructure expansion projects, larger wagons, and other accomplishments made under the first phase of Rail 2000. Within Phase one of Rail 2000, the average train-kilometres per day were increased by 14%, to 337,000 kilometres, and the introduction of the hub system reduced travel times between Swiss cities to 70% of their original travel time requirements in some cases (SBB, 2004).

In 2000, 90% of the population above the age of six would participate in traffic daily, with the most common means of transportation being the car, at 67 of every 100 km travelled (Keller et al., 2008).

By 2008, long-distance journey times of public transportation was shown to be reduced by 7% compared to only 4% by individual vehicle transportation, which is significant considering customers' greater sensitivity towards train frequency and journey times in comparison with other transportation variables (Keller et al., 2008). Eight percent of railway transportation growth can be attributed to timetable changeover from 2004-2005. The Lötschberg tunnel saw a 74% increase in passenger numbers between 1999 and 2016 and a 408% increase in goods transportation volumes in the same time period (BLS, 2017).

In 2016, 75% of CO_2 emissions from the transport sector came from private passenger vehicles (Jörling, 2018). Freight transport made up 18% of sector emissions and 66.6% of that was due to heavy-duty vehicles (Jörling, 2018). Rail transport of goods had a share of 39% in total tonne-kilometres in 2016 (Jörling, 2018).

The strong support of finance towards rail operations has contributed to such successes. Switzerland spends five times more per capita on railway than its neighbour, Germany, for example (Wüpper, 2021). Funding has been aimed towards both small and large infrastructure investments, as well as research and assessments. The shift of revenue from road traffic to rail investment is a unique and valuable element of the policy shift and could be a lesson for other countries.

Though not directly related to modal transport shift, it is likely that the liberalisation of rail infrastructure helped to make rail use more attractive. The vertical integration of the Swiss system allows for exceptional performance and is often cited as such. Other countries that are often praised for rail systems, like Japan, also have vertically integrated rail systems.

However, the objective of Rail 2000 to make rail services "more attractive for all regions" may not have been fully accomplished, as satisfaction rates of rail services were surveyed to be noticeably higher in German-speaking regions of Switzerland in comparison to West-Swiss and Tessin citizens (Keller et al., 2008). This may still be an avenue for improvement in the overall system design.

Each of the major stages of Swiss transportation policy were submitted to a popular vote or referendum, such as Rail 2000, the Alps initiative, the GPF, and financing of public infrastructure projects (Desmaris, 2014). The unique nature of public engagement in Switzerland is another contributor to the success of the rail system. As referenda and direct democracy is strongly supported in the region, long-term stability of transit projects is provided through the engagement with a variety of public stakeholders and stakeholder interests. Public authorities need to be proactive towards the stances of the public in order for their suggested projects to pass and consult the views and interests of public groups. This requires greater transparency between the public and project planning. After a project has passed a popular vote, it is less likely for there to be disruptions due to pushback during implementation, as has been the case on other transportation projects within Europe, for example the village of San Didero in Italy (Matalucci, 2021). The political system's consensus building and continuation play important roles in the overall policy shifts (Jörling, 2018).

However, the success of Switzerland's rail and transportation policies has also been limited by several factors. As a land-locked country, neighbouring countries and transportation abilities strongly affect Swiss transportation. All of Switzerland's large neighbours must comply with EU transportation mandates and regulations, which can make modal transportation shift more complicated. In 2007, 64% of freight measured in tonnes came through the Swiss Alps via railway, in contrast to neighbouring France and Austria, where the majority of freight was transported by road (Federal Department of Home Affairs, 2022e). Further modal shifts are limited when neighbouring countries are not able to enforce stricter regulations on freight road transportation or achieve as efficient services. Freight that must cross between neighbouring countries may then require "combined transport" for most efficient transportation costs, in which the mode of transport for cargo is offloaded from road to rail or vice versa in its journey (Federal Department of Home Affairs, 2022e). Such mismatch leads some companies to avoid transportation through Switzerland or to continue with road use in consideration of the greater journey.

More directly, Switzerland must also cooperate in agreements with its EU neighbours. The EU's interest in free trade across Europe can hamper Swiss efforts to reduce road usage. One concrete example is the compromise when Switzerland agreed to raise its weight limit for trucks on roads (Federal Department of Home Affairs, 2022e). The absence of EU member requirements allowed Switzerland greater leeway in their modal shift design. Therefore, the Swiss modal shift policies may have shifted heavy-duty vehicle road transportation from Switzerland into neighbouring EU countries which were not able to effect modal transportation shifts in the same way (Jörling, 2018).

Greater coordination and complimentary transportation shift would be an asset to EU members. European cooperation is beneficial to Switzerland, but could be more so with EU modal transport shift support. Switzerland has benefitted not only from CO_2 emissions reductions, but also through the reductions of noise, health, and landscape health (Jörling, 2018). The share of freight railway transport crossing the Swiss Alps was 71% in 2016, while it was 15% in France and 28% in Austria (UVEK, 2017a as cited in Jörling, 2018).

The Swiss Federal Department of Environment, Transport, Energy, and Communications (DETEC) found that freight transport CO_2 emissions would have been at least 30% higher in 2007 without modal shift policy instruments (Jörling, 2018). The instruments considered include the heavy-vehicle levy, night-time freight road ban, railway transport liberalisation, and extension support for the rail network (BAV (2017), as cited in Jörling, 2018).

The NRLA achieved greater energy efficiency through the decrease in the slope of the line (Jörling, 2018). Some have estimated that energy consumption was 15-20% lower after the construction of the NRLA in the Swiss portion of the Gotthard axis tunnel (UVEK (2017), as cited in Jörling, 2018).

The success of the NRLA greatly depended on negotiations with neighbouring countries, as the amount of freight transportation could only have increased if Germany and Italy had expanded their routes and modernised the Rotterdam-Genoa axis, as was agreed in 1995 (Federal Department of Home Affairs, 2022d). All European countries can aim to offer equally efficient and complementary rail services.

6.4.10 Discussion

ZEB was discussed in relation to CO_2 emissions reductions, in that traffic is the biggest producer of greenhouse gases in Switzerland (Wyss & Halder, 2009). In this sense, by promoting more efficient transportation methods, this would inherently help accomplish CO_2 emissions reductions goals. The Swiss rail system allows energy-efficiency through its low rolling resistance wheel/track system (Ibid.). SBB produces the majority of energy for trains from hydroelectric power and the rest almost exclusively from nuclear power (Ibid.). Even if coal, gas, or oil were used to produce the electricity to power Swiss trains, as is the case with some train systems elsewhere in Europe, CO_2 efficiency of Swiss rail would still be at least three times that of the road equivalent (Ibid.). The Sustainability Indicators for Rail Infrastructure Projects (NIBA) process is used to evaluate rail infrastructure projects and found that ZEB would generate a reduction in CO_2 emissions worth CHF 18 million a year through cost-benefit analysis (Ibid.). However, further stability in the rail network was forecasted to be possible only with larger and more flexible investments (Ibid.).

SBB is subject to multi-annual contracts, in which the Confederation established strategic operational targets, orders for expected passenger and freight services, infrastructure requirements, and amounts for public compensation every four years (Desmaris, 2014). Meanwhile, the SBB's performance goals were becoming more specific over time (Finger & Holtermann, 2013). The SBB will continue to hold a position of some ownership as long as the state has significant ownership within the company (Ibid.).

The political objectives were set out in qualitative terms in the Federal Council announcement of 1985, giving mention to general improvements in direct routes, comfort, and the modal transportation split between rail and road transportation (Bundesrat, as cited in Keller et al., 2008). Rail 2000 would modernise the rail system for the cost of CHF 30 billion over a 20-year period (SBB, 2004). This was one of the first instances in which voters favoured a bill for transportation policy that supported railways and discouraged future road use (Ibid.). It specifically planned to modernise the railways, construct new railway base tunnels at the Gotthard and Lötschberg, connect to the European high-speed network, complete noise remediation of the trunk line network, and propose new financing to extend the system (Keller et al., 2008). Rail 2000 was the most comprehensive single extension and modernisation project in Swiss rail history at the time (Ibid.). Rail 2000 included a new timetable system for smoother connections and introduced trains that would serve stations at the same minute every hour or half hour, to allow better accessibility throughout Switzerland (SBB, 2004). The clock-face scheduling would minimise passenger waiting times, provide schedule alignment, and reduce overall travel times, while allowing trains to serve more stations (Desmaris, 2014).

6.5 Lessons for the European Union

The identified case studies offer several lessons that could facilitate an increase in the utilisation of railways in the EU (Treber, 2021). These could be grouped into three main categories: (1) further Europeanisation of the railways' governance, (2) increasing the role of public funding for infrastructure development and provision of transport services, (3) setting minimum targets for railways development for the EU member states.

While both case studies highlight the various accomplishments of vertically integrated systems in Japan and Switzerland, EU policy relies on the separation of infrastructure and operation with right-of-access laws. However, multiple aspects of Japan's and Switzerland's railways policy are unrelated to their vertically integrated structure, and replicable within the EU. Both case studies show the impact of top-down governance on railways development. This feature is missing in the case of the European Union. While the European Railway Agency (ERA) has already facilitated operations of trains across different countries by standardisation safety and operational requirements, its role is mostly technical. The Connecting Europe Facility does fund the development of railway infrastructure, with around EUR 26 billion for 2021 to 2027, but the budget is a lot less than what is needed for infrastructure development and operation of connections that are not (yet) economically viable but necessary for modal shift from aviation and road transport (Treber, 2021). In the framework of the Recovery and Resilience Funds submitted by the member states, an additional EUR 85 billion is to be invested in railways, but most of the investments are to be executed by 2026, resulting in much needed but short-term infrastructure improvements.

To make European railways compatible with the EU's climate ambitions, ERA's competences and resources should be significantly expanded. Alternatively, it could be incorporated into a new European Railways Research, Investments, and Information Agency. Its responsibilities could include:

- Developing more comprehensive planning of railways infrastructure that would take into consideration not only existing but also future mobility needs.
- Co-funding development of transboundary connections — both in terms of regional trains as well as long-distance connections.
- Facilitating research that would allow faster decarbonisation of railways stock and development of rapid trains.
- Ensuring better coordination between timetables for intercity connections to make journeys across different countries more efficient, and competitive with aviation.
- Developing a pan-European booking system that would allow seamless train booking across the EU and, whenever possible, beyond.

The issue of funding railway infrastructure and the operating of unprofitable but essential connections constitute another lesson learnt from the non-EU case studies. In order to meet EU's "climate neutrality" goal, a massive modal shift from intra-EU aviation and road transport and significant investments in infrastructure are needed — ones that not only take into consideration current needs, but also satisfy future demand for mobility services. Such investments need to be covered to a large degree from public resources — as was the case for road transport. While, as mentioned above, the EU and its member states provide some funding for selected projects, to ensure a lasting scale-up of construction capacities, a steady flow of funding needs to be ensured. In Switzerland, some of the funding of the railway infrastructure is coming from the taxation of road freight transport. At the EU level, such an approach could also include fees on aviation, thus resulting in a bonus-malus system accelerating the necessary modal shift. Such a modal shift would also increase the popularity of connections that, due to low occupancy, would not be initially profitable, but necessary to replace other modes of transport. Before this happens, such connections need to be subsidised from public resources (Treber, 2021) — which increases the needed for a more permanent funding scheme.

Finally, as is the case in other policy areas, especially the electricity sector, the EU should be empowered to introduce initially "indicative", later mandatory, targets for the role of railways in the transport sector. To increase the acceptance of these targets among member states, they should be supported by funding. Such targets could concern some of the following indicators (Treber, 2017), focusing on infrastructure and quality of travels:

- Density of railways network (e.g., km / 1000 citizens);
- Minimum average speed of intercity trains;
- Share of passenger-kilometres in modal split, inclusive of a comparison to share of other modes of travel for intra-EU trips;
- Share of settlements above 1000 inhabitants with at least x train connections;
- Share of electrification of the railways.

To reflect the different starting points of different countries, the targets, as well as the corresponding funding, should be adapted to the respective circumstances.

Introducing these changes, particularly those focused on increasing the ease of cross-border rail travel – among many others more specific to the national and local circumstances — is essential to provide a competition to carbon-intensive modes of transport, especially by car and intra-EU aviation. In addition, faster and more reliable train connections could decrease activity levels for extra-EU aviation by providing an attractive alternative for extra-EU travel.

6.6 Conclusions

The rise of the personal vehicle and air travel have posed many challenges to rail transport networks in the EU, resulting in fewer train services, lower investment in rail, and exploding GHG emissions from transport. Counteracting this trend, however, is key to the goal of carbon neutrality and provides additional benefits in the form of cleaner air, lower congestion, and easier commutes.

The existing policy framework, which has managed to provide both funding allowing member states to invest in their rail network, and the technical guidance allowing trains to safely operate across borders, on its own is insufficient in providing the transformative change necessary to effectively decarbonise the transport sector. As the case studies from Japan and Switzerland demonstrate, providing a seamless travel experience without having to change trains, and investing heavily in infrastructure that significantly reduces journey times are crucial to ensuring railways remain a consequential competitor to cars and planes, allowing people to easily commute to work, visit family over long distances, and travel to new destinations.

The current energy crisis gives further impetus to improving rail networks: with oil prices higher than they have been in years, many citizens find themselves unable to afford driving to work, while also lacking viable public transport alternatives. While the privatisations in Japan were designed to wean the JR companies from government support for operational costs, it is a combination of regional and national government funding that allows rail companies to build new infrastructure and open new lines, as well as maintaining locally important, yet unprofitable connections. Switzerland has likewise seen the importance of heavily investing in infrastructure, creating a financing scheme akin to a “polluter pays" principle that further makes transport by rail more appealing.

Railways in the EU experienced manifold challenges in 2022. To alleviate the cost-of-living crisis, many governments provided financial support to incentivise public transport and rail travel. The German scheme in particular has provided insight into both the decarbonisation potential of railways, and the investments needed for them to be viable alternatives to personal vehicles: millions of tonnes of CO_2 emissions were avoided, the ease of having just one ticket for the whole of the country without having to navigate multiple regional ticketing options proved popular, and many complained of crowded trains and having to switch multiple times. Given the proper governance structure at the EU level, and requisite funding both to expand infrastructure, and provide fast and easy cross-border connections with simple ticketing options, the EU and its member states would greatly benefit from an increase in rail ridership, lower congestion and GHG emissions, and a more connected citizenry.

7. Archetype 6: Renewables

7.1 Introduction

Despite the EU's attempts to accelerate its renewable energy deployment to reduce greenhouse gas emissions and avoid the worst consequences of climate change, it faces an enormous challenge. While the EU needed to accelerate renewable energy deployment levels manyfold before Russia's invasion of Ukraine, it is now even more urgent to scale renewable energy capacity in Europe due to energy sovereignty concerns. The EU remains dependent on Russian natural gas and oil imports and a shift away would require the much faster deployment of renewable energy sources. This need to accelerate deployment is acknowledged by the European Commission in the most recent REPowerEU proposal, which aims to end dependence on energy imports from Russia by 2027 (EU Commission, 2022).

Correspondingly, the EU Commission has proposed to increase the EU's 2030 renewables target from 40% to 45% (EU Commission, 2022b). Even without this increased target, according to IFFRI, the EU needs to add 600 GW of wind and solar capacity by 2030 to achieve the 'Fit-for-55' renewable energy target of 40% of the energy mix (Eyl-Mazzega, et al., 2022). To achieve the more ambitious goal of the REPowerEU package, an additional 170 GW of wind and solar capacity is required. In 2021, the total installed wind and solar capacity in the EU was only 346 GW (Ember, 2022).

The current pace of renewable energy expansion is insufficient to reach these targets. For wind power, for example, analysis by Ember shows that EU member states' policies are on track to achieve only less than 50% of the annual capacity additions required to reach the REPowerEU targets. Only four out of 27 EU countries are projected to reach the required increase in installations (Fox et al., 2022). The wind power industry estimates a best-case 18 GW annual increase in wind growth in the EU by 2025, far below the necessary annual deployment which would be at least twice that level (WindEurope, 2022a).

The challenges facing the deployment of wind and solar today are no longer the ones of the past. While high technology costs, cheap competition by fossil fuels, and volatile political commitment to climate action has hampered the deployment of renewable energies in the past, this is no longer the case. In most EU member states, wind and solar are among the cheapest forms of energy, political commitment to climate action is strong and institutionally enshrined, and financial resources are no longer a bottleneck. Instead, other factors are holding back the expansion of renewables. Too little area is dedicated to renewable energy sources, and permitting procedures are prohibitively slow and complicated (WindEurope, 2022b). Moreover, the shift from a centralised fossil-fuel-based electricity system to a decentralised system based on intermittent renewables requires substantial changes to infrastructure (IRENA, 2022). In short, some of the major challenges facing renewable energy expansion now relate to permitting and infrastructure planning.

This report considers the cases of Norway and Australia to draw lessons for the EU's efforts to accelerate the deployment of renewables. While far from perfect in all respects, both countries have in recent years witnessed strong growth in renewable power and hold important lessons for addressing the implementation gaps in the EU.

This report starts with a case study of the permitting policies in Norway. Norway has rapidly built up wind power in a short period of time through changes in the permitting system and effective support policies. However, as will be shown, the rapid expansion of onshore wind power and procedural justice concerns have put Norway's wind power future in danger. The case study therefore holds important lessons for the EU for the permitting process, spatial planning, and the social acceptance of wind power.

The second case study in this report focuses on Renewable Energy Zones in Australia (REZ). REZ are meant to integrate the planning and implementation of grid expansion with renewable energy projects. It is part of Australia's effort to transition to a renewable electricity system and facilitate the infrastructural changes that are implied by it. As such, it is an interesting testing ground for innovative ways to plan electricity infrastructure.

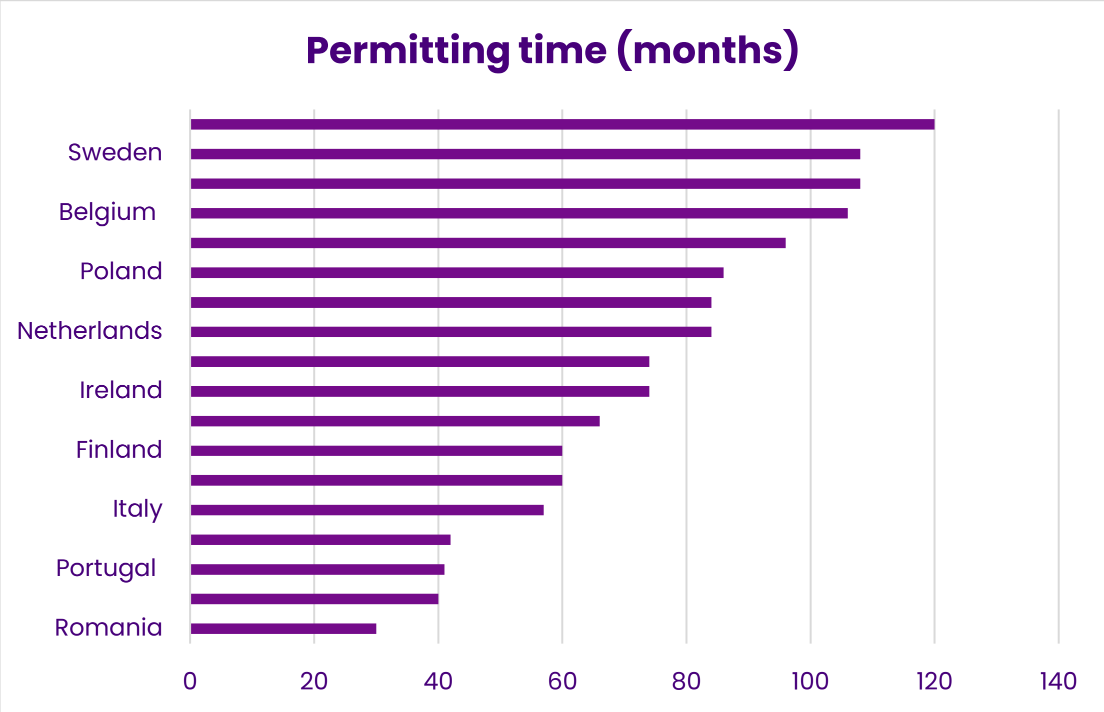
The case studies presented here are based on desk-research and expert interviews. We identified important explanatory factors with the help of grey literature and academic publications. In addition, we analysed official policy documents as well as media reports. These helped to identify the relevant actors, institutions, policies, and processes. Next to desk-research, we conducted six semi-structured interviews with Norwegian and EU stakeholders and experts as well as one interview with an Australian energy policy expert. While their identity cannot be revealed, Appendix A lists their respective background and provides some example questions. Interviews helped to identify the main barriers of permitting in the EU, explanatory factors for Norway's permitting experience, the advantages and disadvantages of the Norwegian system, and to triangulate findings. The interview with the Australian expert helped to situate REZs in Australia's climate and energy policy context. The collected information was then used to develop a comprehensive narrative that describes and explains permitting in Norway and REZs in Australia. Based on the case studies and expert interviews, general lessons for the EU were drawn.

The report proceeds as follows. The next two sections (Section 7.2 and 7.3) motivates the case study selection further by discussing the relevance of permitting and Renewable Energy Zones for the deployment of renewables. Section 7.4 presents the case study of permitting in Norway. Section 7.5 presents the case study of Renewable Energy Zones in Australia. Section 7.6 draws some lessons for EU policy-making, and the last section concludes.

7.2 Why consider permitting and Renewable Energy Zones?

Permitting is key to renewable energy deployment. It represents an important stage in project development. This report follows the EU Commission's (2022b) definition of permitting — also referred to as licensing — specifically, the administrative process of granting all relevant permits to build, repower, and operate plants to produce energy, including necessary impact assessments and grid-connection permits. It covers the whole administrative process, from acknowledging the validity of an application to the notification of the final decision by the relevant authority.

Figure 7.1: Wind permitting times in 24 EU member states.



Note: The Renewable Energy Directive establishes a 24-month limit for the permit-granting process. Note that the permitting time also includes the grid connection process in this analysis. *Source*: Reproduced from Ember (Fox et al., 2022) analysis based on WindEurope data

Permitting is considered the main barrier to increasing renewable energy deployment in Europe. Regarding increased EU renewable targets under REPowerEU, the EU wind power industry association, Wind Europe (2022b), has stressed that "the technology and finance are available, and costs have come down. But the key challenge is permitting." Furthermore, according to Banasiak et al. (2022), "[B]arriers related to administrative processes are now the biggest roadblock to developments [of renewable energy projects]". According to analysis by Ember and as can be seen in **Figure 7.1**, onshore wind permits, including grid connection, take between 30 months in Romania and 120 months in Bulgaria. Of the 24 EU member states analysed by Ember, none managed to issue all permits below the 24-month limit established in the EU's Renewable Energy Directive (Fox et al., 2022). With this timeframe, a project initiated at the time of writing (July 2022) might not receive its permit by 2030. Therefore, it is necessary to establish faster permitting procedures to reach the EU's ambitious renewable targets.

Issues with permitting primarily relate to (1) spatial planning and compliance requirements and (2) administrative procedures (Banasiak et al., 2022; WindEurope, 2021a). First, for spatial planning, the main issue is a lack of designated areas for new developments (EU Commission, 2022a). The lack of designated areas is exacerbated by compliance requirements, that apply mostly to onshore wind power. The most pervasive requirements that limit available space are minimum set-back distances to residential buildings, visual and noise pollution limits, and tip-height restrictions (WindEurope, 2022b). Compliance requirements also exist to protect the environment and conserve biodiversity, especially for birds and bats, with special rules and regulations applying to Natura 2000 sites. Although these regulations protect the environment, they have been criticised for being focused too much on individual animals and not on the population level (e.g., Agora Energiewende, 2021). Moreover, one may argue that the compliance requirements insufficiently account for the biodiversity consequences of climate inaction. Lastly, a lack of centralised and harmonised spatial and environmental data complicates the application process for project developers (WindEurope, 2021a). In many instances, project developers must collect their own data or acquire them from multiple decentralised sources to file a permit application. This lack of accessible information creates unnecessary coordination needs that complicate the application process.

Second, there are issues with administrative procedures. One major cause of slow permitting procedures is the lack of legal certainty and predictable judicial standards for granting permits. For example, many countries lack clear standards for applying biodiversity laws (Schmidt et al., 2021). Moreover, renewable energy installations often conflict with other public interests, such as air traffic, military interests, or species protection. In the absence of clear legislative decisions on the hierarchical ordering of interests in the permit-granting procedure, the difficult task of balancing competing interests rests with the bureaucracy (ibid.). This lack of a clear hierarchy of interests creates uncertainty for project developers, but also creates inefficiencies within the permit-granting process since public agencies lack clear guidance on how to apply rules and regulations.

Box 7.1: Permitting in the EU's Renewable Energy Policy

The Renewable Energy Directive (RED) provides a comprehensive framework to increase the deployment of renewable energy. The RED originally established a target to increase the percentage of renewable energy consumed in gross final energy consumption to 20% by 2020 from 14% in 2010, which the EU overachieved at 22% in 2020 (European Commission, 2009, 2022a). In 2018, the RED was amended to introduce a new renewable energy target of 32% of gross final energy consumption by 2030 known as RED II (European Parliament and Council, 2018). Recognising that excessive delays in permit-granting can slow down the clean energy transition, the European Commission introduced an article in RED II that clarifies binding requirements for permitting. Specifically, Article 16 of RED II mandates a two-year deadline with a one-year possible extension for new power plants and a one-year deadline with a one-year possible extension for smaller installations and repowering projects. It also requires the establishment of a single contact point for all communications related to the permit application and grant process (i.e., a "one-stop-shop") (European Parliament and Council, 2018).

With the proposal of the "Fit for 55" package the Commission aims to reduce greenhouse gas emissions by 55% by 2030 relative to 1990 levels. Correspondingly, the European Commission increased the RED II renewable energy target to 40% of final consumption (Wilson, 2021). Due to Russia's war of aggression against Ukraine, the Commission has proposed to raise the renewable energy target further to 45% as a part of the REPowerEU plan to reduce dependence on Russian fossil fuels (European Commission, 2022b).

The REPowerEU plan includes amendments to Article 16 of RED II and a recommendation on permitting, which together provide more thorough guidelines on permitting (European Commission, 2022b; Simson, 2022). For example, they introduce renewable "go-to" areas, where member states should designate areas with renewable energy potential and low environmental impact. In the amended RED II, projects in "go-to" areas would have a one-year permit deadline with a three-month possible extension for new projects, shorter than the current deadlines. Most projects in "go-to" areas are exempt from environmental impact assessments, except for those that pose concerns for other EU member states. Furthermore, the recommendation provides guidance to member states such as encouraging the designation of renewable energy as an overriding public interest, positive administrative silence (i.e., lack of reply from officials implies a positive permitting decision), the prioritisation of simultaneous applications (i.e., projects that require multiple permits and submit them simultaneously as opposed to projects that have not submitted permit applications simultaneously), the limitation of exclusion zones (i.e., where projects are not possible) to a minimum, and so on.

Another cause for delays and inefficiency in the permit-granting process is the involvement of multiple administrative agencies (Banasiak et al., 2022; WindEurope, 2022b). The lack of single contact points and authorities, or 'one-stop-shops', creates coordination needs between different authorities. Whereas spatial planning and construction permits are oftentimes the responsibility of local or regional authorities, the licence to operate a plant and grid connection is handled on the national level. Project developers often coordinate with different agencies and may even have to submit multiple applications to the respective authority, creating redundancies and unnecessary complexity. Furthermore, insufficient staffing and expertise slow down permit-granting in many member states.

Even though licensing and permitting issues arise for all types of renewable energy sources, the most severe challenges relate to expanding onshore wind power. In contrast to rooftop solar power, for example, wind not only requires land but also raises concerns such as noise pollution, shadow flicker, and impacts on endangered species. Ground-mounted solar power faces similar issues with regards to spatial planning and environmental protection trade-offs, but it has received less politicisation than wind in the past. For this reason, our discussion focuses on onshore wind power, which often faces the most pronounced barriers.

Box 7.2: Why is permitting relevant for investment?

Evidently, fast permitting of renewable energy sources is essential for the energy transition. While indirectly relevant to integration, innovation, and — most obviously — infrastructure, permitting is directly affecting investment.

Renewable energy is capital intensive. Large-scale, up-front investments are necessary to construct all the wind and solar power parks needed for climate neutrality. Whether or not project developers will be granted a permit to construct and operate a power plant is a crucial factor for any investment decision. Lengthy, complex, unpredictable, or untransparent permitting processes create risks for investors that may deter them from developing projects. Permitting processes and their perceived efficiency and predictability influence investors' risk analysis and thus change the cost structure of projects (Noothout et al., 2016). In other words, permitting processes — besides the direct costs of the application and conducting all required impact assessments — create indirect costs that stem from the opportunity cost of capital and foregone profits: a risk premium. Broughel and Wüstenhagen (2022) in their study on the Swiss wind power sector, for example, find a substantial premium associated with permitting risk. Renewable energy policies, such as feed-in tariffs or long-term power purchase agreements, aim to provide certainty and thus lower the cost of capital. However, slow and unpredictable permitting procedures can counteract these measures. It is thus important to create fast, efficient, and transparent permitting procedures to lower the cost of capital of renewable energy projects and accelerate the energy transition.

7.3 Why consider Renewable Energy Zones?

The transformation to a climate neutral EU and the transition to a largely renewable energy system creates challenges for the electricity grid. In order to efficiently connect sufficient amounts of renewable generation capacity to the grid, the power grid will have to be developed. Power system planning is critical to successfully transform our energy systems in order to host high shares of variable renewable energy.

The distribution and transmission infrastructure currently in place and use is predicated on fossil fuels and centralised electricity generation. With increasing deployment of renewable energy sources, there is a growing misalignment between generation and distribution infrastructure (Renewables Grid Initiative, 2011). The transition from fossil fuels to renewable energy is not just a matter of building wind parks and installing solar panels, but it is also a question of what grid infrastructure is required. This is because renewable energy sources are usually not located where demand is high. Their location is determined by natural factors, and they cannot be relocated. Therefore, the grid must connect remote and varied sources of energy with where they are consumed. Moreover, renewable energy sources are variable by nature. An adequate grid infrastructure is essential for ensuring a reliable supply of electricity through interconnection and storage capacities. The electrification of end use sectors and questions of sector coupling pose additional challenges for grid development — grid operators must engage and cooperate with different actors across sectors to anticipate demand and energy system needs.

Transforming the grid to facilitate decentralised and variable renewable energy is a challenge for transmission system operators and regulators. More renewable energy projects are coming online, while network expansion is unable to keep up. Insufficient grid capacity and interconnection can lead to congestion and curtailment. Ultimately, insufficient grid infrastructure may depress investment in renewable energy projects as investors may fear that curtailment decreases profitability. Grid expansion and reinforcement must ideally anticipate the development of renewable energy projects. Planning of new generation on the one hand, and distribution and grid-level storage on the other, must be aligned. Spatial planning of the former must be coordinated with the latter. This requires substantial coordination among different actors, across different jurisdictions and levels of government. Moreover, permissions for new grid infrastructures are slow and complex, further complicating the adequate development of grid infrastructure.

The chicken-egg transmission problem and location-related concerns are the key issues to be addressed as the EU seeks to decarbonise its power system. Whereas developing a new wind or solar project may take three to four years, developing adequate high voltage transmission and associated infrastructure to support RE integration may take two to three times as long due to multi-layered planning, permitting, and construction requirements. The mismatch creates a challenge between RE projects, TSOs, and regulators, as wind and solar investors have difficulty securing financing without adequate transmission access. Without wind and solar projects and a guaranteed usage of line capacity, transmission regulators are loath to approve new projects (EnergyCo NSW, 2022b; H. X. Li et al., 2020).

When seeking to address interconnection, capacity, congestion, and curtailment concerns, Renewable Energy Zones (REZs) may be a power system planning strategy which serves as a useful stepping stone towards the broader transformation of the power system. REZs are a power system planning tool used to coordinate renewables' development with the necessary grid and accompanying infrastructure. REZs take the "if you build it, they will come" approach in directing transmission projects to areas with significant renewable energy potential, anticipating generation capacity rather than waiting for it to be created. This induces generation investment patterns which are more socially efficient by connecting parties which would otherwise act independently, and optimising scarce network resources (Pozo et al. 2013).

Although the practical implementation of an REZ is highly region and system-dependent, in general, REZs share several essential characteristics which work to overcome the planning challenges highlighted above. REZs are typically geographical areas specifically designated to enable the development of profitable and cost-efficient, grid-connected renewable energy projects. To qualify for consideration, the site must have high-quality RE resources (typically wind or solar, ideally both) with topography and land-use designations suited to development. Suitable areas should have previously demonstrated interest from developers, but perhaps not any significant projects yet — signalling optimal generation location for future private investment (N. Lee, 2017; Simshauser, 2021).

As the development of an REZ is a power-system level regulatory step, initiatives typically must come from the transmission regulator, who will identify candidate zones and assess renewable resources, looking for areas where high potential and commercial interest overlap. The regulator develops a transmission options scenario — looking at zone options, conducting cost-benefit, cost of production, and stability and reliability analyses for each transmission option. Typical stakeholders in this process may include relevant government ministries and agencies, TSOs and DSOs, power system planners, private renewable energy investors, environmental interest groups, and community representatives (AEMO, 2021).

REZ development enables the system planner to overcome the timescale difference which typically hinders connection of VRE projects to the grid. By taking an alternative and proactive approach to system planning, the system planner can direct RE development to the most efficient and productive regions while developing the legal and regulatory framework necessary to continue transmission upgrades to support the energy transition.

Box 7.3: How are Renewable Energy Zones driving investment?

Moving from a centralised electricity system based on dispatchable sources of energy that can be ramped up or down depending on demand, to a decentralised one relying on clean but mostly variable renewables, will result in significant changes in electricity flows. Lacking grid capacity to transport the energy generated during windy or sunny times constitutes a limit on renewables' development in different countries and regions. It leads to long waiting periods for permissions for new connections and the curtailment of existing installations (Hove, 2020; REN21, 2021; WindEurope, 2022c). Consequently, insufficient grid infrastructure and its uncertain development depress investment in REs. Moreover, lack of coordination between renewable energy projects and grid planning may also increase system costs and cause inefficiencies.

By simplifying the permitting process for new electricity connections and determining areas where renewables can be developed without the risk of curtailment due to grid limitations, investment in renewables can be more profitable and the rate of return more predictable, reducing the financing costs. Such zones, equipped with adequate storage capacity, can play a balancing role in the electricity system, facilitating investment into REs and accelerating decarbonisation of the electricity sector.

7.4 Case study 1: Wind power permitting in Norway

To investigate key lessons to improve permitting procedures to benefit the expansion and acceleration of wind power in Europe, Norway is used as a case study. The case study presented here is structure by opening with Section 7.4.1 to provide the background and contextual information on Norway's energy system and renewable energy politics. Section 7.4.2 describes Norway's permitting process and discusses the 2008 Planning and Building Act reform and Section 7.4.4 details the recent developments, such as the 2019 proposal for a national framework for wind power, and subsequent political resistance. Section 7.4.5 critically evaluates Norway's permitting experience, and finally, Section 7.4.6 concludes and discusses some of main lessons policy-makers can learn from Norway's experience.

7.4.1 Context and background

To better understand the role of permitting in the roll-out of renewables, the first case study examines the case of Norway. While the wind power roll-out in Norway was slow at first, it has accelerated substantially since 2008 and now accounts for around 8% of total power production (IEA, 2022b). In 2020, Norway led European countries in new onshore wind power installations (WindEurope, 2022a). General fixed cost reductions and support policies, such as a green certificate scheme and linear depreciation rules, have led to this rapid growth. However, this acceleration can also be partially attributed to changes in the permitting system.

Norway introduced a one-stop-shop in 2008 by centralising permitting authority with its energy agency, the Norwegian Water Resources and Energy Directorate (NVE). The NVE is the single contact point for permit applications and has authority over both the building permit and the energy licence process, thus streamlining spatial planning and licensing (Gulbrandsen et al., 2021). However, the Norwegian case is also interesting for studying the potential pitfalls of a centrally driven energy transition. In response to growing public resistance against (planned) wind power projects, the Norwegian government halted all new permit applications in 2019 (Reuters, 2022a).

Norway's permitting system is by no means perfect. It has not 'solved' permitting and permitting lead times are not faster than in most EU countries. However, Norway is an important case study on permitting policies because of its centralisation of authority in one agency. In addition, the recent developments in Norway's wind permitting politics also hold important lessons for policy-makers wishing to accelerate renewable energy deployment. So, while studying Norway's permitting policies is not necessarily a best practice case study, it is still instructive.

Norway's energy system and the state of renewables

Renewable energy dominates Norway's energy system. Norway generates 98% of its electricity from renewable resources. The majority, 91.7%, comes from hydropower. About 7.5% of Norway's electricity is generated from wind, and almost exclusively from onshore turbines (Ember, 2022). Like its supply, Norway's demand for energy is substantially electrified. In other words, almost half of Norway's total final energy consumption is met by electricity, due to the widespread adoption of direct electric heating and electric vehicles. For these reasons, Norway has one of the lowest-emitting power sectors in the world. At the same time, Norway is one of the world's largest exporters of energy, primarily exporting fossil oil and gas. Norway exported around 87% of its energy production in 2020 and the oil and gas industry accounts for 14% of the country's GDP (BBC, 2021; IEA, 2022b).

Wind power is playing an increasingly important role in Norway's energy mix. Norway has some of the best wind resources in Europe. For a long time, however, Norway did not develop these resources. In 1999, Norway's parliament adopted the goal to have at least 3 TWh of annual onshore wind power production by 2010, to diversify supply as an energy security measure. However, the country missed the target, and in 2010, annual power production from wind was only 1 TWh (Blindheim, 2013). Blindheim (2013) attributes the low deployment rate of wind power before 2010 to political uncertainty and the lack of support policies. The Norwegian government failed to establish a functioning support scheme for wind power and did not give potential developers the long-term certainty needed to make investments (see Box 7.2). Moreover, permitting processes in the NVE was slow due to a lack of staff and because the OED did not prioritise renewable energy. Nearly all permits were appealed and the OED, which handles the appeals process, took a long time to process them. Moreover, an abundant supply of hydropower meant that Norway had sufficient renewable electricity resources to meet current demand and there was a limited need to prioritise additional renewable energy supply for climate reasons.

Wind power became relevant in Norway politically in the late 2000s for four main reasons (Skjærseth & Rosendal, 2022). First, binding EU targets required Norway to plan to increase the share of renewable energy in final energy consumption. Second, the Norwegian government realised the potential to export electricity to other EU countries. Third, domestic pressure for additional renewable energy resources grew. Economic interests, most notably the wind industry and political interests such as climate groups started lobbying for more support for renewable energy. Lastly, onshore wind has considerable cost advantages compared to hydropower. The rapid cost reductions in wind turbines mean that wind is now the cheapest form of electricity in Norway (IEA, 2020; OED, 2020).

Since 1994, Norway has been a member of the European Economic Area (EEA). It participates in the Single Market, including the energy market, and must implement EU legislation relevant to the EEA. Membership in the EEA implies that many, though not all, EU directives apply. EU legislation, therefore, influences Norway's energy policy. For example, the Environmental Impact Assessments Directive or the Renewable Energy Directive impact Norway's wind policies. Norway also participates in the EU Emissions Trading System (ETS), which means the country has a carbon price in the power sector and most other industries.

One of the most influential EU regulations for the development of renewables in Norway is the Renewable Energy Directive (RED) (Skjærseth & Rosendal, 2022). Negotiations on the RED started in 2007, and the legislation was adopted in 2009. The RED set a target of 20% reliance on renewable energy for 2020 (European Commission, 2009). It also included binding member state targets, that were based on the then-prevailing renewable energy share in each member state and the member state's GDP per capita. Because Norway has one of the highest GDPs per capita in the EEA and a high share of renewable energy, it received the highest target among all EU/EEA members. Under the 2009 RED, Norway had to increase its renewable energy consumption from 58.2% to 67.5%. Norway's government initially opposed the target. It feared that surplus electricity would increase overall system and electricity costs while depressing public revenues and having little impact on national GHG emissions (Skjærseth & Rosendal, 2022). However, the Norwegian government ultimately accepted the target and overachieved the goal.

According to Skjearsteht and Rosendal (2022), Norway's acceptance of the RED targets can in part be explained by the Directive's flexibility. EU member states and EEA members can jointly implement their national targets by making "statistical transfers", according to Article 6 of the RED. Moreover, Article 11 of the RED allows member states to establish joint support mechanisms, where renewable energy produced within the territory of one participating country may count towards the national overall target of another participating country. Norway used these regulatory flexibilities to cooperate with Sweden, joining Sweden's green certificate scheme in 2012. The certificate scheme was Norway's main support mechanism to reach its EU RED targets.

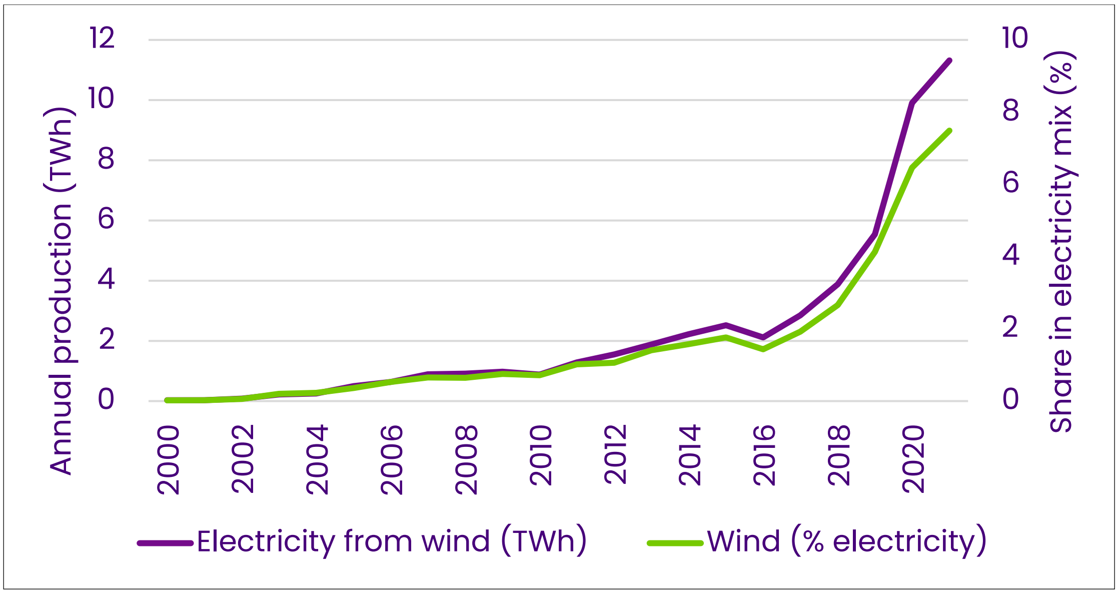
The Swedish-Norwegian tradable green electricity certificate scheme is technologically neutral, meaning that the level of policy support does not differentiate between different types of renewable energy sources (Boasson et al., 2021). Under the certificate system, renewable energy generators receive a certificate per megawatt-hour of energy delivered on the electricity grid for 15 years, which they can sell in the Swedish-Norwegian certificate market (Finjord et al., 2018).

The certificate market operates on a demand-supply basis. The demand for certificates depends on the demand for electricity. Electricity suppliers and obligated consumers are required to purchase certificates that correspond to a specific percentage of annual energy consumption. Electricity users pay indirectly for renewable energy development as costs are passed on. The supply comes from issued certificates per year and those accumulated from earlier years (Finjord et al., 2018). Therefore, renewable energy producers who comply with Swedish and Norwegian regulations receive revenue for renewable energy from both the electricity market — integrated for all Nordic countries — and the common green certificate market (Amundsen & Bergman, 2012). In 2020, the Swedish and Norwegian governments decided to end the scheme ten years early — in 2035, as opposed to 2045 — due to strong market incentives in place for renewable energy without government support (Buli, 2020). Furthermore, all projects commissioned by January 1 2022 can generate and sell certificates for 15 years, though no projects commissioned after this date will receive them (Swedish Energy Agency, 2021).

Wind power roll-out in recent years

From 1998 to 2017, Norway experienced slow and limited growth in wind power. At the end of 2012, the first year of the Swedish-Norwegian certificate scheme, Norway had approximately 703 MW of installed onshore wind power capacity (Jagan, 2022). In 2017, wind power production in Norway began to accelerate, increasing from 881 MW of installed onshore wind power capacity in 2016 to 1.205 MW in 2017 (Jagan, 2022). This growth has continued, with installed onshore wind capacity reaching 4.644 MW in Norway in 2021 (Jagan, 2022; WindEurope, 2021b). In 2020, Norway led Europe in establishing onshore wind turbines, adding 1.5 GW capacity, though some speculate that growth in wind power will slow due to political uncertainty (Gulbrandsen et al., 2021). **Figure 7.2** shows the growth in Norway's wind power production over time.

Figure 7.2: Wind power generation in Norway: annual production (TWh) and share in the electricity mix (%).



Source: Our World in Data (2022) based on BP Statistical Review of World Energy & Ember.

Norway's wind power success has been described as the product of two mutually reinforcing factors (Skjærseth & Rosendal, 2022). First, the existing flexibility mechanisms in the RED gave Norway the liberty to pursue a joint implementation approach with Sweden, and thus establish the collective green certificate scheme. This scheme represents a robust support framework for renewable energy. Second, the cost advantages and support policies strengthened domestic political actors to push for wind power. Strategic considerations by the government to increase electricity exports, moreover, led to changes in depreciation rules and changes in the permitting system, creating favourable conditions to new wind power development. While Norway's permitting practices are seen as only one factor in the acceleration of onshore wind deployment among our interviewees[20] and in the literature (e.g., Gulbrandsen et al., 2021; Skjærseth & Rosendal, 2022), it still remains a significant factor. The next section explains the role of permitting in accelerating deployment in more detail.

7.4.2 Description of permitting in Norway

The following section describes wind power permitting in Norway. It first describes and discusses the 2008 Planning and Building Act reform, which was in place until 2019. The

[20] Interview, Policy Expert, Fridtjof Nansen Institute (FNI), 12.05.2022; Interview, Representative, Norwegian Wind Energy Association (NORWEA), 23.05.2022

second section then turns to the latest proposals for changing the system, and the consequent political backlash against wind power in Norway.

Norway's permitting system until 2019

There is no single legislation in Norway that regulates all aspects of the permitting procedure (Darpö, 2020). Several Norwegian laws are relevant to renewable energy permitting, such as the Pollution Control Act (which is meant to avoid pollution), the Nature Diversity Act (which implements the UN Convention on Biological Diversity), and the Planning and Building Act (which lays out provisions for planning and building). The Planning and Building Act contains provisions regarding required environmental impact assessments (EIAs). For RES, and specifically wind power, the Energy Act is critical to the permit procedure as it contains provisions on energy generation, transmission, conversion, trading, distribution, and use. Since Norway is a member of the EEA, many EU directives apply to Norway, such as the Environmental Impact Assessment Directive, the Public Participation Directive, and the Renewable Energy Directive. However, some important regulations that impact permitting regulations in the EU, such as the Birds Directive or the Habitats Directive, do not apply to Norway.

All projects above a capacity of 10 MW must go through a multi-stage licensing process. The central authority handling the process and granting the permit to construct and operate power plants is the Norwegian Water Resources and Energy Directorate (NVE). The NVE is the executive agency of the Ministry for Petroleum and Energy, OED, which has legal authority in all permitting decisions. The NVE (2021) states that the goal of the "processing of licence applications is to ensure that benefits of the proposed project are greater than the disadvantages that follow. NVE has particular emphasis on preserving the environment."

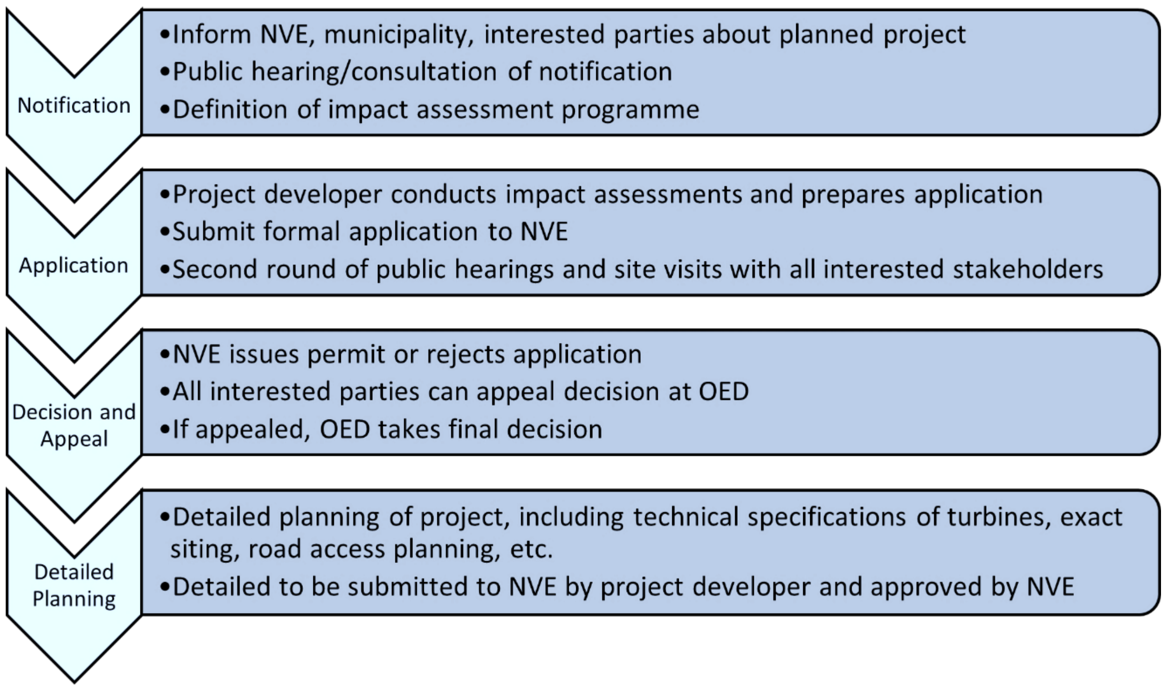
Two main stages exist in the permitting process (see **Figure 7.3**): a project notification stage and a permit application stage[21]. First, when a project developer has identified a suitable project site and decides to apply for an application, the developer submits an early notification to the NVE. This first announcement is meant to inform all interested parties about a planned project and provide information about the project's size, location, and potential impacts. The second stage is a public hearing of the notification and the EIA programme. All interested parties can submit their inputs at this stage. This public consultation process takes the form of formal hearings and local meetings. The goal of this requirement is to hear from all stakeholders and for the NVE to gather information for drawing up the requirements for the EIA. Next, the NVE approves the EIA programme, based on official requirements under Norway's Nature Diversity Acts and the EU's EIA Directive. Moreover, the NVE uses information from the public hearing to help define the EIA programme. The applicant then

[21] See Inderberg et al. (2020, pp. 2–3) for a good overview.

collects all the necessary information and conducts the EIA, which is usually outsourced to consultancies. Once all required documents are finalised, the project developer can submit its formal application to the NVE. At the application stage, another public consultation exists where, based on all information — the project details and the EIAs — a second round of hearings takes place. The hearing includes all relevant interests, including local and regional authorities as well as other stakeholders (i.e., environmental protection or recreation organisations). Finally, based on the whole application process, the NVE grants or rejects a permit.

In most cases, developers or stakeholders appeal the decision, meaning the OED assumes responsibility for a second evaluation of the application and final decision. However, in most cases the OED agrees with the decision of its regulatory agency (Gulbrandsen et al., 2021). After the NVE grants a permit, the more detailed planning of the project begins, and the project developer submits a detailed plan to the NVE. At this stage, the NVE consults with the project developer and approves technical details. Other stakeholders are no longer involved.

Figure 7.3: Overview of the permitting process in Norway.



Source: Author's representation based on Inderberg et al. (2019).

2008 Planning and Building Act Reform

The Norwegian government reformed the permitting process for wind power to the procedure outlined above in 2008. These changes were partly motivated by Norway's obligations under the RED and pressure from domestic wind power interests.

Before the reform, permits to build wind farms in Norway needed two separate approvals: municipal approval under the Planning and Building Act, and a permit decision from a national agency under the Energy Act (Darpö, 2020). By exempting wind power installations from a municipal-level permit-granting process, the 2008 reform streamlined the process by introducing a de facto 'one-stop-shop', meaning that only one government agency handles the permit-granting process. The centralisation of authority over permitting decisions has conferred much discretion to the NVE. Gulbrandsen et al. (2021) emphasise that the NVE is inclined to prioritise its energy agenda over other legitimate interests, such as nature protection or recreational interests, due to its history as an energy agency that is a part of the OED.

The centralisation of decision-making power over permits in a mostly autonomous agency with a strong interest in promoting renewable energy is believed to have benefitted the rapid expansion of wind power in Norway (Gulbrandsen et al., 2021; Inderberg et al., 2019).[22] The Planning and Building Act Reform has brought several advantages:

- Centralising decision-making power with the energy agency allows for top-down planning of the energy system. The NVE not only handles wind power permits, but also coordinates network planning with the publicly owned distribution system operator, Stattnet. Consequently, the NVE can prioritise projects based on energy system needs, allowing for more efficient network and wind power planning.
- Municipalities no longer have formal decision-making power over permit-granting. This measure removes the number of veto players and, in theory, should allow the NVE to grant permits based solely on energy system considerations.
- Project developers only need to coordinate with one agency, thus reducing the amount of paperwork needed and eliminating parallel permit processes for separate building and energy permits.[23] Moreover, the NVE is in close contact with project developers from the initial inception of a project and guides developers through the application process. This represents what is usually referred to as a one-stop-shop, something both the EU industry organisation WindEurope and the EU Commission have long called for (EU Commission, 2022; WindEurope, 2022b).

[22] Interview, Representative, Norwegian Wind Energy Association (NORWEA), 23.05.2022
[23] Interview, Representative, Norwegian Wind Energy Association (NORWEA), 23.05.2022

- The NVE has developed expertise and administrative capacity, allowing for proficient and effective handling of applications. Consequently, municipalities do not need to devote resources and capacity to managing permit applications. Furthermore, municipalities may lack trained personnel who can oversee permit applications effectively.
- Permits only have loose conditions attached, which gives project developers flexibility with regard to technological choices, as one interviewee pointed out.[24] Since some time usually passes between application and the realisation of a project, this flexibility allows developers to use the latest available technology. While this design flexibility is not an intended feature of the Norwegian system, it is akin to 'envelop' or 'box' permits called for by the European Wind power association, Wind Europe (WindEurope, 2021a).
- Centralisation allows the NVE to mediate conflicts between project developers and municipalities through public consultations, involving local and other relevant interests in the permitting process. The NVE, in cooperation with municipalities and project developers, can organise site visits to define the EIA programme and help decide on permit applications. However, although the NVE seeks the opinion of local interests, local stakeholders have felt insufficiently involved in the permit-granting process, as we discuss below.

While centralisation has not caused the acceleration of wind power in Norway, it has facilitated it. As one interviewee described it, the Planning and Building act reform was conducive for the market process to unfold.[25] By centralising responsibility for awarding permits and removing responsibility from municipalities — which may not have the capacity for complex procedures — Norway's reforms helped accelerate wind power deployment. This expansion has, however, come at the cost of increasing resistance to wind power related to conflicts with landscape and biodiversity protection, recreational activities, and Sami reindeer herding rights.

Criticism of the 2008 reforms

Since the 2008 reforms, municipalities have complained that they are insufficiently involved in decision-making. However, even though municipalities no longer have a formal veto, many argue they have informal veto power (Gulbrandsen et al., 2021; Inderberg et al., 2019). Only a few projects rejected by local communities have been approved. According to Gulbrandsen et al. (2021), project developers rarely proceed to the application stage if the host municipality is opposed to the project. Moreover, if host municipalities submit a negative

[24] Interview, Representative, Norwegian Wind Energy Association (NORWEA), 23.05.2022
[25] Interview, Policy Expert, Fridtjof Nansen Institute (FNI), 12.05.2022.

opinion during the public hearings, the NVE tends to decide against granting a permit. From 2000 until 2019, the NVE had granted only one permit when the host municipality issued a negative opinion (Inderberg et al., 2020). So, while host municipalities no longer hold a formal veto right due to the 2008 reform, their opinion is still influential in the permitting process. A positive or neutral host municipality seems to be a necessary but insufficient condition for a permit to be granted.

Despite informal influence over permit decisions, municipalities often feel marginalised in the decision-making process for new wind power developments after a permit is granted. Wind power permits do not usually make detailed provisions about the technical specifications of the plants. Developers only share these provisions in the detailed plan submitted after the permit is granted. The NVE must approve the detailed plan but does not need to involve the municipalities. Project developers tend to change technical specifications considerably at the stage of detailed planning (Gulbrandsen et al., 2021). Such changes include increasing the height of the wind turbines (sometimes by up to 100%), increasing the installed capacity, or changes to access road planning. While this flexibility is perceived as a best practice by the wind industry, it is not seen in a favourable light by municipalities and local residents, even those initially in favour of the project.

In addition to the lack of formal decision-making authority, local stakeholders also criticise project developers' lack of transparency. The decisional discretion of the NVE and the lack of transparent criteria for granting permit decisions has resulted in dissatisfaction among various interest groups. Norway has strong local environmental groups and recreational interests, such as the Norwegian trekking association, Den Norske Turistforening (DNT), which tend to view wind power critically. While the NVE considers environmental concerns in permitting decisions and states that all projects which require a full licence must conduct EIAs, it is not clear how the NVE weighs environmental protection interests among others (Gulbrandsen et al., 2021). This lack of transparency about the prioritisation of interests and on what basis a decision is taken has given rise to dissatisfaction with the process.

However, patterns of past wind power permit decisions do not fully support the charge of environmental interest groups that the NVE ignores environmental protection concerns. Inderberg et al. (2020) show that projects with a high environmental impact have a lower chance of being granted a licence. At least in terms of permitting outcomes, the NVE seems to consider environmental concerns — as reflected in EIAs — duly.

In 2019, the NVE proposed a new national framework for wind power that was supposed to address some of these concerns (NVE, 2019). However, municipalities and other interests protested the reform proposals, and the government halted all new permitting in 2019 (Reuters, 2022a). The Norwegian government is currently considering steps to undo some of the initial Planning and Building Act reforms and increase the participation of local stakeholders. Correspondingly, the Norwegian government has presented a white paper with reform options which is under deliberation at the time of writing (OED, 2020, 2022). The next section discusses these developments further.

7.4.3 Proposed changes to the Norwegian permitting system

The failed 2019 National Framework for Wind Power

In 2017, the Ministry of Petroleum and Energy (OED) asked the NVE to draft a proposal for a national framework for onshore wind. They requested that the proposal include the production of resources that provide comprehensive information on all social and environmental aspects of wind power and mechanisms to increase available spatial and environmental data for project developers. Most importantly, the OED tasked the NVE to identify priority areas for wind development. In April 2019, the NVE presented its framework and opened public consultations (NVE, 2019). The framework included state-of-the-art information on the social and environmental impacts of wind power for project developers, municipalities, and other stakeholders in the form of reports, and identified 13 designated priority areas for wind development. The NVE also provided detailed maps to assist in the identification of potential project sites within these priority areas. While new wind projects would have also been possible outside of the designated priority areas, the NVE stressed that it would give priority to applications for projects in the designated areas. At the same time, the NVE stressed that permit applications for projects in designated areas would not immediately receive a permit without due process. The NVE intended the identification of priority areas to be a 'management tool'. Therefore, individual projects in these areas would still undergo the normal assessment process, where a permit decision would be taken.

The Norwegian government scrapped the proposal in October 2019 due to widespread public resistance to the NVE's plans. Individuals from designated priority areas submitted more than 5000 comments during the public consultation, which were mostly negative. The municipalities affected were similarly dissatisfied with the identification of their regions as wind power hot spots. In the public consultation, 49 of the 56 most affected municipalities disapproved the proposal and three more were sceptical (Solberg et al., 2019).

The responses to the consultation reflected a shift in public opinion. Surveys by the Centre for International Climate Research (CICERO) show that public support for onshore wind power declined dramatically (Aasen et al., 2022). In 2019, a representative sample of the Norwegian population showed that 51% of Norwegians supported new onshore wind power developments, compared to 64.5% in 2018. Support was strongest among youth below age 30, and relatively equal across most other demographic variables. While data are not publicly available for the next few years, it is highly plausible that support continued to decline based on general public resistance.

Consequently, Prime Minster Erna Solberg halted all pending permit-granting processes for onshore wind power in 2019, declaring that no new applications were to be accepted until a new proposal was made by the NVE for a permitting process that improves the involvement of municipalities.

Box 7.4: Minority and cultural heritage interests in the permitting process

Opposition to wind power has not only focused on environmental protection, noise pollution or changes to landscape, but also on minority and cultural heritage interests. In October 2021, the Norwegian Supreme Court reversed the permitting decisions for the two already-constructed Storheia and Roan wind farms in central Norway, concluding that the two wind farms infringed on Sami cultural heritage rights under international law (Taraldsen et al., 2022). Specifically, Sami plaintiffs argued that the wind farms infringed upon cultural practices of reindeer husbandry (Hofverberg, 2021). According to the former President of the Sami Parliament of Norway, Aili Keskitalo, since reindeers prefer cool weather, they tend to herd in windy regions — often preferred regions for new wind power developments (Vetter, 2021). The two wind farms are the biggest farms in one of Europe's largest onshore wind projects (Taraldsen et al., 2022). Following the Supreme Court decision, some Sami leaders have called for the removal of all 151 turbines in the two farms (Euronews, 2021).

However, the current government has no plans to discontinue the wind farms. While the Supreme Court ruled the permit for the two wind farms invalid, it did not rule the project itself illegal. Correspondingly, the government has argued that the wind power developer can take steps to mitigate effects on reindeer herding and reapply for a permit (Taraldsen et al., 2022). Still, such reversals in permitting processes for already-constructed wind farms may dissuade future investments in wind power, thus suggesting that incorporation of minority and cultural heritage interests and a locally accepted standard of procedural justice are integral to the permitting process. In its 2020 whitepaper, the NVE proposes to consult the Sami Parliament in permit decisions for projects located in Sami reindeer husbandry regions (NVE, 2019). Reindeer husbandry is land-intensive and affects about 40% of Norway's land area.

Political resistance

The NVE's initial intention for the national framework was to improve the permitting system. Many environmental groups opposed wind power and the NVE's handling of permits, which, they argued, downplayed environmental protection considerations (Inderberg et al., 2019). Likewise, recreational interests, as represented by the Norwegian Trekking Association (Den Norske Turistforening, DNT) were also dissatisfied with the growth of wind power in Norway and its impact on the landscape.[26] The NVE's reports on how wind power projects affect biodiversity and ecosystems, and how these effects can be minimised, were meant to address some of these concerns (NVE, 2019). However, environmental protection groups considered that simply providing more information was insufficient to address their concerns.

The Norwegian government intended to provide greater guidance for the spatial planning of wind power development for the priority areas by pre-identifying suitable regions based on technical and socio-economic considerations. However, the listed priority areas made the prospects of new wind power visible to local communities. In combination with the existing discontent of communities over the lack of procedural participation and formal say, the priority areas served as a magnifying glass for their grievances. Local protest groups have sprung up all over the country, protesting the construction of new wind parks (see e.g., Bjørneset, 2020; Eriksen & Hole, 2020; Kalkenberg, 2020). For example, in Frøya, where Trønderenergi and Stadtwerke München are building a wind park, local politicians tried to stop the project and activists blocked the streets to obstruct the transport of the wind turbines (NRK, 2019).

Political opposition to wind power development has also been prominent in the Norwegian parliament. Jonas Gahr Støre, the then leader of the opposition Labour Party (and Prime Minister as of 14 October 2021), welcomed the stopping of the NVE's proposal and declared it a success for local democracy (Solberg et al., 2019). Likewise, environmental parties, such as the Sosialistisk Venstreparti, welcomed the end of the national framework as they saw wind power as increasingly infringing upon ecosystems. Even within the conservative government, few politicians wanted to back the NVE's proposal in the face of vocal public opposition. In consequence, the government put all permitting on hold and instructed the NVE to develop a new system that gives municipalities more representation and consideration and ensures other public interests are considered.

Changing the permitting system: the 2020 white paper

In 2020, the NVE and its ministry submitted a white paper proposing legislative changes to the permitting process (OED, 2020). Under the proposed system, the NVE would continue to be the decision-making authority over all wind power permits. However, the NVE would involve counties and municipalities much earlier than before in the permitting process. According to the plan, the county governor and the municipality would be actively involved in the planning process of individual projects, provide their judgement, and decide on deadlines for each stage of the permitting process (notification, application, assessment, detailed planning). The county governor would be involved in defining the impact assessment programme. Furthermore, the NVE would require strict deadlines for all steps in the licensing

[26] Interview, Policy Expert, Fridtjof Nansen Institute (FNI), 12.05.2022.

process to ensure permits are processed within reasonable timeframes while involving local interests. Moreover, the NVE would introduce more transparency in the process through, among other things, a more systematic assessment of the various socio-economic, cultural, and environmental implications. Permits would include more restrictive conditions than they used to in the past by clarifying the maximum capacities of wind parks and defining other technical specifications. Finally, according to the white paper, the environmental impact assessment requirements are to be assessed and revised in cooperation with the environment agency.

The NVE and OED purposely did not include any provisions to formalise the veto powers of the municipalities in the 2020 white paper. Although the NVE and OED clarified the consultation role of municipalities, their proposed changes would not have meant a formal veto power for municipalities. The NVE explicitly stated that an "absolute right of veto for municipalities cannot be reconciled with a licensing system in which national and regional considerations are also emphasised." (OED, 2020, p. 31, own translation). Therefore, under the proposed changes, municipalities would still need to appeal granted permits at the OED and would not have the authority to block a permit themselves.

However, the recent change in government from Conservative to Labour and the political backlash to onshore wind have resulted in substantial shifts in Norway's energy policy. In April 2022, Terje Aasland, Minister of Petroleum and Energy, instructed the NVE to resume wind permitting according to the new guidelines set out in the 2020 white paper (OED, 2022a). However, Aasland stipulated that the permitting application of new onshore projects should only move forward if the host municipality has given its written approval. This approval must be attached by the developer to its permit application to the NVE. With this provision, municipalities have a de facto (but not de jure) veto over permitting. Municipalities can stop new wind projects in their region even before the application has been submitted to the NVE. Only when a project has sufficient local support can the developer initiate the next steps of the permitting process (Hilt, 2022).

Moreover, the Norwegian government will most likely reintegrate wind power into the Planning and Building Act, reversing the 2008 reform (Kalajdzic & Tollersrud, 2020). With these changes, Labour's minority government intends to codify the decision-making power of municipalities. While the Norwegian government is still discussing these revisions, and they need to pass the Norwegian parliament, these reforms would likely result in a stricter regulatory framework for the planning and development of onshore wind power projects. While some regard municipal veto powers as antithetical to the expansion of renewable energy, there is broad political support for greater, local decision-making over onshore wind permits. The formalisation of the municipal veto, therefore, seems likely.[27]

[27] Interview, Representative, Norwegian Wind Energy Association (NORWEA), 23.05.2022

Altogether, the centralisation of permitting and the recent boom in wind power have resulted in political backlash. This political backlash will likely result in a fundamental reform of Norway's centralised permitting system, that redistributes decision-making powers to the municipal level. However, Norway needs to expand its production of renewable energy to meet the increasing demand resulting from the electrification of end-use sectors (IEA, 2022b). Against the backdrop of these developments and the acceptance barriers to onshore wind, the government is reconsidering its energy strategy. As onshore wind faces strong domestic barriers and new hydropower potential is limited, the government is turning to offshore wind (OED, 2021). In May, the Norwegian government announced a plan to develop 30 GW of offshore wind capacity by 2040, which would lead to an estimated increase from two offshore wind turbines today to 1500 offshore wind turbines by 2040 (Buli, 2022). Most of the additional energy production will be exported and the Norwegian government is already calling for grid expansions to Germany, the United Kingdom, and the Netherlands (Simony & Svendstorp, 2022).

The Norwegian government sees industrial opportunities in offshore wind. Offshore wind power can generate the necessary renewable energy to consolidate Norway's position as a future supplier of green hydrogen for export and its own industry (Buli, 2022).[28] Moreover, while onshore wind technology is almost exclusively manufactured in other countries and the industry is mature, the offshore industry is still in its infancy. The Norwegian government, therefore, hopes to build up a home-grown manufacturing industry, which may provide a long-term alternative to its current fossil-fuel-based export industry. Although the Russian invasion of Ukraine has given more urgency to the expansion of renewables, the Norwegian government seems to prioritise the short-term expansion of oil and gas and the long-term deployment of offshore wind over the expansion of cheap onshore wind power.

The future of onshore wind in Norway is uncertain. The country has managed to increase wind power output in a short timeframe. However, while the permitting system has facilitated the fast roll-out of new renewable energy sources, it has created political dissent and resistance against wind power. The next section evaluates the successes and failures of Norway's wind power policy and permitting system.

7.4.4 Evaluating Norway's permitting system

Norway has experienced a wind power boom in recent years. From a small share of the Norwegian electricity mix in 2010, wind power will soon account for almost 10% of electricity production. Furthermore, the country has led new onshore installations in Europe in 2020 (WindEurope, 2021b). The rapid cost reduction of wind technology in Norway is an important explanatory factor for wind power's expansion. Costs for new wind turbines have dropped by

[28] Interview, Policy Expert, Fridtjof Nansen Institute (FNI), 12.05.2022.

almost 40% between 2012 and 2019 (OED, 2020). Support policies, such as favourable depreciation rules and the green certificate scheme, improved the economic competitiveness and profitability of wind power, helping it to become the cheapest source of energy in Norway. Other than these economic considerations, the permitting system has been an important factor in increasing the onshore wind power deployment rate. While it is difficult to ascertain the permitting system's exact contribution to the expansion of wind power, it can be considered a necessary although insufficient condition for Norway's rapid expansion of wind power.

The following section discusses some key characteristics of Norway's permitting system, focusing on three aspects: the role of centralisation, the advantages and disadvantages of political discretion, and, last, the relevance of local buy-in for new projects.

Centralisation and procedural justice

As previously discussed, the centralisation of permit-granting decisions within the NVE has had several advantages and disadvantages. The most direct advantages stem from the fact that planning and regulating of individual wind projects is centralised in a single institution with comprehensive capabilities — the NVE. Such institutional capacity is a key factor for the success of renewable energy, according to Sovacool and Lakshmi Ratan (2012). The agency integrates multiple energy system planning processes and can thus plan energy system developments in a top-down fashion. It has developed considerable expertise and capacity over time and is making efforts to collect and centralise data. Moreover, the permitting process is simplified for project developers with the NVE as the single contact point. These features all reduce transaction costs and contribute to a more efficient and a potentially more effective permitting process.

Centralisation also has major disadvantages, as the Norwegian case shows. The most important drawback of the Norwegian permitting system relates to a lack of community acceptance (Darpö, 2020; Gulbrandsen et al., 2021; Inderberg et al., 2019). Community acceptance, as defined by Wüstenhagen et al. (2007), is one key aspect of social acceptance of wind power and relates to procedural and distributive justice as well as trust. The social and environmental costs of renewable energy production are concentrated locally, while its benefits are dispersed.[29] Land-use planning tends to be a local or regional affair and, from the perspective of procedural justice, one may argue that residents should have a say over how their region develops.[30] In the Norwegian permitting system, municipalities and local

[29] There are also local costs and benefits resulting from the manufacturing of wind and solar technology. These are not considered here.
[30] Procedural justice is the extent to which there is a fair decision making process that gives all stakeholders the chance to participate in decision-making (Wüstenhagen et al., 2007).

interests only have had a consultative role. Given this, political resistance may be seen as legitimate.

Procedural fairness has been shown to be an important factor in community acceptance of wind power (Rand & Hoen, 2017), which the Norwegian experience seems to confirm. While centralising formal decision-making powers may make the permitting process easier, compromising on local standards for procedural justice can result in widespread political resistance, as evidenced in Norway. Although the roll-out of renewable energy is urgent, deliberation over land-use and siting decisions still needs to take place. The Norwegian government with its most recent reform proposals is increasingly moving away from a fully centralised system by giving municipalities a formal role throughout the permitting process. This may be akin to what Wolsink (2007) has called a 'collaborative approach' that builds institutional capital — i.e., the knowledge resources, relational resources, and administrative capacity — to involve all stakeholders in the planning process.

Attaining procedural justice in wind power development and maintaining an efficient and effective permitting system is a difficult balancing act. It remains to be seen if the Norwegian attempt to reconcile the two by giving municipalities a formal say will be successful. As Darpö (2020) has shown, a look at Norway's neighbour, Sweden, may be instructive in that regard. Sweden codified a municipal veto in 2009 when it decided to abandon local planning requirements for renewable energy. In Sweden, special regional permit bodies grant permits, but only if the host municipality has given its formal approval. A municipal veto is the most common reason for rejecting a permit. The municipal decision comes late in the application process, only after EIAs have been conducted and a formal application has been filed. This requirement gives municipalities the chance to study all impact assessments but also creates substantial costs for project developers if the permit is denied in the end. Moreover, municipalities tend to attach conditions to the permit, forcing project developers to adopt less efficient technologies (e.g., smaller turbines). Because municipalities apply the veto rule inconsistently, legal uncertainty is created, which may dampen investor confidence. However, despite the municipal veto, Sweden has experienced strong wind power growth, which provides some hope for the prospects of wind power in Norway under the new proposals.

Furthermore, in Norway, the municipal veto will likely be much earlier in the process — before an application is filed. Municipalities generally opposed to wind power will have the power to obstruct new wind development in their region. This ability may create a conflict with national goals for renewable energy deployment and may be antithetical to the realisation of an efficient energy transition and the fight against climate change. One may argue that there is a risk that this veto option emboldens a 'not in my back yard' attitude (NIMBY) of municipalities. However, as research has consistently shown, NIMBY inadequately captures the dynamics of local acceptance and disapproval (Rand & Hoen, 2017). In other words, institutional and procedural factors are much more important for the acceptance of wind projects than NIMBYism, and particular siting decisions are much more important than preconceived attitudes towards any wind project in one's region. Given this, the envisioned reforms of the permitting system may not embolden obstructing municipalities, but help generate greater community acceptance.

Norway will keep important features of its centralised system. Most importantly, the NVE will remain as the main contact point for project developers and will coordinate the application process. Still, interviewees expect permitting to be slower, and in individual cases less successful than under the former system. However, given the political situation, one interviewee representing the Norwegian wind industry did not see a way around involving municipalities more in the process. While greater municipal involvement may slow down permitting, the hopes are that it will foster more acceptance in the medium term.[31]

Political discretion and transparency

The wide decisional discretion of the NVE in the permit-granting process is another notable characteristic of the Norwegian permitting system that is important to discuss. As described above, the NVE has enjoyed considerable freedom in the permit-granting process so far. There is little political steering by the OED, and the ministry usually never interferes with individual permits until there is a formal appeal (Gulbrandsen et al., 2021). Specifically, the NVE prioritises its objective to deliver energy security and ensure the cost-effective development of the Norwegian energy system. In fact, the NVE has prioritised the development of renewable energy over other, potentially conflicting, interests, which has benefitted the development of wind power. This scenario illustrates how powerful a politically isolated and administratively capable bureaucracy can be for advancing the development of wind power, especially with regard to an issue where opposition is locally concentrated. Whereas local and regional decision-makers may be more responsive to such opposition, a central, politically isolated bureaucracy is less so. From this perspective, political discretion and centralisation has considerable advantages.

The NVE's discretionary powers are aided by the difficulty of litigation in Norway, which contributes to slow permitting in other countries. Litigation against administrative decisions related to wind power licences is almost non-existent in Norway (Darpö, 2020). This low litigation rate has to do with the high costs involved. Furthermore, as one interviewee has pointed out, NGOs and other interest groups that may oppose a wind project are aware of the high level of discretion the NVE enjoys.[32] The prospects for success in a legal case are very low, which impedes legal action against onshore wind power projects. The opportunity

[31] Interview, Representative, Norwegian Wind Energy Association (NORWEA), 23.05.2022.
[32] Interview, Policy Expert, Fridtjof Nansen Institute (FNI), 12.05.2022.

to appeal a permit at the OED may be another factor that pre-empts litigation against wind power. However, in most cases, the OED tends to back the decision of its agency.[33]

As noted above, the NVE's political discretion and lack of transparency in its priorities in the permitting process is one of the greatest sources of dissatisfaction with the permitting system in Norway. Various public interests can conflict, and governments must make decisions on which interests to prioritise. There are legitimate reasons to prioritise the development of wind power over other interests, such as environmental protection. Local costs such as landscape changes or environmental impacts may be justified on the grounds of climate action or energy security. Importantly, it must be emphasised that the NVE does not ignore various public interests. It may be argued that the main issue with the NVE's high level of political discretion and prioritisation relates to the tension between democracy and technocracy; the NVE's mandate to prioritise wind power over other public interests is not as clear as its actions seem to imply. If there were a much clearer mandate, it would have been much harder to criticise the NVE's decision-making and any change to the mandate would have to come through political decision-making.[34]

There seems to be a larger point connected to the issues of transparency and democratic deliberation: efforts to speed up the deployment of renewable energy cannot compromise the (local) deliberation of alternative land uses and impact analyses. Those granting permits must weigh interests on a case-by-case basis. The agency must assess the socio-economic and environmental impacts of wind power plants. After all, local biodiversity loss and ecosystem degradation are equally important considerations to climate interests. Permit-granting processes often take time, and there may be a natural limit to speeding up permitting. This is not to say that permitting should not, and cannot, be streamlined. However, short-cutting impact assessments and due consideration of various interests is not the most effective way to speed up permitting, given that it may amplify resistance. This means that if permitting is supposed to be efficient and effective, administrative capacity to handle many of these deliberative processes and impact assessments must be available. If procedures cannot be cut, they must at least be managed in an efficient way, including by devoting enough staff to ensure their fast and professional handling. Otherwise, political discretion and a lack of transparency may lead to rapid onshore wind power deployment in the short run but may undermine it in the medium and long-term.

[33] The OED upheld the agency's decision in more than 80% of all appeal cases (Inderberg et al., 2020).
[34] The EU is now urging member states to declare the development of renewable energy sources an 'overriding public interest', thus improving its legal standing vis-à-vis other public interests (EU Commission, 2022). This would make legal action against wind power projects, for example, more difficult.

Local buy-in and ownership

Resistance to wind power in Norway is not only motivated by dissatisfaction with the permit decision-making process. Another important factor may be the lack of local/communal ownership and financial participation in wind power projects.[35] In fact, in Norway, local ownership is virtually non-existent. According to the NVE, as of October 2020, foreign investment funds owned more than 60% of wind power in Norway in terms of installed capacity, a number which was increasing at the time (Skeie et al., 2020). National and regional power companies are involved in wind projects and Norwegian companies are among the developers, but ownership is overwhelmingly not locally anchored. This disparity contrasts with (small-scale) hydropower, which tends to be owned by the public through counties and municipalities or state-owned enterprises.[36] Such ownership patterns may lead to resistance from local stakeholders who worry about procedural and distributive equity on the part of developers with little stake in their communities beyond wind power projects, as has been the case in Norway. Evidently, it is not conducive to the acceptance of wind power if host municipalities do not benefit economically from the project but must bear the majority of costs.

The literature discusses community ownership and local compensation as potential mechanisms to increase community support for new onshore wind power projects and achieve equitable outcomes (e.g., Darpö, 2020). This is the strategy the Norwegian government pursues. In 2021, the government announced a new tax on onshore wind power production of NOK 0.01 per kWh (Nyhus & Hatlestad, 2022). The tax will be collected nationally but will flow back directly to the budget of host municipalities. The government hopes that the tax will improve municipal support for wind power. However, research indicates that financial compensation and local ownership are incomplete solutions for improving acceptance (see Box 7.4). Financial compensation is limited without procedural participation. In fact, a survey of German adults found that participation in planning for wind energy projects (through both formal/legal and informal processes) was preferred to local compensation (Langer et al., 2017). Nonetheless, the efforts of the Norwegian government to improve the economic participation of host municipalities in wind projects may lead to greater acceptance in the medium-term and may also ease the now foreseen introduction of a municipal veto.

[35] Interview, Policy Expert, Fridtjof Nansen Institute (FNI), 12.05.2022.
[36] Ibid. note 15

Box 7.5: Local compensation schemes to address wind power approval and distributive justice concerns

Since onshore wind developments tend to lead to disparate, global benefits and concentrated local costs, local compensation is a potential mechanism to increase community support for new onshore wind power projects and achieve equitable outcomes.

Various forms of local compensation exist. For example, Cowell et al. (2011) differentiate between four types: (1) a lump-sum payment, (2) direct investments in public goods, (3) community ownership of wind projects (i.e., municipality-owned, cooperative-owned, and so on), and (4) use of local goods and services in constructing new wind power projects. It is important to note, however, that local compensation will not automatically lead to support for new wind power developments. For example, Jørgensen et al. (2020) show that in the case of three Danish wind energy projects, distributive justice concerns are inseparable from procedural justice concerns and local compensation does not necessarily lead to approval in the absence of active local stakeholder involvement. In several case studies, community members argue that compensation does not address perceived non-monetary costs (Jørgensen et al., 2020). Furthermore, García et al. (2016) and Jørgensen et al. (2020) argue that schemes have sometimes been associated with bribery, thus, undermining support for wind energy projects. Still, Jørgensen et al. (2020) claim that local compensation does seem to aid perceptions of fairness when the compensation is negotiated with local community members. They recommend considerations of non-monetary values in compensation schemes and transparency with and recognition of local stakeholders in decision-making. Altogether, the literature makes contesting claims on the effects of local compensation on acceptance, and therefore, the effects of local compensation on approval are ambiguous; they seem to depend on the scheme and context (i.e., based on community-specific negotiations).

However, from a distributive justice perspective, local compensation is clearly relevant for policy-makers to consider. To address perceived distributive concerns, the mechanism for local compensation matters. For example, in a survey of households in Sandnes, Norway, on a hypothetical wind farm, García et al. (2016) found that local public goods tend to be preferred over private compensation to the most affected individuals, even though public goods tend to cost less. Kerres et al. (2020) also argue that lump-sum payments may lead to distributive equity concerns as some benefit and others deal with perceived costs without renumeration. However, local compensation is not a perfect mechanism to address distributive justice concerns. Cowell et al. (2011) argue, since onshore wind companies tend to be large, negotiations between large energy companies and small, rural communities on local compensation may lead to dissatisfactory results for community members due to inequal power and resources.

7.4.5 Discussion

Norway's wind power politics have been very dynamic. Although Norway's electricity generation is already almost fully renewable, due to large scale hydropower, wind power has experienced a boom in the past decade as a consequence of technology cost reductions, effective support policies, and a conducive administrative framework. However, the political support for wind power has been volatile and the future of onshore wind power is uncertain.

Norway's wind power experience has been characterised by a centralised permitting process that had several advantages for the development of renewable energy sources as it allowed for integrated planning of generation and distribution, the granting of flexible permits that allowed for implementing the most efficient project design, and the presence of a single contact point for project developers. Moreover, the permitting agency had high levels of political discretion and was largely isolated from the pressures of local interests and other stakeholders, which allowed for the prioritisation of energy interests over competing public interests. In these respects, the permitting system has been supportive of the development of renewables.

Still, permitting lead times are still not substantially faster than in many EU countries. The permitting process involves numerous rounds of consultations and allows for appeals at the ministry, which together slows down the process.

Norway's technocratic and centralised permitting system increasingly came out of step with societal demands. As wind power expanded and had a visual impact on Norway's landscape, dissatisfaction with the permitting system grew. Municipalities and locally organised environmental and recreational interests felt insufficiently involved in granting wind power permits and the siting of projects. Wind power has thus become a major source of contention among the public and increasingly politicised. In 2020, all permitting was stopped by the prime minister and only resumed in 2022 after substantial amendments had been made to the permitting process. Crucially, Norway is moving back to a more decentralised system by giving municipalities a formal veto in the permit decision.

Norway's experience has shown the importance of a renewable energy framework that involves all stakeholders and accounts for procedural and distributive justice. Norway's failure to find ways to satisfy local demands for more participation in decision-making has resulted in an abrupt stop to all permit-granting processes with possibly long-term negative consequences for the prospects of onshore wind power in Norway. A key lesson of the Norwegian experience, therefore, is that permitting systems must satisfy procedural justice concerns to generate the long-term social acceptance of wind power. An implication of this lesson is that if permitting systems are supposed to address procedural justice while at the same time being efficient and effective, adequate institutional capacity is key. It requires appropriate resources, skilled staff, and adequate digital infrastructure if the acceleration of renewable energy permitting is not supposed to come at the cost of procedural justice.

7.5 Case study 2: Renewable Energy Zones in Australia

Renewable Energy Zones have been Australia's approach towards optimising regulatory structures, enhance and stabilise the flow of investment into renewable energy development whilst ensuring the electricity grid will support the growth and dynamics of RES in the system. This case study analyses Australia's experience, with Section 7.5.1 opening with the background to Australia's prevailing issues and challenges with its energy market and subsequently around renewable energy development. Section 7.5.2 delves into how Australia headed towards the development of REZs in response to its energy challenges. The discussion then flows into Section 7.5.3 which details the REZ experience in New South Wales giving an explanation into the regulatory process and actors involved, followed by Section 7.5.4 on the development of the project and the challenges it faced. Lastly Section 7.5.5, provides a brief discussion on the lessons and outcomes from Australia's ventures into REZs.

7.5.1 Context and background

Decreasing costs of renewables, combined with extraordinary potential for their development in Australia, resulted in their entry into the market at a relatively rapid pace and in multiple locations. At the same time, renewable energy policy (or lack thereof) in Australia has driven a cyclical boom-and-bust pattern in investment, which has proved a significant challenge to the coordination of investment decisions. Lack of coordination has led to curtailments and connection lags, particularly at the sub-national level (Simshauser, 2021). This differed from the comparatively slow and grinding pace of thermal plant development and access (Simshauser et al., 2021). Changing the generation mix has changed transmission needs, increasing demand for infrastructure, ancillary services, and regulator intervention.

At the same time, Australia is faced with a weak transmission system beset by stability and reliability issues. Australian system planners and network operators continue to attempt to keep up with the changing generation landscape, and are developing innovative system regulation and planning strategies to address the challenges uncovered by the energy transition (Yu et al., 2022). One strategy developed to address system strength and variable renewable energy (VRE) integration challenges is the implementation of Renewable Energy Zones (REZs). Seeking to address VRE integration in a sustainable and holistic manner, REZs were introduced as a planning tool to allocate transmission resources efficiently and induce otherwise independent VRE projects to cluster in a socially optimal manner. Introduced initially at the state level, Australia now has several REZs, which are being used to drive VRE investment and shape the development of the transmission network.

Australian energy market in brief

The Australian energy market is known for high electricity prices and reliability problems. The National Energy Market (NEM) is 20 years old and has vertically integrated into most regions since the 1990s, connecting the six states and territories along the eastern and south-eastern coasts and delivering around 80% of all electricity consumed in Australia. The market is relatively liberalised, with a five-minute settlement bid-based spot market, liquid derivatives forward market, and traditional over-the-counter market for energy trading and balancing, with each of the five regions acting as its bidding zone. The forward and over-the-counter market signals have historically driven a laissez-faire approach to investment in the market and related infrastructure (Energy Exemplar, 2019).

Recent electricity prices have been volatile. Due to high wind and solar generation and mild weather reducing demand in early 2021, the price was relatively low. By mid-June 2022, the situation changed significantly, and the market saw a suspension of trading due to high demand, low generation due to an instituted price cap, and lack of reserve in the market (Macdonald-Smith & Ludlow, 2022).

This price volatility results from an underdeveloped electricity grid. The transmission network is extended and sparsely connected, with load centres internally well concentrated but quite distant from one another. The current regulatory and physical asset framework is designed to combine traditional thermal and hydropower generation to demand centres over long distances, with over 50,000 km of high voltage transmission lines across the five states (The Evolving Australian Electricity Supply Chain, 2019).

In terms of ownership, the NEM transmission network is a public-private mix: Victoria and South Australia have fully privately owned networks, whereas Tasmania and Queensland are fully publicly operated networks, and NSW has a public-private mix, with the transmission system operated by Transgrid (Energy Networks Australia, 2022). Generators have a right to petition for connection to the transmission network but no right to be dispatched.

In 2021, the NEM contained around 53 GW of total generation capacity in the wholesale market. Combined, the installations covered by NEM provide around 200 TWh of electricity load each year to commercial and household consumers (AEMO, 2022a). Private entities control a large proportion of generation in the NEM, with the two largest accounting for 40% of capacity across the NEM, and 60% of output (Australian Energy Regulator, 2021). Private generation capacity is largest in NSW, Victoria, and South Australia, and is mainly comprised of coal and lignite power plants (Australian Energy Regulator, 2021).

Electricity generation continues to be the largest source of carbon emissions in Australia, accounting for a third of all CO_2 emissions in 2019 to 2020 (Australian Energy Regulator, 2021). Within the NEM, as of 2022, 39% of capacity and 65% of all generation was produced by coal-fired power plants, with brown coal accounting for one quarter of all coal-fired generation. The share of fossil-gas is 17% of capacity and 6.7% of output. In terms of electricity mix in New South Wales, in 2020 around 75% energy generation was coal-produced (Australian Energy Regulator, 2022). However, traditional thermal coal plants in NSW are reaching the end of their technical lifetimes, and all five coal-fired power plants in NSW are scheduled to be shut down between 2022 and 2043. Most of the current coal-fired generation stock is expected to be replaced by 2040 and an additional 50 GW (roughly equal to NEM at present) is set to be connected over the next decade (AEMC, 2019). The closure of conventional thermal plants continues to be an opportunity for the growth of renewables in Australia. Still, that growth challenges the fundamental organising principles of traditional generation and transmission infrastructure. Electricity from wind and solar installations are expected to fill much of the gap as thermal plants close.

During 2021 to 2022, renewables contributed 31% of all generation in NSW, up from 26% in 2020. As of 2021, around 30% of homes in the NEM have small-scale solar PV installations, totalling about 15 GW of capacity and grid-scale VRE installations amount to 16 GW of capacity. Grid-scale solar has increased significantly over the past decade, taking advantage of Australia's high level of solar radiation — the highest in the world at 50 million PJ per year. Other transition drivers include community concerns about the impact of carbon-intensive electricity and high energy prices driving rooftop solar uptake. However, funding for large-scale solar projects did not occur at significant levels until around 2018. Commercial solar accounted for 0.5% of generation capacity in 2017, scaling up to 7.4% of power in 2020 (Department of Industry, Science, Energy and Resources, 2021).

As of mid-2022, wind power accounted for 14.8% of total capacity in the NEM, with over 1000 MW of new capacity added since July 2020; the total output from wind generation is up 17% from 2017 and over 70% since 2017 (Paul McArdle,2022). Market penetration is exceptionally high in South Australia, generating 43% of output in 2020. However, the focus on new wind projects has shifted increasingly to NSW and Victoria, with those two states accounting for over 70% of capacity. Queensland had no significant wind projects before 2018 but has one of the country's largest generation capacities of 453 MW. Wind accounts for 25% of proposed and committed generation projects, totalling nearly 24 GW within the NEM (Australian Energy Regulator, 2021). Record wind generation occurred on 16 July 2022, peaking at 7111 MW in the 21:50 interval, marking the first time that wind generation in the NEM topped 7000 MW and accounting for 27% of all generation (Paul McArdle, 2022).

Challenges in the National Energy Market

The NEM is undergoing a significant transition, seeking to pivot from conventional thermal generation on a one-way network from a generator to consumers to a two-way system built around renewable generation by prosumers and batteries. Plants nearing the end of their technical lives tend to be more fragile, with parts more prone to failure. This increases the risk of disruption, as evidenced in 2017 when a heatwave struck. Peak demand coincided with several technical issues at multiple plants, with over 2000 MW offline, resulting in a system overload and significant load shedding (NSW Government, 2019, p. 16).

The NEM hosts a complicated tangle of system strength, grid connection, and congestion issues which challenges the integration of large-scale renewable energy projects and transformation of the Australian energy market. Analysis, completed to support NSW's Transmission Infrastructure Strategy, found that the network was running out of capacity, with only one in 20 proposed generation projects available to connect. High congestion leads to inefficient markets and higher prices. Generators are less likely to be dispatched at total capacity, and marginal loss factors worsen significantly as congestion increases. Areas with high renewable energy potential also tended to be further away from crucial load centres, requiring significant transmission infrastructure that often was not there (Energy NSW, 2018).

Curtailment is the most apparent symptom of these issues. It has become commonplace as the Australian Electricity Market Operator (AEMO) struggles to balance variable renewable energy in a transmission network with little spare capacity and weak connections. In 2019, AEMO took the step of cutting the allowable output from a collection of five solar farms in Victoria and NSW in half, from 347 MW to 172 MW, citing newly developed system strength issues and significant grid-scale solar investment in an area described as "remote and electrically weak" (AEMO, 2022b; Parkinson, 2019a).

While those solar farms had been in operation for some time and it was only new modelling from AEMO that uncovered the new system strength issues, new projects also face delays and potential curtailment before they are even off the ground (Vorrath, 2020b). Despite having initial approval in 2016 and constructing 80 of the largest turbines in the southern hemisphere by 2019, as of 2022, grid tests were still being conducted for AEMO to approve full-capacity generation (Tilt Renewables, 2022). The area faces such significant connection challenges that some renewables investors dubbed it the "rhombus of regret", with the Clean Energy Council estimating over AUD 6 billion of investment could be at risk without network reinforcement. AEMO notes that the rate of connection of new renewable energy generation in remote areas or areas with weak links to the core of the grid is unprecedented in developed power systems (Macdonald-Smith, 2020).

This made it challenging to deploy renewable energy projects, which, in addition to the connection issues, had to go through a planning and approval process lasting several years in close discussion with AEMO and all relevant parties. All in all, these are clear indications that the transmission network and administrative procedures are ill-equipped to deal with the speed at which wind and solar projects are coming online in the NEM (Macdonald-Smith, 2020; Parkinson, 2020). AEMO's most likely generation scenario estimates that, without significant intervention, this challenge will only become more important, as wind and solar capacity is expected to increase nine-fold by 2050 (AEMO, 2020b). AEMO estimates more than 10,000 km of high voltage transmission lines will need to be added to accommodate the expansion of renewables, in addition to upgrades to critical interconnections between states (AEMO, 2020b).

7.5.2 Development of Renewable Energy Zones in Australia on the national level

The conceptual development of REZ regulation within Australian agencies followed a similar outline. In 2016, the Council of Australian Governments (COAG) asked AMEC to undertake reporting on transmission planning and investment, which led to the Coordination of Generation and Transmission Investment review (COGATI), which occurs biannually. Developed as part of the first COGATI review, the REZ discussion paper was published in 2019. It aimed at identifying and facilitating REZs in an explicit workstream to focus on regulatory changes needed in conjunction with stakeholders, as part of the broader reform agenda being pursued by the Energy Security Board (ESB) (AEMC, 2019, 2020). It was published in conjunction with stakeholder and public comment opportunities and a workshop.

Both the ESB and AEMC undertook their work on the reform agenda with the core assumption that Australia's future grid is likely to be focused on a larger number of small, more geographically dispersed generation centres which can be built more quickly than transmission capacity can be added, necessitating transmission infrastructure upgrades and additions. AEMC found that existing grid connection applications were at the edges of the network in areas with high renewable energy potential but weak network capacity and system strength. To facilitate their development, investors had to ensure that their assets would remain profitable even if other installations were connected. Without additional transmission capacity, extra capacity would result in greater generation, congestion, and lower price. This made it challenging to estimate future revenues and increased investment risk. Reducing this risk required better coordination between generation and transmission investment decisions to facilitate energy transition (AEMC, 2019).

To address this challenge, AEMC initially defined an REZ as "a way of enhancing coordination between generators to achieve efficiencies of scale and scope about procuring and using connection assets". However, stakeholder feedback was that this was too narrow. AEMC updated their understanding of an REZ to include "the broader idea of an REZ incorporating augmentations to the shared network" (AEMC, 2019). To further flesh out the typology for REZs, AEMC further identified two archetypes: A and B.

A-type REZs were identified as a cluster of generators connected to the transmission network through a dedicated connection asset. Transmission investment associated with the generators are connection assets and are paid for by the connecting party. The focus of A-type REZs is the coordination between generation investments. B-type zones were conceptualised as a cluster of generators within a geographic area that are connected to the transmission network. Connection and transmission assets are considered as part of the transmission network and are shared — and paid for — by consumers via Transmission Use of System (TUOS) charges. The focus of B-type REZs is the coordination between generation capacity and necessary investments into transmission infrastructure. AEMC further breaks REZs down into greenfield or brownfield zones, for a total of four possible types of REZs, as outlined in **Figure 7.4**.

Figure 7.4: Types of Renewable Energy Zones under AEMC.

A Greenfield	B Greenfield	A Brownfield	B Brownfield
▪A brand new cluster of generators that want to locate in the same area and therefore share connections	•No transmission infrastructure at the moment, but high quality resources, and network to be built out to that location	•Existing substation that new generators want to connect to in order to increase efficiency	•Weak network in the region, and connecting new generators requires network upgrades

Source: AEMC (2019).

Developing this typology, AEMC highlighted the lack of a one-size-fits-all approach for developing REZs. Based on their own inquiry, as well as discussion with stakeholders, AEMC found that the type and specific development of an REZ are likely to depend on several factors, including:

- Location relative to existing transmission infrastructure
- Total (expected) generation capacity of the REZ, as well as dispatched capacity
- Number of projects within the REZ
- Technical considerations
- Adapting grid development plan to REZs

Following the discussion paper and identification of key characteristics and regulatory steps for REZ development, the AEMO included REZs in their Integrated System Plan (ISP), the long-term cost-based network optimisation plan in which AEMO forecasts transmission requirements for 20 years. This meant, effectively, placing REZs in the long-term system planning of the NEM (AEMO, 2020b).

The 2020 ISP identifies key factors for REZ development from a system planning perspective, including:

- Quality of renewable resources
- Cost of developing transmission connections
- Proximity to load centres and network losses from transporting electricity from generation to the load centre
- Physical must-haves to enable connection of new resources and to support system security
- Locational context, including indigenous heritage and land rights, biodiversity, community concerns, and planning challenges.

AEMO's 2020 ISP identified 18 transmission upgrade projects to support RE integration, REZ development, and coal phase-out. Committed projects already underway included system strength improvements in South Australia, transmission upgrades in Victoria to increase capacity at several solar farms, and an upgrade to the Queensland-NSW interconnector. Projects awaiting approval included a series of interconnectors between South Australia and NSW, as well as Queensland and NSW, specifically increasing capacity connections at RE installations. Other projects included a 1500 MW capacity interconnector between Tasmania and Victoria to facilitate solar and wind energy exports from Tasmania and a series of network augmentations to support transfer capacity between the Orana REZ and load centres (Australian Energy Regulator, 2021).

7.5.3 Renewable Energy Zones in New South Wales

While the conceptual development of REZs continued among regulators and agencies, transmission issues and renewable energy policy continued to be contentious in state-level politics. At the same time, New South Wales (NSW) saw a series of environmental and weather-related crises, highlighting perceived federal shortcomings and the need to switch from traditional thermal plants, for both the NSW electorate and political leaders (Morton, 2020).

With reform teed up at the political level, NSW additionally faces an impending energy infrastructure crisis. Like the rest of the country, NSW's energy infrastructure is ageing and increasingly fragile, with most traditional coal plants nearing the end of their technical lifetimes. In particular, the imminent closure of the 2 GW Liddell power station prompted the government to search for alternatives (Doyle, 2022). In deciding between greater use of fossil fuels or boosting support for renewable energy and seeking the least-cost highest-benefit renewable energy policy and grid improvements, the NSW government identified REZs as a potential solution.

REZs were first considered in NSW under the 2018 Transmission Infrastructure Strategy under Energy Minister, Don Harwin. The Strategy sought to support private investment in "priority energy infrastructure projects" to deliver the least cost energy to at least 2040. The Strategy identified three critical aims for NSW's transmission network:

- Boosting interconnections
- Increasing capacity by prioritising REZs to diversify the energy mix and improve transmission
- Working with other states and regulators to streamline regulation and improve investment conditions

The Transmission Strategy focused on creating REZs and "bringing forward large-scale shared network upgrades", identifying three test-balloon REZs in the New England, Central-West, and South-West regions. The three proposed REZs were areas with high-quality wind and solar resources and had already planned upgrades to enable multiple projects to connect at a lower cost. For the electorate, the Transmission Strategy emphasised the benefit of local construction jobs and regional investment, in addition to slightly reduced electricity bills. At the industry level, the Transmission Strategy aimed to decrease investment barriers through regulatory changes and identify red tape extending the transmission development process. For this purpose, it obligated NSW to work with COAG, AEMC and ESB to advocate for efficient and streamlined regulatory processes and ensure that NSW processes are efficient (Energy NSW, 2018).

Having initiated the development of REZs at the system-planning level, the 2019 Electricity Strategy outlined a more specific plan to officially implement the first REZ in Australia, the Central-West Orana REZ (NSW Government, 2019). The Electricity Strategy prioritised supporting the development of new transmission to connect renewable energy projects to the grid through REZs. The government would do so by seeking competitive generation proposals, ensuring "necessary regulatory changes are made", including streamlining planning and approval processes, and developing a strategic master plan for REZ development in a "timely and efficient way" (NSW Government, 2019). The Electricity Strategy initially provided an AUD 9 million outlay as seed funding for the initial set-up of the REZ. In order to meet the goals set out in the Electricity Strategy and Transmission Strategy, the NSW Government introduced the Electricity Infrastructure Investment Act 2020, which would be driving legislation behind the creation of REZs (Electricity Infrastructure Investment Act 2020, 2020).

Regulatory process and actors

The regulatory framework which supports and enables the development of REZs in NSW is continually evolving as the selected REZs enter different stages of development. The Electricity Infrastructure Roadmap developed in the Electricity Infrastructure Investment Act 2020 (Energy NSW, 2020; Electricity Infrastructure Investment Act 2020, 2020) coordinates investment in transmission, generation, and storage infrastructure to support the transition towards renewables, as coal-fired plants retire. The development of Renewable Energy Zones is one of the five key actions outlined in the roadmap to meet the goal of installing at least 12 GW of renewable energy generation capacity and 2 GW of storage by 2030.

In order to do so, the Roadmap and Electricity Infrastructure Investment Act 2020 identify a total of five REZ areas: Central-West Orana, Illawarra, New England, South West, and Hunter-Central Coast, with specific zones identified in conjunction with AEMO's study into the most cost-effective areas for REZ development in its 2020 ISP (Filatoff, 2020a), see Appendix B for additional information on the multiple REZs. The Roadmap and Electricity Infrastructure Investment Act 2020 additionally provide a statement of process, identifying several actors critical to the regulatory process.

AEMO is designated the Consumer Trustee, acting as "the custodian of the long-term financial interests of NSW consumers", with the power to authorise infrastructure projects, administer tenders, and set long-term energy service agreements with generators (NSW Department of Planning, Energy, and Environment, 2021). This also ensures that action taken in NSW to upgrade the transmission network will remain in line with AEMO's Integrated System Plan and the long-term transmission needs of the entire NEM.

Australian Energy Regulator

The Australian Energy Regulator (AER) was appointed as the Regulator for NSW REZs. Its responsibilities include:

- Making five-year revenue determinations for any project authorised by AEMO
- Making annual contribution determinations regarding the Electricity Infrastructure Fund established in the Electricity Infrastructure Investment Act 2020
- Approving risk management frameworks set out by the Consumer Trustee
- Reviewing tender rules for long-term energy service agreements

AER is concurrently undertaking the development of contribution determinations which would determine the annual amount of revenue recovered from NSW electricity distributors (Ausgrid Endeavour Energy, and Essential Energy) to help fund ongoing projects as well as to be passed on to consumers (AER, 2022).

EnergyCo

The Government of NSW designated the Energy Corporation of NSW (EnergyCo) as the statutory authority responsible for the delivery of the Electricity Infrastructure Roadmap. As the statutory authority, EnergyCo responsibilities include:

- Working with RE project developers to plan "efficient solutions that minimise cumulative impacts on the community" (EnergyCo NSW, 2022d)
- Community engagement with stakeholders
- Developing the project scope
- Acquiring any land and easements necessary for network infrastructure
- Overseeing the Environmental Impact Statement processes
- Running the competitive tender process to appoint a TSO, who will design, build, finance, operate, and maintain the REZ network

In addition, EnergyCo selects Network Operators for each REZ through a competitive tender process. AER will make an assessment to determine the amounts payable to each Network Operator for network infrastructure projects as part of the procurement process. AER assessments occur at two points in the competitive tender process: first, at the beginning of the procurement stage, to determine whether the proposed procurement process is likely to result in prudent responses with all the information required to make a revenue determination. Second, following the selection of a Network Operator, at which point the successful party will submit a revenue proposal to AER for consideration. The Revenue Determination Guidelines are still in the draft stage, following a public comment period in mid-2022, with publication due in mid-2022 (AER, 2022).

As part of its mandate, EnergyCo is also undertaking a regulatory reassessment, reviewing network connection, authorisation, and access regulations. EnergyCo is drafting new Network Authorisation Guidelines to codify the REZ development process and outline the function of each stakeholder, following the official designation of an REZ. The draft guidelines cover the network options development process, in addition to the authorisation of those projects, and are centred around crucial approaches which should guide the Infrastructure Planner and Consumer Trustee as they develop the REZ infrastructure plans (EnergyCo NSW, 2022e).

As outlined in the Electricity Infrastructure Investment Act, EnergyCo nominally places a high value on social licence and community support for REZ development and has developed a series of engagement principles and requirements for Infrastructure Planners in the draft Network Authorisation Guidelines. EnergyCo has emphasised the need for "genuine and meaningful engagement" with local communities, particularly those that will be most impacted by construction projects (EnergyCo NSW, 2022f).

The draft regulation would allow EnergyCo to supersede REZ network operators, to prohibit network connections for projects where there is "significant local community opposition" that may threaten community support for other infrastructure projects in the REZ. EnergyCo argues that community support within REZs is critical to the success and legitimacy of the project, in addition to the considerations which need to be made to ensure continued respect for indigenous land rights.

Project development

The Central-West Orana REZ was designated in the Electricity Infrastructure Investment Act 2020 as the first of three pilot REZs, and promoted as the model for the (at least two) others. Central-West Orana REZ was chosen as the pilot due to a "host of approved and planned projects, relatively low build costs and a strong mix of solar and wind resources", and was supported as the pilot location by AEMO, AEMC, ESB, and the NSW Department of Energy and Environment (Filatoff, 2020b). The Central-West Orana REZ was designated with a target of 3000 MW of renewable energy capacity to be developed by 2027 in line with AEMO's 2022 ISP.

NSW signed a Memorandum of Understanding with the Commonwealth Government in January 2020, totalling AUD 2 billion for emissions reductions initiatives, which includes specific underwriting for the development of the network to support REZs, with the goal of being "shovel ready" by 2022 (Filatoff, 2020b). Wind and solar developers were initially somewhat wary, taking a wait-and-see approach. The concerns included the fact that REZ could force in centralisation of new projects in one area while reducing development options in some areas (Parkinson, 2019b). Other concerns included burden-sharing of transmission costs under new regulations, but they were quickly overshadowed as REZ development kicked off in earnest.

In 2020, the call for project proposals for the pilot programme through the "Registration of Interest" (RoI) process was announced, allowing EnergyCo to gauge interest in renewable energy and transmission development in the newly designated REZ. It aimed especially at better estimating the interesting new generation and storage capacities being developed, including their type, size and development status (Mazengarb, 2020b). EnergyCo would then use information collected to officially develop the Central-West REZ, consult with communities in the region, and establish a market for competitive project proposals.

The RoI for the Central-West Orana REZ was quite successful, with 113 registrations of interest, totalling 27 GW, within one month of announcement. This significant interest may be attributed partly to the fact that an announcement accompanied the RoI announcement, that said the state would add AUD 31 million of funding to the original AUD 9 million, easing industry anxieties (Ho, 2020). Estimates based on the registrations of interest, find the Central-West Orana REZ would likely be capable of powering over 1.3 million homes using renewables across the NEM (Vorrath, 2020a). Concurrently, TSO TransGrid announced a highly detailed feasibility study for transmission updates associated with the REZ, estimated at AUD 16.2 billion, in addition to AUD 5 million in funding secured from ARENA, targeted at creating and demonstrating a pathway for development of future REZs in the NEM (Ho, 2020).

Following the RoI, EnergyCo entered the second phase of development. In March 2020 it announced development of the other two pilot REZs in the South-West and New England areas. The South-West REZ is centred around the regional township of Hay, anticipating just under 5 GW of generation capacity added (Mazengarb, 2020a). The New England REZ is centred around Armidale and expects another 5 GW of capacity. In addition to added generation capacity, EnergyCo anticipates AUD 20 billion of private sector investments and 2000 long-term construction jobs in those regions, diversifying local regional economies post-drought and bushfire.

By the end of 2020, the REZ projects were declared a "Critical State Significant Infrastructure Project", a classification which gave it priority status throughout the government approvals process in a bid to speed up the planning stage (Carroll, 2020b). The Central-West REZ was given this classification partially due to its status as an experiment; its development is closely watched by state and national agencies and regulators to determine the viability of REZs as a tool for RE integration and network development (EnergyCo NSW, 2022d).

EnergyCo published a proposed timeline for developing the physical infrastructure construction in the Central-West Orana REZ, to be used as a template for developing other REZs in NSW. Stage One took place between 2020 and 2021 and included planning, studies, and physical infrastructure construction. EnergyCo identified three Energy Hubs, which will collect the electricity generated from the renewable energy projects within the REZ, to transform the voltage to transmit it out of the REZ and into the TransGrid network (EnergyCo NSW, 2022d). Energy Hubs are anticipated to be 50 hectares each, plus buffer. EnergyCo is engaged in negotiations with landowners and local communities to secure suitable sites. Stage One also included the identification of crucial study corridors with the potential to build core transmission infrastructure at 500 kV and 330 kV. The initial study corridor was released for a consultation to mixed responses, with feedback included in the revised study corridor.

Stage Two began in early 2022, with a consultation on the revised study corridor based on landowner, community, and environmental concerns, a proposal for Energy Hub locations, and a continuation of discussions with potentially affected landowners and custodians. In the framework of these consultations, EnergyCo received public feedback on the initial study corridor, including criticism from local farmers and landowners concerned about impacts on prime agricultural land. As a reaction, EnergyCo announced a revised study corridor and a new set of studies to ensure minimal impact on crucial agricultural land as well as to assess the effects on local communities more clearly (EnergyCo NSW, 2022g). Field investigations also began, including ecological and geotechnical surveys, hydrology surveys, noise monitoring and heritage investigations. Stage Three, starting in mid-2022, continues the narrowing of Energy Hub and transmission corridor locations and the beginning of easement and land acquisition processes.

Starting in July 2022, EnergyCo has been conducting extensive fieldwork to support the developing the Stage Four Environmental Impact Statement (EIS), accompanied by Cultural Heritage Assessment. EnergyCo is responsible for the EIS for the REZ network infrastructure and anticipates the draft EIS will be made available for public consultation in the second quarter of 2023. Following the finalisation of the EIS, EnergyCo expects the network infrastructure project to be determined and sent to the Minister for Planning, Energy, and Environment for approval, by the end of 2023 (EnergyCo NSW, 2022d).

In addition, EnergyCo opened the competitive tender process to identify the network operator within the REZ, announcing three shortlisted tenders in May 2022 (Department of Planning, Industry & Environment, 2022). Candidates include ACE Energy (a conglomerate of Spanish multinationals Acciona, Cobra, and NSW DSO Endeavour Energy), Network REZolution (comprised of Pacific Partnerships, UGL, CPB Contractors, and APA Group, which is Australia's most significant fossil gas infrastructure firm), and NewGen Networks (Plenary Group, Elecnor, Essential Energy, and Secure Energy) (Carroll, 2022; Department of Planning, Industry & Environment, 2022). Formal tender submissions from the shortlisted candidates are expected in late 2022, with the contract to be awarded in 2023.

7.5.4 Challenges for the development of REZs

A significant challenge in the development of REZs is the number of communities impacted by the development and eventual construction of massive infrastructure projects. Landowners, indigenous communities, and rural communities are the most likely to be affected by transmission projects. There has been some community resistance to new project development, particularly from landowners who could face land acquisition or easements to facilitate infrastructure development. Developments in several states have faced opposition from rural communities and landowners, going so far as to storm a community meeting in Queensland to demand answers from TransGrid about the development of transmission projects, and ploughing opposition messages into fields in which the proposed transmission line would impact (A. Murray, 2021).

The pilot Central-West Orana REZ faces a somewhat more organised opposition, with farmers and landowners forming the Merriwa-Cassilis Alliance (MCA) to voice their concerns about land use and property rights around a 180 km planned transmission line (Kinbacher, 2021). RE-Alliance, a coalition focused on the humanitarian impacts of renewable energy development, finds that, while opposition to the REZs makes up quite a small proportion of the overall population, effective community consultation is necessary for the ongoing success of such significant projects (RE-Alliance, 2021b). The MCA was relatively successful in its opposition, and in early 2022, the NSW Energy Minister announced a change in the planned route to minimise impacts on the contested agricultural land (D. Bell, 2022). The long and contentious community consultation process for the Merriwa-Cassilis line highlights the challenges that states have, and will continue to face, as the planning stages of the REZs continue. The issue of social licence has been highlighted by the NSW government, with government Director for Energy Infrastructure and Zones Chloe Hicks stating at a forum, "Social licence is central to the delivery of [Renewable Energy Zones] and the Roadmap and its enabling legislation" (Mazengarb, 2021).

The issue of social licence and community resistance has also come up in the development of REZs in Victoria. It has impacted how the Government of Victoria initiated project planning. AusNet's Western Victorian Transmission Network Project (WVTNP) has faced vocal opposition from farmers who fear the line would cut through their property, destabilise property values, and threaten crops and livestock (Somerville, 2022). AusNet estimates the proposed route would cut through over 200 private properties, with the announcement generating tractor protests, threats to padlock key access gates, and crude messages cut into fields (Energy Networks Australia, 2021; McNaughton, 2021; The Courier, 2022). The residents argue that by the time project developers consult with the community, most significant decisions have already been made, and any concerns brought up by residents typically receive a lacklustre response. Victoria has sought to centre social licence in its development approach, assessing projects based on their contribution to local communities in the short and long-run. The consultation paper for the proposed development framework from the Department of Environment, Land, Water, and Planning states that community consultation, heritage, and social considerations must be as embedded in the development process as economical and technical concerns (Department of Environment, Land Water and Planning, 2022; Government of Victoria, 2022).

7.5.5 Discussion

The development of REZs within NSW, and in comparison to Victoria and Queensland, highlights the challenges of transmission planning and the transition away from fossil fuels. It also illustrates potential strategies to integrate variable renewable energy into the grid successfully. Transmission planning is complex and time intensive as a function of its scope and scale; however, planning tools which streamline permitting and incentivise efficient investment and development offer a potential solution. Effective REZ planning and construction require clarity and definitive action. The establishment of an agency with clear responsibilities and scope is essential to ensure that all pieces of the process are taken care of in a reasonable time, with minimal confusion and conflict over competences, which could take up valuable time and prolong the application process. Additionally, definitive and binding targets which are ambitious enough to encourage investors and effectively replace fossil fuel generation need to be set.

The REZs are most effective if their geographical coverage is not too large. While their scope naturally depends on natural resources and the state of the grid in the area, if the goal is to encourage renewable energy investment, setting an overly large REZ may be counterproductive, leading to inefficient scattering of renewable energy installations within the REZ. Development needs to be carefully considered and targeted to ensure the most efficient investment and development patterns for the region.

By the same token, coordination needs to occur at least at a regional level, to ensure that connecting the REZ to the broader grid and inter-regional interconnections does not pose long-term congestion and system strength challenges, especially if the REZ is expected to bring a significant amount of capacity online. In Australia, a delegation of project approvals to AEMO aims to ensure that individual action taken by states does not cripple the broader network or threaten interconnections and lead to the same curtailment that REZ development was attempting to address. By implementing REZs, states can optimise their regulatory structures, spur significant investment in renewable energy and ensure the electrical grid can effectively support a transition from traditional fossil-based generation.

7.6 Lessons for the European Union

The two selected case studies underline the importance of streamlining the permitting process for renewables development. As the EU is trying to accelerate development of renewables to not only mitigate climate change but also to decrease EU dependence on fossil fuels imports, the simplification of procedures to avoid slowing down deployment of wind and solar energy gained new urgency. Norway's experiences with simplifying the permitting procedure, and Australia's with REZs, come with lessons that can be useful for the EU and its member states as they attempt to rapidly scale up deployment of renewables.

The first critical lesson is that member states' permitting processes need to be fast and effective without compromising procedural justice. In other words, speed and effectiveness cannot come at the cost of procedural justice or the short-changing of formal and informal environmental, landscape, and cultural impact assessments. Existing permitting systems are unnecessarily complex and bureaucratic while at the same time not delivering on procedural justice. Future-proof permitting systems must be simple and effective, but still generate long-term social acceptance by satisfying procedural justice concerns.

At the same time, in designated areas, such as REZs, with optimal resources and potentially low opposition to renewable energy installations, the permitting process could be significantly simplified and streamlined. Development of the necessary infrastructure within the REZ, especially in terms of the electricity grid that would be ready for uptake of additional capacity, could reduce the need for grid connection permission. Instead, all projects selected as a result of a dedicated renewable energy auction, could automatically be granted access to the grid. Concentration of different kinds of renewables, complemented with storage and hydrogen capacity, could decrease the costs of infrastructure development lead from outside of the REZ and treat it as a dispatchable power plant.

However, in the case of REZs, Norway's own try at REZ resulted in a failed attempt to devise priority areas for the development of onshore wind power should lead to some caution regarding the Commission's proposed "go-to" areas. As part of the REPowerEU package, the Commission proposed that member states designate "go to" areas, where high potential for renewable energy supply exists and environmental impacts are minimal (see Box 7.1). Interviewed experts expressed no consensus on whether project-specific impact assessments can be replaced by strategic assessments of larger areas, i.e., whether the Commission's proposal would be feasible. However, if it were possible to speed up the permitting process by doing impact assessments on a regional, rather than project, level and at the same time ensure environmental integrity, such go-to areas have large potential. Still, the fact that member states must select priority areas may aggravate discontent in the affected regions, as it has been the case in Norway. These designated "go-to" areas put the spotlight on specific regions, the inhabitants of which may feel that the burden of the energy transition is not distributed equally across the country. Moreover, the process by which these areas will be identified is important. The Norwegian experience indicates that regions where "go-to" areas are to be located need to be involved early on and partake in the decision. Similarly, affected communities must feel that they benefit from the concentration of wind power in their region through financial benefits or the provision of public goods.

Another important takeaway is that member states need to increase administrative capacity for assessing application and issuing permissions. To ensure the long-term social acceptance of wind power, the permit-granting process must be transparent and involve communities. Compromising on community involvement and transparency may backfire, as has been the case in Norway. Therefore, EU member states must invest in administrative capacity to handle the higher application load without compromising on community involvement and the assessment of environmental and socio-economic impacts. Improving administrative capacity means dedicating enough staff to permitting and training them adequately. It also requires establishing an adequate digital infrastructure for the whole permitting process and setting clear deadlines for all stages of the permitting process.

Finally, member states should improve the availability of centralised data. Norway has made efforts to improve data availability for project developers. The NVE started to collect spatial and environmental data for project developers and other interested parties centrally. This has substantial advantages over decentralised systems, where project developers must collect data from multiple sources. The efforts of the NVE can, and should, be replicated by other EU member states. One outcome for the EU to consider is the standardisation on the quality and availability of data that should be available, particularly considering the different starting points and conditions of member states. Additionally, EU offering support to member states from a data oversight perspective can be another approach to take.

7.7 Conclusions

Considering more ambitious greenhouse gas emission reduction goals and Russia's war of aggression against Ukraine, the EU aims to accelerate the deployment of renewable energies substantially. However, it is facing numerous challenges that hold renewable energy back. Two of the most important barriers are: slow permitting processes, and inadequate infrastructure to facilitate high levels of renewable energy. As the EU is looking for solutions to these challenges, this report has looked at the cases of wind power permitting in Norway and Renewable Energy Zones in Australia for useful lessons.

While far from perfect in all respects, Norway and Australia have witnessed strong growth in renewable energy in recent years. Australia's Renewable Energy Zones may turn out to be effective and innovative mechanisms to integrate the planning of electricity networks and the spatial planning of renewable energy projects. Because REZs are still in the planning stage, their benefits are still unclear. Nonetheless, they are an innovative proposal that EU member states should watch closely. Similarly, wind power permitting in Norway is at a crossroads. While it has facilitated the roll-out of wind power in the past, it must now adapt to accommodate the interests of local stakeholders to safeguard the future of onshore wind power in Norway. For the EU, the Norwegian case highlights the importance of ensuring procedural justice in the permitting process on the one hand, and adequate institutional capacity on the other.

The case studies and findings presented here warrant some caution and highlight the need for future research. First, since permitting and planning systems are highly specific to their legal, historical, and political context, it is difficult to translate findings from one country to another. What worked in one context may not work in another, and vice versa. Moreover, all permitting and planning systems are different and face their own bottlenecks and barriers.

Nonetheless, the lessons drawn here are of a very general nature and in this regard may still be instructive. Second, the case studies presented here are exploratory and based on secondary literature and qualitative evidence, derived from document analyses and expert interviews. Through this approach, it is not possible to exact the causal effect of the investigated policies. Further research should focus on providing ex-post analyses of how implementation has affected outcomes. For example, with regards to permitting, these analyses could compare two similar jurisdictions with different permitting and licensing practices or take event-study approaches that track developments within a single jurisdiction before and after permitting or licensing practices have been changed.

Finally, the case study work has shown how little empirical research has investigated planning and permitting practices, especially with a view on improving the permitting and planning for renewables development. Future research should consequently focus on establishing best practices and more robust empirical analyses of planning reforms.

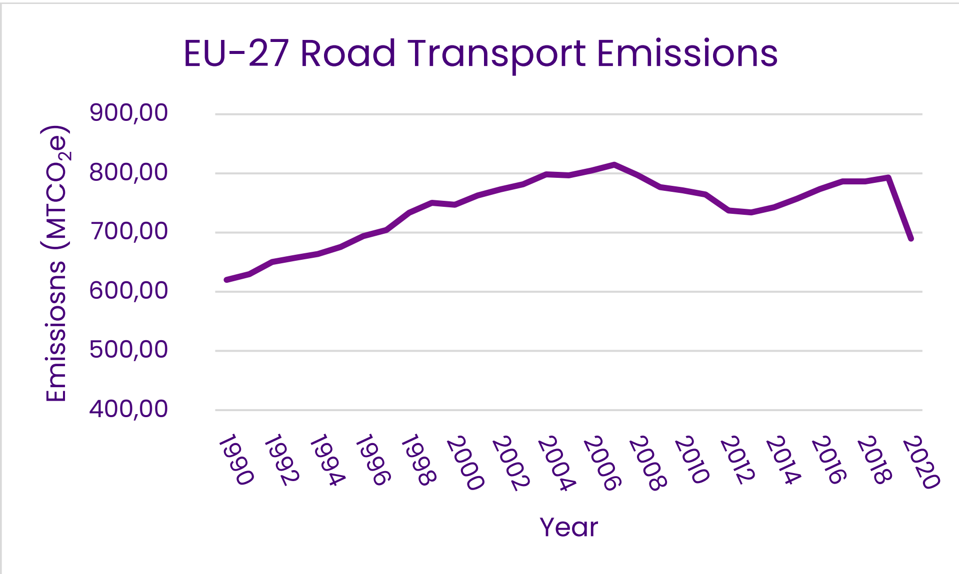
8. Archetype 7: Decarbonisation of passenger cars

8.1 Introduction

The transport sector is a major source of emissions in the European Union (EU), with domestic transport accounting for one fifth of the EU27's emissions in 2019. While emissions in 2020 appeared to drop due to the COVID-19 pandemic, the overall trends still show emissions from the sector to rise. Despite an apparent peak in 2008, emissions have been rising since 2012 (**Figure 8.1**). In 2020, 2.24 million battery electric vehicles (BEVs) were sold in the EU27. Over 94% of these were passenger cars, yet this figure only represents about 1% of all passenger vehicles driven in Europe. The EV ownership distribution in the EU is heavily concentrated in Germany, France, the Netherlands, Sweden and Belgium, with these countries accounting for 75% of the EV fleet (Wappelhorst, 2021).

In 2022, 280 million passenger vehicles were in use across the EU (European Alternative Fuels Observatory, 2022). In the first and second quarters of 2022, almost 500,000 BEVs and more than 400,000 PHEVs were sold across the EU27. This represented a 28% increase for BEVs and almost a 10% decrease for PHEVs in compared to the previous year (ACEA, 2022c).

Figure 8.1: Emission trends of the EU's domestic transport sector from 1990 to 2020.



Source: EEA (2021).

The EU is investing heavily to support the growth of electric mobility. The Connecting Europe Facility (CEF) is the financing mechanism that will allocate funds for investments. The Alternative Fuels Infrastructure Facility (AFIF) was introduced as part of the CEF that allocates EUR 1.6 billion between 2021 and 2023 for investment in green infrastructure projects to support the changing needs of alternative fuel vehicles such as Electrically Chargeable Vehicles (ECVs) (European Commission, 2021a). The goal is to install 1 million changing points by 2025 and 3.5 million by 2030 (EIB, 2021). In 2022, under the 'Fit for 55' packages, the Commission released its proposal of the new Alternative Fuel Infrastructure Regulation (AFIR). Moving from a Directive to a Regulation, the AFIR now has a suite of legally binding targets deemed sufficient by the Commission to achieve the necessary cuts in CO_2 emissions from vehicles. Amongst the many proposed targets, by 2030 the proposal sets out to have 34.4 million BEVs in use, with an average annual millage of 13,414 km per ECV and a total of 39 million changing stations (ACEA, 2022b).

EV subsidies are provided at the member state level, with conditions varying greatly between each member state. The majority of EU member states have introduced financial incentives to support the enhancement and promotion of electric vehicles on the market in the form of tax reductions or exemptions and/or purchase incentives (ACEA, 2022c). In 2021, only 17 member states provide purchasing incentives of EVs, while the remaining 10 offer only tax reductions, exemptions or one-off grants (ACEA, 2021). However, 2022, saw a shift in approaches by many MS. Now 21 MSs offer purchase incentives and/or tax reductions, whereas only 6 MS still offer only some form of grant tax exemption (ACEA, 2021). . For example Poland is one such country that has changed its position on purchase incentives and has initiated a long-term public support scheme for the purchase of EVs (KPMG, 2021).

A study by the EEA (2021) clearly showed that countries that promote incentives for EVs experienced reductions in transport sector emissions. The Netherlands introduced a tax system to promote EVs and light electric vehicles (LEVs) between 2010 and 2017, while time increasing stringency on tax exemptions on PHEVs resulted in further uptake of BEVs. These measures were found to have reduced CO_2 emissions by more than 3% in this period. Other examples include Italy, which offers a tax exemption for the first five years of ownership of EVs, combined with "eco-bonuses" of up to EUR 6,000 for cars emitting ≤ 20 gCO_2/km and costing less than EUR 50,000; and a "malus" payment of EUR 2500 for vehicles with 290 gCO_2/km or more. Additionally, grants of up to EUR 2000 are available for BEVs and PHEVs. Romania has a similar system, but offers a more generous subsidy of EUR 10,000 for BEVs, up to EUR 4500 for PHEVs with a fuel efficiency of <50 gCO_2/km and an additional EUR 1250 for scrapping an old car (KPMG, 2021).

8.2 Why consider alternatives to the existing policy framework for passenger cars?

The EU's policy framework for reducing the Union's emissions exists under the Emission Trading Scheme (ETS) and the Effort Sharing Regulation (ESR). Road transport has never been covered by the EU ETS and therefore not subject to a crediting system. Traditionally the ESR set out targets and goals to reduce emissions but leaves member states with the flexibility on how they will develop and implement their own polices to reach their targets.

With Regulation 2019/631, the EU adopted the emissions reduction target for new vehicles as an average for the vehicle fleet of a given manufacturer. By 2025, average emissions from new vehicles should be 15% below 2021 levels. By 2030 emissions reduction should be 37.5% below 2021 levels (European Parliament and the Council of the European Union, 2019). According to the study by Transport & Environment (2021), due to the many loopholes and exemptions in the regulation, effectively, carmakers only have to reduce emissions by 2% instead of 15% by 2029. The flexibility arrangements in the regulation offered certain allowances for the use of "eco-innovations" and for exceeding EV production quotas. Another pitfall of the regulation design is that the Commission does not present many interim targets, running the risk that carmakers or governments will wait towards the end of these deadlines to make the necessary reforms. In the framework of the "Fit for 55" package of proposals, the European Commission proposed increasing these targets to a 55% reduction by 2030 and a 100% reduction by 2035 (European Commission, 2021c).

The "eco-innovation credits" are the sole crediting system that the EU introduced for carmakers outside of the realm of the EU ETS. Meanwhile, the case studies presented show that an industry-wide crediting system as a market-based tool can, firstly, encourage carmakers to shift to zero or near-zero emission cars and, secondly, encourage an alternative financing stream that can be reinvested into subsidies for consumers. Additionally, we see that in California, even more ambitious targets were set and not only were they reached by 2020, but they were exceeded, with excellent compliance.

It is clear that purchase incentives are crucial for the uptake of EVs. However, existing subsidies have largely been financed through public funds, either through national budgets or EU budgets, such as the Recovery and Resilience Fund (RRF). This ultimately expends billions of euros across member states from public money. Given that the widespread decarbonisation of the continent will continually need to be financed, it begs the question whether it is effective to finance the electric vehicles solely through public funds, and whether private investment is needed to fill the gap.

8.3 Case study 1: Low-carbon fuel standard in California

California leads in the US as a state in reducing its emissions through progressive and ambitious fuels standards and intelligent investment mechanisms. This case investigates California's experiences, from its successes and pitfalls. Section 8.3.1 provides the context and background on California's economic growth and the resultant emissions trends in the state as well as the passenger car sector and introduces the system California uses for emission standards. Section 8.3.2 looks at the history of policy development and outlines the metamorphosis of California's policy framework around decarbonisation and climate action, with an explanation of how the low-carbon fuel standards emerged, how it functions, how calculations made for carbon intensify, and credits. Section 8.3.3 highlights the impacts that the LCFS has had on trends and compliance. Lastly, Section 8.3.4 provides an overview of the lessons the EU can learn from and adopt.

8.3.1 Context and background

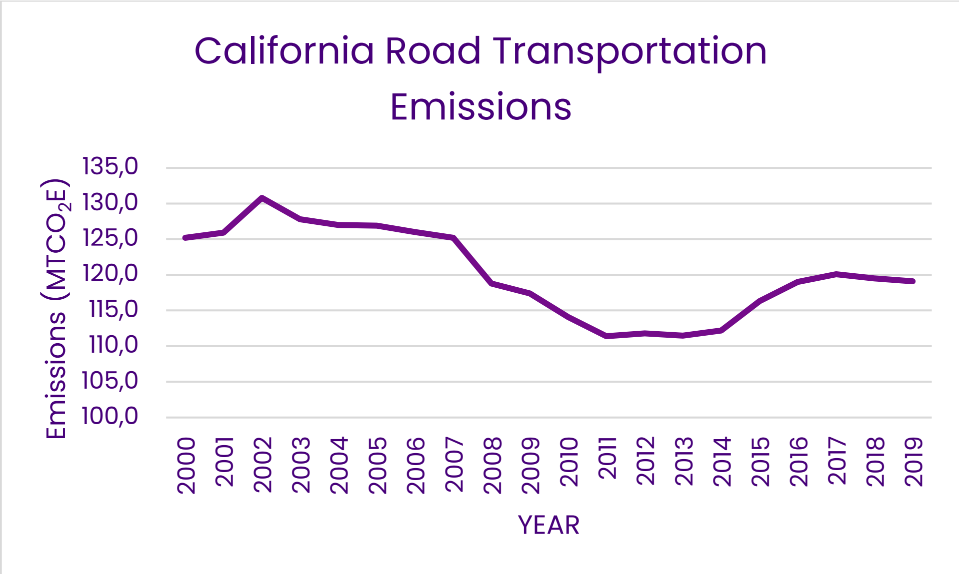
California state economy and emissions

It is estimated that California's residential population in 2021 reached 39 million, with a projected growth of 45 million residents by 2050. California's population grew at a rate of 10% per annum between 2000 and 2010, with a slightly lower rate of change, 6%, between 2010 and 2020 (Johnson et al., 2022).

In 2000, California's Gross State Product (GSP; listed in 2012 chained dollars) was USD 1.69 trillion. By 2010, that number rose to USD 2.03 trillion, with the most recent data for 2021 estimating GSP at USD 3.4 trillion, or around 14.5% of US total GDP (U.S. Bureau of Economic Analysis, 2022). Per capita, GSP is estimated to have risen from USD 50,310 in 2000 to USD 70,662 in (Statista, 2021). If accounted for as its own country, California would be the world's fifth largest economy, between Germany and India, with finance, business services, government activities, and manufacturing as the most significant contributors to GSP (U.S. Bureau of Economic Analysis, 2021).

California's emissions peaked at 490 $MtCO_2e$ in 2004. This value excludes emissions from land use, land-use change, and forestry (LULUCF), a significant part of which comes from increasingly frequent forest fires. In 2006, California adopted the goal of reducing emissions to 1990 levels, estimated at 427 $MtCO_2e$ by 2020. This goal was achieved in 2016. By 2019, state-wide emissions were 9 $MtCO_2e$ below the 2020 goal, or 11% below 2000 levels, despite a population increase of 16% (California Air Resources Board, 2020, 2022b; AB 32, 2006). In 2016, Senate Bill 32 (SB-32) established the goal of reducing emissions to at least 40% below 1990 levels by 2030 (SB 32, 2016). Overall emissions continue to trend downwards, and the carbon intensity of California's economy (amount of CO_2 emitted per USD million of Gross State Product (GSP)) continues to drop, as seen in **Figure 8.2.**

Figure 8.2: California road transport emissions from 2000 to 2019.



Source: California Air Resources Board (2022b).

Transportation continues to be the largest source of GHG emissions in the state of California, contributing nearly 41% of all emissions in 2019 (California Air Resources Board, 2022b). Almost 70% of these emissions come from passenger vehicles. An increasing share of petrol was ethanol blends, which more than doubled from 4% in 2000 to almost 10% in 2019 (California Air Resources Board, 2022g).

Introduction of the Low Carbon Fuel Standard and funding

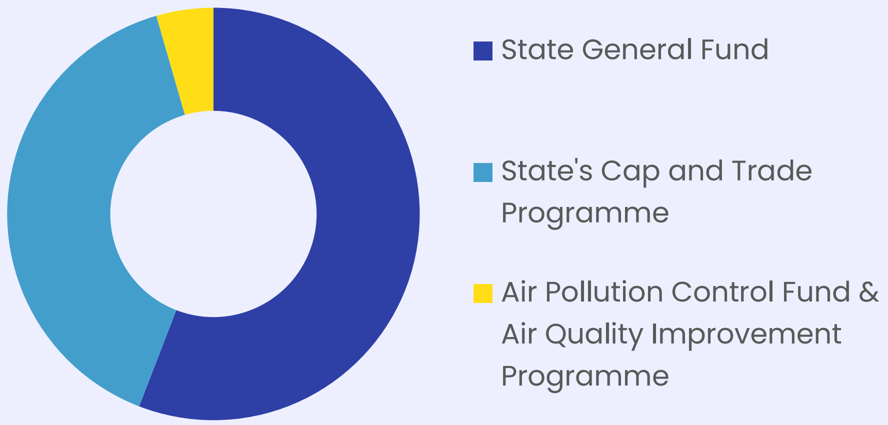
In order to understand the role of vehicular transportation in the decarbonisation of transport, the first case study examines the Low-Carbon Fuel Standard (LCFS) implemented by the state of California, in the United States. The growth of alternative fuels and new energy vehicles (NEVs) in California has been somewhat slow in the past decade; however, through policy changes at the state level, California accounted for 38.7% of all electric vehicles in the US in 2020. While the United States falls behind the EU in average emissions standards for road transport, California has set more ambitious targets and has been able to exceed them in 2020. California has introduced policy mechanisms with essentially three pillars: strict emission standards on new vehicles, the use of crediting and trade as a means to accelerate financing and investment, and the development of technology and a compliance mechanism.

Through the introduction of the Low-Carbon Fuel Standard policy, California has experienced an uptake in the sales of alternative fuels, especially of electric vehicles. In particular, the Clean Fuel Reward programme has been successful in delivering rebates amounting to USD

250 million in a short period of time. From 2022, a percentage of credits held will be used to finance the electrification of the transport systems in rural and disadvantaged communities. The evolution of California's LCFS and crediting system has grown to be more complicated as it has accommodated new and diverse stakeholders, fuels and technologies. However, it remains a guiding example on how harmonisation can be facilitated.

Box 8.1: Government Financial Investment in California's Electric Mobility

Through the Infrastructure, Investment and Jobs Act (IIJA), California was allocated USD 7.52 billion in federal funds for 2022 of which USD 57 billion (approximately 7%) was towards electric vehicles, buses and ferries (State of California, 2022). At the state level, California has appropriated a three-year budget of USD 3.9 billion as an investment to accelerate the promotion of zero-emission vehicles and changing infrastructure. The California Air Resource Board (CARB) has approved USD 1.5 billion in investments for clean transport incentives that will target low-income communities.



Source: State of California (2022)

Through this investment budget, several projects have been funded to accelerate the clean technology uptake. The Clean Vehicle Rebate Project, with an allocation of USD 525 million will offer rebates for zero or near-zero emission passenger vehicles, USD 10 million of which will go towards rebates for electric bicycles (California Air Resources Board, 2021c).

8.3.2 Policy framework for the decarbonisation of passenger vehicles

California has a history of acting independently from the federal government when dealing with climate issues on institutional and legal levels. The institutional frameworks which enabled the enactment of a low-carbon fuel standard (LCFS) have roots in California's response to the 1970s oil crisis and the Organization of the Petroleum Exporting Countries (OPEC) oil embargo. In reaction to the embargo, the Warren-Alquist Act was passed in the state legislature, establishing the California Energy Commission with core responsibilities, including encouraging energy efficiency and transforming the transportation sector (CA PRC § 25000 et Seq., 1974). The sluggishness of the federal government and public pressure due to high prices at the petrol pump drove the Californian leadership to act. Its goal was to set a clear precedent for acting unilaterally regarding emissions and energy efficiency within the state and set the institutional stage for future fossil fuel regulation (Hanemann, 2007).

The 2000 to 2001 electricity crisis further spurred climate and energy action in California, after a series of outages, price spikes, and utility insolvency highlighted California's ongoing dependency on fossil fuels (U.S. Energy Information Administration, 2002). As part of the response to the crisis, Californian energy agencies were required to develop plans to deal with future electricity outages and price spikes. One of the requirements established by executive order was to ensure that such programmes include strategies to reduce fossil fuel dependency and GHG emissions. As a result of this requirement, the CEC Integrated Energy Policy Report was adopted, in 2003. Among others, it identified climate change as a severe risk to the state of California, emphasising GHG reductions as critical to energy procurement and mitigation, and adaptation strategies in planning and policy documents for all state agencies (California Energy Commission, 2022b). It also pointed out emissions from the transport sector as a matter of concern for future action.

California's climate action under Governor Schwarzenegger

Governor Arnold Schwarzenegger, who had been elected in a recall election, motivated by the energy crisis, sought to take action based on the electoral mandate that enabled his Governorship, and signed Executive Order S-3-05, establishing GHG emissions reductions targets and placing the California Environmental Protection Agency (CalEPA) as the lead agency for climate policy in the state (Patterson, 2003; Executive Order S-3-05, 2005). Following S-3-05, CalEPA was obliged to report on California's progress towards achieving these goals biennially and investigate critical strategies for reducing emissions. This obligation resulted in the publication of 20 technical reports by January 2006, in an "unusually broad research effort" led by the Climate Action Team within CalEPA and spearheaded by the Deputy Secretary of CalEPA (Hanemann, 2007). The technical reports were distilled into a list of 38 regulatory suggestions for state agencies — notably the California Air Resources Board (CARB), which would become the key regulatory agency behind the LCFS, with exclusive power to regulate air quality and emissions concerns.

In concert with climate action at the executive level, there was a significant legislative push to reduce GHG emissions in California, setting the stage for further delegation of regulatory power to California's environmental agencies, and developing the LCFS regulatory mechanism. It resulted in the adoption of the California Global Warming Solutions Act of 2006, also referred to as Assembly Bill 32 (AB 32). The bill pointed out climate change as a threat to California's economic well-being, natural resources, and public health, which was a designation driven partly by the 2003 CEC report and 20 technical reports from CalEPA. It also noted increasing emissions levels in California, particularly in the transportation sector (AB 32, 2006). Public opinion was critical to the passage of this bill, which had been left to the end of the 2006 summer session. Advocacy from public interest groups, such as the Union of Concerned Scientists, as well as a series of high-profile op-eds in the Sacramento Bee and the Los Angeles Times, both of which have significant local and national influence, helped spur the passage of the bill within the final 48 hours of the 2006 summer session (Thomson, 2014; Union of Concerned Scientists, 2014).

AB 32 set the fundamental groundwork for implementing an LCFS in California, creating both institutional mandates and goals for state regulatory institutions. AB 32 set a goal of decreasing GHG emissions to 1990 levels by 2020. It required CARB to establish a set of measures to reduce GHG emissions by June 30 2007, to be implemented by 2010 (AB 32, 2006). The bill also required the identification of "discrete early action measures" and policies utilising the maximum "technologically feasible and cost-effective emissions reductions" policies. The bill specifically authorised the development of market-based regulations and compliance solutions — establishing further legislative groundwork for the successful development and implementation of the LCFS (Ibid.). By the autumn of 2006, greenhouse gas reductions were established as an important regulatory policy goal at the executive, administrative, and legislative levels of government within the state of California and specific planning and research requirements had been set to achieve those goals.

Shifting the focus to the transport sector

Referring to the technical reports and policy recommendations from CalEPA, and to achieve the emissions reductions requirements set forth by AB 32, Governor Schwarzenegger signed Executive Order S-1-07, establishing a state-wide mandate specifically focusing on emissions from transport (Executive Order S-01-07, 2007). The executive order required the Secretary for Environmental Protection to coordinate the actions of CARB. At the same time, the California Energy Commission (CEC), the University of California (UC), and other key agencies and actors were asked to develop protocols for quantifying the life cycle carbon intensity (CI) of transportation fuels, in addition to setting an initial CI reduction goal of 10% (Farrell, Sperling, Arons, et al., 2007; K. McCarthy, 2009). In response, scientists at UC conducted a two-part study on the feasibility of a low-carbon fuel standard, including a technical and policy analysis assessing the low-carbon fuels options and presenting several scenarios for mixes of fuels that might meet CI standard reductions of 5%, 10%, and 15% (Farrell, Sperling, Brandt, et al., 2007).

Regarding the development of the specific goals and mechanisms of the LCFS, the UC study represented the most precise visualisation of the policy yet. It became the framework upon which the final regulation was built. The study identified six LCFS scenarios and concluded that a goal of a 10% average CI reduction by 2020 in comparison to 2010, was "ambitious but attainable" (Farrell, Sperling, Arons, et al., 2007). They noted that all the major low-carbon options have technical and economic uncertainties that needed further research and evaluation but an LCFS was well in line with the legislature's request that all proposed measures are actionable and cost effective (Farrell, Sperling, Brandt, et al., 2007). The UC study recommended that an LCFS in California should:

- Apply to all petrol and diesel used in California for use in transportation, including freight and off-road applications.
- Allow providers of non-liquid fuels such as electricity or natural gas sold for use in transportation to participate in the standard or have the associated emissions covered by another regulatory programme.
- Oblige fuel providers to report on the sustainability impacts of their fuels, especially those related to biofuels.
- Oblige the state to periodically assess the impacts of the standard in California, the US, and globally, and consider policies to mitigate the adverse effects.

At the same time, different groups of actors consolidated around the issue, which had an impact on the policy outcome. The Office of the Governor, Assembly Democrats led by Nunez, CalEPA, and CARB were all working on the issue within the government. Civil society groups, represented by the Union of Concerned Scientists, the University of California, and local media, including the Los Angeles Times and the Sacramento Bee, all advocated further development of green fuel policies. In the business sector, an opposition formed, mostly comprised of fossil fuel interest groups, and included the Chamber of Commerce, National Association of Manufacturers, trucking industry groups, and the American Fuels and Petrochemical Manufacturers group (APFM).

The development of the draft LCFS directly flows from the executive push to address GHG emissions in transport and the relative flexibility engendered by the language of AB 32 at the legislative level. AB 32 required technologically feasible and cost-effective solutions but did not implement a specific regulatory path, allowing CARB and associated interest groups flexibility to achieve the required emissions reductions. A significant impact on the policy outcome resulted from the consultations prescribed in AB 32 with state energy agencies and interest groups to account for "equity, health, and economic considerations" (AB 32, 2006).

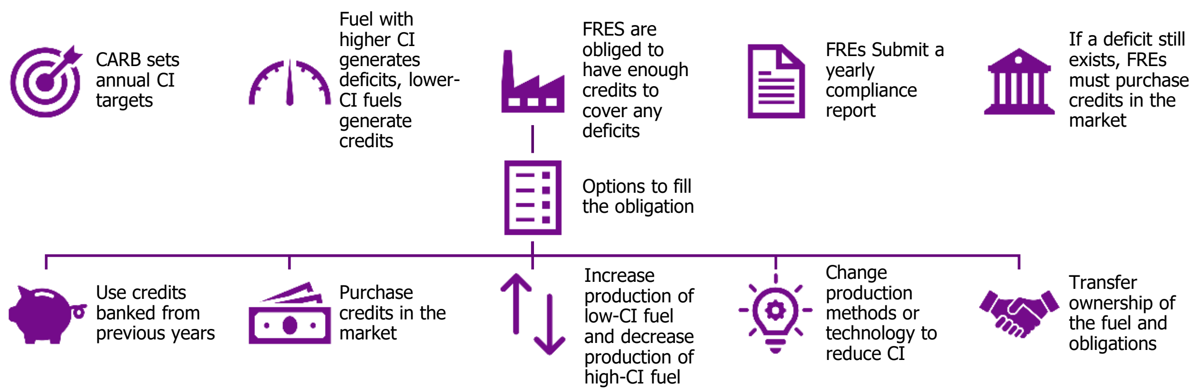
These consultations led to the development of a policy framework, driven by scientists and policy-makers, combining new scientific research and insights with institutional knowledge of market-based mechanisms and regulations, based on emphasising limits and hard caps on emissions. Combining political will at all levels of state government, a dearth of new scientific research into reducing emissions, and taking advantage of institutional knowledge of market-based regulation, the Low-Carbon Fuel Standard crystallised (Bandivadekar & Heywood, 2004; Farrell, Sperling, Brandt, et al., 2007). Established by Governor Schwarzenegger, through executive order on 18 January 2007, the Low-Carbon Fuel Standard was set into law, to be fully enforceable from 1 January 2011.

8.3.3 Implementation of the 2007 Low-Carbon Fuel Standard

As instituted by Executive Order S-01-07 in 2007, the LCFS is a market-based policy which implements a set of life cycle carbon intensity (CI) targets on all transportation fuels within California to reduce the CI of the transportation fuel pool and decrease GHG emissions over time. CI benchmarks fall over time, with an initial goal of a reduction of 10% below 2010 levels, by 2020. In 2018, the regulation was extended until 2030, targeting a reduction of 20% below 2010 levels. In this way, the LCFS incentivises moving to less carbon-intensive energy sources.

CARB administers the LCFS under the direction of the Executive Officer, who has primacy to regulate GHG emissions according to the federal Clean Air Act and the authority of the California Legislature (California Air Resources Board, 2022c). The LCFS applies to any fuel sold, supplied, or offered for sale in California, with a few exceptions for key applications. The market mechanism functions much like other market-based carbon cap systems. It involves regulated parties selling or refining high-CI fuel generating deficits, lower-CI fuels generating credits, and trade between the two groups to ensure that deficits are covered, and that credit generation is financially rewarded. **Figure 8.3** (below) briefly outlines the mechanism.

Figure 8.3: Graphic of California's Low-Carbon Fuel Standard components.



Source: Global CCS Institute (2019).

The following sections take an in-depth look at the specific text of the regulation, including amendments, outlining the targets, scope, and mechanisms of the LCFS at its initial implementation and beyond.

Purpose and scope

The policy aims to reduce greenhouse gas emissions by reducing the carbon intensity of the transportation fuel, taking into consideration the fuel's full life cycle GHG emissions (California Air Resources Board, 2022e). The scope of the first iteration of the LCFS was determined on two levels:

1. Level 1: by fuel type and sales volumes within the state of California, regardless of point of origin. The policy applied to any "transportation fuel, as defined in Section 95481 that is sold, supplied, or offered for sale in California".
2. Level 2: by business type and function in the fuels market. The policy here applied "to any person who (…) is responsible for a transportation fuel in a calendar year" (referred to as Regulated Parties).

In terms of Level 1, the policy identified several fuels covered by the law, including different kinds of petrol, diesel, and natural gas. Distinct from those, it also named several fuels that could be voluntarily covered (opt-in fuels), which were assessed to have life cycle carbon intensities lower than standard, automatically meeting compliance requirements. Fuel providers or other entities dealing in these alternative fuels could generate LCFS credits by choosing to opt into the LCFS as a regulated party and meeting compliance obligations set for alternative fuels. Such fuels included electricity from 100% renewable sources, hydrogen (including its blends), and varieties of biogas.

The LCFS included a few exceptions from its applicability. These included fuels used in military or racing vehicles, fossil propane and CNG used in school buses and locomotives. Ocean shipping and aviation were also excluded, as well as liquified petroleum gas and alternative, not biomass-based, fuels. Fuel suppliers, refiners, or importers who believed their fuel to be exempt from the LCFS had the burden of proving their fuel to be exempt and were obliged to submit for a specific exemption.

Regarding those covered by the policy, the Regulated Party designation was specifically focused on ensuring all entities within the production process were regulated appropriately as credit or deficit generators. For petrol and diesel, the regulated entity was either the importer or the fuel producer. Transfer of ownership of the fuel in question additionally constituted a transfer of LCFS compliance obligation.

Specific prescriptions applied to electricity. When used as a transportation fuel sourced from a multi or single-family home in the form of EV charging, the Electrical Distribution Utility (utility) was determined to be the Regulated Party and eligible to produce credits. However, credit generation by utilities, in this case, was contingent upon the utility using all credit proceeds to benefit current or future EV customers. It also had to provide rate options, incentivising off-peak charging and grid integration of home charging and batteries. Finally, the utilities had to provide yearly compliance reports, summarising efforts to reach the above requirements. Regarding publicly accessible charging points, the utility was determined to be a Regulated Party, capable of credit generation for all public EV charging points within its territory and for which it had submitted an official request to opt into the Executive Officer.

Other electricity-as-fuel applications for which a utility was allowed to generate credits included electricity provided to EV fleet vehicles at private workplaces or businesses. Other cases could be determined on an individual basis. It is important to note that electricity supplied through a fixed guideway system (such as with trolleybuses or electric trams and trains) generated credits for the transit agency which operates the system, not the utility.

In addition to the electrical utilities and providers of charging opportunities, several other entities could opt in to become a Regulated Party, eligible to produce and sell credits. Out-of-state producers of oxygenate or biomass-based diesel for blending with gas or diesel, entities within the distribution chain between the initial producer and the importer (i.e., an intermediate entity), or entities with an "innovative production method" for crude oil which results in a lower-CI fuel, were all allowed to opt in (Cal. Health & Saf. Code Tit. 17 § 45480 et Seq., 2009, p. 45).

Box 8.2: Life Cycle Carbon Intensity (CI)

Carbon intensity is measured in several different contexts. It can therefore have other units or meanings but, in general, CI is an accounting of how much of a given GHG (in CO_2 equivalence) is emitted relative to the production of some unit (in this case, per unit of fuel energy). CI scores can vary for a single fuel type depending on the fuel pathway, taking into account the feedstock, transportation, and end-use location (Andress et al., 2010; Cal. Health & Saf. Code Tit. 17 § 45480 et Seq., 2009).

Average carbon intensity requirements

Having established Regulated Parties by both fuel type and business type, the 2007 LCFS set average CI requirements from 2011 to 2020, gradually increasing the stringency, with the goal of back-loading the requirement to generate early buy-in from Regulated Parties and build up the credit bank early on. Although the regulation was to be in place from 2010, the programme's first year had no reduction target, but only the quarterly and annual reporting requirements. **Table 8.1** shows the first set of CI requirements for petrol and petrol alternatives and for diesel and diesel alternatives from 2010 to 2020. The diesel alternatives are also applicable to biodiesel, provided it is used in all classes of vehicles, including off-road applications.

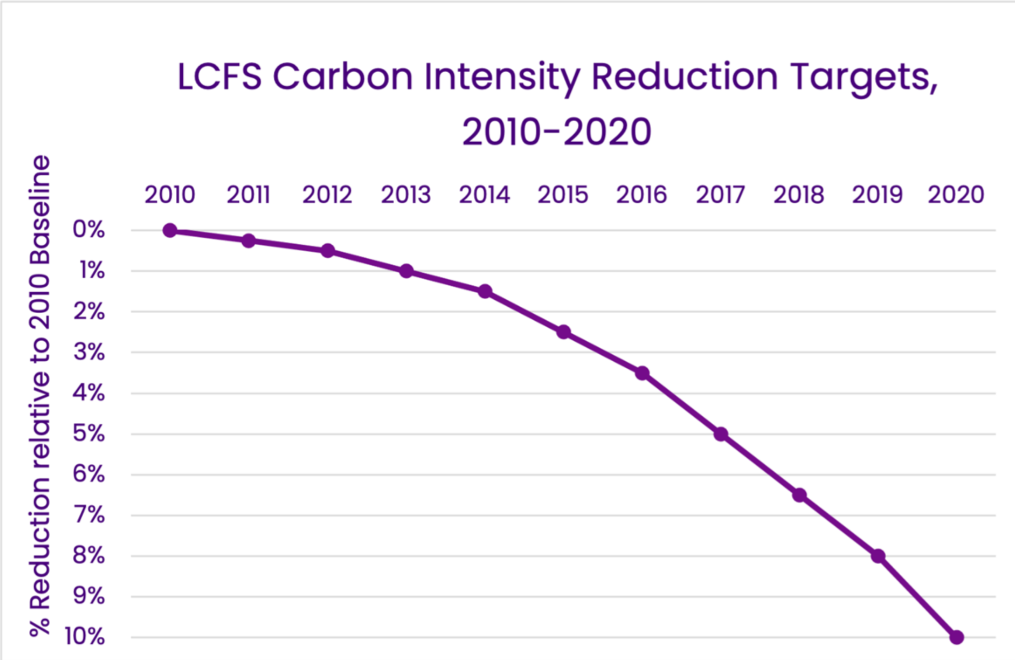
Table 8.1: CI Requirements for petrol and petrol alternatives and diesel and diesel alternatives from 2010 to 2020.

Year	Average Carbon Intensity (gCO_2e/MJ)	Average Carbon Intensity (gCO_2e/MJ)	% Reduction
	Petrol and Petrol Alternatives	Diesel and Diesel Alternatives	All
2010	Reporting obligation only	Reporting obligation only	
2011	95.61	94.97	0.25%
2012	95.37	94.24	0.5%
2013	94.89	93.76	1.0%
2014	94.41	93.29	1.5%
2015	93.45	92.34	2.5%
2016	92.50	91.40	3.5%
2017	91.06	89.97	5.0%
2018	89.62	88.55	6.5%
2019	88.18	87.13	8.0%
2020 and beyond	86.27	85.24	10%

Source: California Air Resources Board (2022e).

Reductions were calculated based on a 2010 base year value of average CI, using data from crude oil supplied to California in 2006. This number was updated in 2013, and the 2013 to 2018 values are based on a revised 2010 baseline, using data from crude oil supplied to California in 2010. The same revision applies to diesel fuel. The reductions targets are visualised in **Figure 8.4** below.

Figure 8.4: Carbon Intensity targets over time.



Source: California Air Resources Board (2022g).

LCFS compliance

Following the establishment of CI targets, the LCFS mandated a reporting requirement for all Regulated Entities, to help ensure compliance. Annual compliance reports were mandatory for all entities. They had to show that the entity had retired enough credits from its account to meet the compliance obligation (e.g., the deficits it had generated over the year). The compliance obligation is generally used as a proxy for CI reductions, as Parties providing fuel above the CI target generate deficits, and those below create credits. Therefore, a Party with a negative credit balance will not have met the target for the year, as opposed to a Party with a positive balance, which indicates fuel production with an average CI at or below the target. Compliance obligations began in 2011 and are calculated from 1 January to 31 December of each year. For each yearly compliance period, an entity's credit balance was calculated as:

$$CreditBalance = \left(Credits^{Gen} + Credits^{Acquired} + Credits^{CarriedOver}\right) - \left(Credits^{Retired} + Credits^{Sold} + Credits^{OnHold} + Credits^{Exported}\right)$$

Where:

$Credits^{Gen}$ are the credits generated in the compliance period;

$Credits^{Acquired}$ are the credits purchased or otherwise acquired in the compliance period;

$Credits^{CarriedOver}$ are the credits carried over from the previous compliance period;

$Credits^{Retired}$ are the credits retired within the LCFS in the current period to fulfil compliance obligations;

$Credits^{Sold}$ are the credits sold within the credit market in the current period;

$Credits^{OnHold}$ are the credits on hold for administrative or enforcement reasons — they cannot be used to meet compliance obligations;

$Credits^{Exported}$ are credits exported to programmes outside of the LCFS in the compliance period.

Upon submitting the compliance report and calculating each Party's credit balance, the total number of credits and deficits generated was calculated and issued into the account of the Party. The calculation of credits and debts within the LCFS was specific to each fuel type and source. However, credits may generally be retained indefinitely, retired to meet a credit obligation, or transferred through the credit trading system. Credits are calculated in $MtCO_2e$, and fuel quantities are calculated in MJ. For each Regulated Party, credits and deficits are calculated as follows:

$$Credits^{Gen}(MT) = \sum_{i}^{n} Credits_i^{gasoline} + \sum_{i}^{n} Credits_i^{diesel}$$

$$Deficits^{Gen}(MT) = \sum_{i}^{n} Deficits_i^{gasoline} + \sum_{i}^{n} Deficits_i^{diesel}$$

Where:

$Credits^{Gen}$ are total credits, zero or a positive number;

$Deficits^{Gen}$ are total deficits, negative number;

i is the finished fuel or blendstock index;

n is the total number of finished fuels or blendstocks provided by a Regulated Party in a compliance period.

Fuel pathways and credit/deficit calculation

Fuel pathways are used to calculate credits or deficits for fuels not provided for in the fuel or blendstock index. Fuel pathways involve a novel life cycle GHG emissions assessment of a fuel — from source, extraction, method of refinement or conversion to fuel, and type. This type of analysis is often called the "wells to wheels" approach. It means that the same fuel types may have very different carbon intensities and emissions, depending on the producer and location. Fuel pathways are designed to allow for a certain level of flexibility and responsiveness to changing circumstances and technology within the regulation, ensuring that calculations are completed with up-to-date data and accounting for all reasonable variations.

California uses an adapted version of the Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies (GREET) model, initially developed by the Argonne National Laboratory. Between 2009 and January 2016, the Californian government used the CA-GREET Model version 1.8b to calculate the simplified CI of all fuel pathways. The GREET3.0 uses data to calculate life cycle GHG emissions for site-specific inputs and fuels. It is open source, incorporating Oil Production Greenhouse Gas Estimator (OPGEE2.0), the Global Trade Analysis Project (GTAP-BIO) and the Agro-Ecological Zone Emissions Factor (AEZ-EF) model. Land-Use Change (LUC) is accounted for specific crop-based biofuels, based on the GTAP model (California Air Resources Board, 2022d; Cal. Health & Saf. Code Tit. 17 § 45480 et Seq., 2009).

As a rule, the calculation of credits or deficits generated by a particular fuel is done such that:

$$Credits_i^{XD}\left(Deficits_i^{XD}\right)(MT) = \left(CI_{standard}^{XD} - CI_{reported}^{XD}\right) \times E_{displaced}^{XD} \times C$$

Where:

$Credits_i^{XD}\left(Deficits_i^{XD}\right)$ is the number of credits or deficits, by fuel or blendstock under the average CI requirement where XD is fuel type;

$CI_{standard}^{XD}$ is the average CI requirement for a given year;

$CI_{reported}^{XD}$is the adjusted CI value for a fuel or blendstock in gCO_2e/MJ;

$CI_{reported}^{XD} = CI_i/EER^{XD}$, where CI_i is the CI of a fuel or blendstock, determined by a CA-GREET pathway or custom certified pathway, and EER^{XD} is the Energy Economy Ratio relative to petrol, diesel, or jet fuel;

$E_{displaced}^{XD}$ is the total quantity of fuel energy displaced, in MJ, by using an alternative fuel;

$E_{displaced}^{XD} = E_i \times EER^{XD}$, where E_i is the energy of the fuel or blendstock in MJ, determined by energy density, and EER^{XD} is the dimensionless Energy Economy Ratio of the fuel XD and particular vehicle combination;

C is the value factor used to convert credits to Mt from gCO_2e.

Calculating carbon intensity of fuels

The LCFS allows for three ways of calculating the CI of a fuel used in the above credit/deficit equation: a lookup table, a Tier 1 pathway, or a Tier 2 pathway (California Air Resources Board, 2022i).

Table 8.2: Common fuel Carbon Intensities and pathways categorisation and standards.

Fuel	Fuel Pathway Code	Fuel Pathway Description	CI Values (gC02e/MJ)
CARBOB	CBOB	Based on the average crude oil supplied to California refineries and average California refinery efficiencies	100.82
Diesel	ULSD	Based on the average crude oil supplied to California refineries and average California refinery efficiencies	100.45
Compressed Natural Gas	CNGF	Compressed Natural Gas from Pipeline Average North American Fossil Natural Gas	79.21
Propane	PRPF	Fossil LPG from crude oil refining and natural gas processing used as a transport fuel	83.19
Electricity	ELCG	California average grid electricity used as a transportation fuel in California	93.75
	ELCR	Electricity that is generated from 100% zero sources used as a transportation fuel in California	0.00
	ELCT	Electricity supplied under be smart charging or smart electrolysis provision	Mentioned elsewhere
	HYF	Compressed H2 produced in California from central SMR of North American fossil-based NG	117.67

Hydrogen	HYFL	Liquefied H2 produced in California from central SMR of North American fossil-based NG	150.94
	HYB	Compressed H2 produced in California from central MR Of biomethane (renewable feedstock) from North American landfills	99,48
	HYBL	Liquefied H2 produced in California from central SMR of biomethane from North American landfills	129.09
	HYEG	Compressed H2 produced in California from electrolysis using California average grid electricity	164.46
	HYER	Compressed H2 produced in California from electrolysis using zero-CI electricity	10.51

Source: California Air Resources Board (2022i).

Lookup table pathways are the simplest and include values generated using the CA-GREET3.0 model and certified by CARB. These values apply to petrol, ultra-low sulphur diesel, compressed natural gas, propane, and California average grid electricity, and are not expected to change significantly across fuel providers. Certain fuel types require a lookup table pathway application, including 100% renewable electricity, electricity used in EV charging and electrolysis, and certain types of hydrogen production. **Table 8.2** gives examples of lookup table CI values and pathway descriptions (California Air Resources Board, 2022i).

The next classification for CI calculation for fuels not included in the lookup table is a Tier 1 pathway. Tier 1 pathways are classified as pathways which CARB staff have extensive experience evaluating. They may be site or producer-specific but are generally calculated using a simplified CI calculator in combination with CA-GREET3.0 modelling and CARB expertise.

Fuels not included in either of these classifications require more specific pathway analysis and CI calculations. Tier 2 pathways are classified as pathways which CARB staff have relatively limited experience evaluating and certifying. Tier 2 pathways primarily include fuel production methods which are not commonly used and encompass all fuel production methods not listed in the lookup table or Tier 1 pathways. Due to their relatively obscure nature, Tier 2 pathway applications must contain extensive documentation. Required documentation includes detailed descriptions of the CI pathway calculation, a life cycle GHG analysis report, a facilities description, and other documentation to demonstrate that the life cycle analysis is 'scientifically defensible' in the Executive Officer's "best engineering and scientific judgement" (Cal. Health & Saf. Code Tit. 17 § 45480 et Seq., 2009). All applications are additionally open for a public comment period during the application process.

Other pathway considerations include the establishment of temporary pathways for fuels that have indeterminate CIs, which are valid for the reporting quarter in which they are certified. Provisional pathways may also be granted if the reported does not have the generally required 24 months of operational data to apply for a pathway, in the case of brand new facilities or ongoing process changes.

Regulated Parties who apply for, and receive, Tier 1 or Tier 2 pathway certification are required to send reports to CARB to ensure the accuracy of any CI calculations made. Regulated Parties must send their fuel pathway reports to CARB no later than March 31 of the calendar year. Attesting to the maintenance and accounting of operational CIs, fuel pathway holders may decide to keep the original or request a replacement certification based on the most recent 24 months of data, allowing for the development and implantation of new technologies and processes in the fuel refining industry.

To account for changes in the CI of crude oil over time, base deficits and incremental deficits for each fuel and blendstock must be calculated separately. This calculation relies on the three-year California Crude Average CI value, updated yearly, in addition to the CI for crude oil production and transport based on location, including international imports and production within North America. Additional credits are available for innovative refining and production techniques, such as the production of diesel fuel partially or wholly using energy produced using renewable hydrogen. These factors are all accounted for within the life cycle CO_2 emissions approach using the CA-GREET model to ensure accurate CI (and therefore credit/deficit) calculations.

Credit trading and the marketplace

After successfully calculating credit and deficit generation, Regulated Parties are left with several options, depending on their specific balance and obligations. Those with an excess of credits are allowed to bank said credits, which may roll over from year to year, potentially using them in the future to ease stricter compliance burdens. They may also opt to sell them in the annual credit clearing market or a separate transaction. The 2007 iteration of the LCFS regulation left credit transactions relatively loosely regulated, with prices and quantities of credits available for transfer determined by market demand and supply. Several types of credit transfers are allowed:

A. Type 1: An over-the-counter sale agreement reaching maturity no more than ten days after Registered Parties enter the transaction agreement.
B. Type 2: An over-the-counter agreement reaching maturity more than ten days after Registered Parties enter the transaction agreement, or involving multiple transfers over time.
C. Type 3: A brokered agreement through a clearing service provider.

Those with a deficit balance are obligated to purchase and then retire enough credits to cover at least their pro-rata share or, if possible, their entire annual deficit balance. Suppose a Regulated Party has a year-end obligation without sufficient credits to meet its commitment. In that case, a credit clearing market occurs, and it is obligated to purchase its pro-rata share of credits. Following submissions of compliance reports for the previous compliance year, on the first Monday in April, the Executive Officer issues a call for credits to be listed for sale in the Clearance Market and informs Regulated Parties of the year's maximum credit price. Trading in the Clearance Market occurs between 1 June and 31 July. When a Clearance Market occurs, the Regulated Party must, to be considered in compliance, purchase and then retire the credits sufficient to cover its pro-rata obligation or retire sufficient credits, with interest, to cover its annual obligation within five years.

If a Regulated Party participates in the Clearance Market for two years in a row it is required to submit a compliance plan to CARB, detailing steps to meet its obligations for the next five years. The plan must include a clear list of specific strategies to achieve a positive credit balance, including a target timeline and list of management practices and personnel executing the strategies, as well as quantification of anticipated credit shortages, generation, and acquisitions, and, finally, any relevant records which demonstrate compliance with the proposed plan.

Public reports of credit generation and transfers are published quarterly and include total credits or deficits incurred, balances and current holdings, and credit transfers for the most recent quarters. Further details include the total number of credits, parties making transfers, and the average price.

Compliance, verification, and enforcement

Regulated Parties are obliged to submit quarterly fuel transaction reports and annual compliance reports to CARB. This ensures compliance with CI targets, and the obligations are clearly listed in the online portal used by regulated Parties and on CARB's LCFS public calendar. Data for fuel transactions must be uploaded within the first 45 days after the end of the quarter to ensure accurate auditing and credit/deficit reconciliation. Transaction data that Regulated Parties must report include fuel amounts, transaction types and dates, business partners, fuel application, and fuel pathway codes. Blendstock, petrol, and diesel producers must additionally report the crude oil name designation, volume, and country of origin for each crude supplied during the quarter.

In addition to quarterly reports, Regulated Parties must also submit annual compliance reports, in which transaction reports are aggregated, accounting for all credits and deficits carried over, credit transactions, and total credits retired to meet compliance obligations. Reports must additionally include a series of so-called "significant figures", including:

1. Carbon intensity.
2. Credits or deficits, expressed to the nearest whole metric tonne CO_2 equivalent.
3. Fuel amounts, in the units specified by fuel type.

Record-keeping is also regulated under the LCFS, and all Regulated Parties must maintain relevant records, data, and calculations for ten years. Since 2020, appropriate records, data, and calculations are subject to inspection and audit by the Executive Officer and a third-party accredited verification body and must be made available by the Regulated Party within 20 days upon request. All pathway applications, annual reports, transaction reports, volumes reports, and projects and refinery reports are subject to third-party verification and audits, to ensure accurate CI reporting. Verification must be completed annually by a verification body that the Executive Officer has accredited. Verification must happen in person and on site at least once annually, in addition to off-site documentation reviews. On-site audits involve interviews with key personnel, observation of production equipment and accuracy measurements. Off-site verification includes standardised data checks, focusing on the most uncertain data, and data with the largest contribution to GHG emissions. A complete annual verification includes a validation statement, an independent review of the verification findings, and a statement of completion of findings from the verification body.

Regarding enforcement, the Executive Officer may opt to enter a written protocol with any person or entity and "identify the conditions under which the person may lawfully meet the record-keeping, reporting, or demonstration of requirements" (Cal. Health & Saf. Code Tit. 17 § 45480 et Seq., 2009, p. 218). Any Regulated Parties, opt-in entities, brokers, or verification bodies are subject to the jurisdiction of the State of California, the administrative authority vested in CARB, and the jurisdiction of the superior courts of the State of California to address violations of any obligations under state law.

Violations of any obligation are subject to state law and are therefore subject to the assessment of all appropriate penalties and remedies permitted under state law. Each day that any report or reporting requirement remains unsubmitted or inaccurate constitutes a separate violation of the regulation. Additionally, each deficit that is not eliminated at the end of a compliance period, or is not carried over in the proper manner, constitutes a separate violation and is subject to a maximum penalty of USD 1000 per deficit. Additional penalties may be assessed for "willful or intentional" violations of the LCFS, amounting up to USD

250,000 per violation, in addition to a further USD 50,000 per violation in the case of negligent violations and up to USD 35,000 per violation for other violations. Enforcement of said violations may be carried out through the courts, and penalties assessed are typically paid into the Air Pollution Control Fund (Cal. Health & Saf. Code § 43015, 2022).

Any accounts that require administrative adjustment or are in violation of the LCFS, as determined by the Executive Officer, are noted publicly on CARB's website, including notes on settlement discussion and ultimate settlement agreements, including litigation. Account balance adjustments are also listed publicly and reported as a result of inaccurate reporting by the obliged entity (California Air Resources Board, 2022c).

8.3.4 Subsequent updates to the LCFS

The 2015 and 2018 amendments

In response to early litigation and implementation challenges, CARB adopted a series of amendments to the LCFS in 2015 and 2018. The 2015 update implemented a USD 200 price cap on credits and introduced a five-year deficit rollover (at a 5% annual interest rate) in case of a market-wide credit shortage. It also streamlined the process for certifying fuel pathways and changed estimations of CI for crop-based biofuels due to lower estimates of land-use change emissions. It backloaded the compliance schedule through the 10% target in 2020, easing compliance requirements in 2016 and 2017 (Yeh et al., 2016). All updates to the regulation were subject to a series of public hearings and comment periods (California Air Resources Board, 2022f).

The 2018 amendments to the LCFS were significant, reworking large parts of the regulation, changing terminology from "Regulated Party" to "Fuel Reporting Entity (FRE)", extending the mandate to 2030, adding additional protocols for credit generation from Carbon Capture and Storage (CCS) projects, as well as integrating an EV and ZEV incentive programme to adapt the LCFS to updated emissions reductions goals passed in the state senate in 2016 (California Air Resources Board, 2018c; SB 32, 2016).

The headline update was the extension of the mandate to 2030, increasing the reduction goal to 20%, and aligning the LCFS with updated emissions reduction goals passed in the state legislature. The 20% target does reflect a more ambitious target than was previously expected, as earlier documentation suggested an 18% target for 2030 (Boutwell, 2018). Although CARB increased the reduction goal to 20% by 2030, they softened compliance targets to 2020, with a 2020 target of 7.5% instead of the initial 10%. The 2018 update added Alternative Jet Fuels as a regulated opt-in fuel, setting CI reduction targets from 2019 to 2030. The updated targets for petrol and petrol substitutes are seen below in **Table 8.3**.

Table 8.3: Updated Carbon Intensity targets for 2018.

Year	Average Carbon Intensity (gCO_2e/MJ)	Year	Average Carbon Intensity (gCO_2e/MJ)
2010	Reporting only		
2011	95.61	2021	90.74
2012	95.37	2022	89.50
2013	97.96	2023	88.25
2014	97.96	2024	87.01
2015	97.96	2025	85.77
2016	96.50	2026	84.52
2017	95.02	2027	83.28
2018	93.55	2028	82.04
2019	93.23	2029	80.80
2020	91.98	2030 +	79.55

California Air Resources Board (2022e).

The other significant updates were the inclusion of new protocols for EVs and CCS programmes. In the EV sphere, the calculation for credits from EV charging was changed, and credit-generating opportunities were expanded. Upon the calculation of base credits generated by residential EV charging, utilities (EDUs) were required to contribute a specific portion of those credits to California's Clean Fuel Reward programme, which provides rebates for EV and ZEV purchases. The schedule of contributions is illustrated in **Table 8.4**. The Clean Fuel Reward programme was explicitly created in tandem with the 2018 update and provides rewards based on the specific battery capacity of the hybrid or electric vehicle purchased, with higher rewards for pure-electric vehicles.

Table 8.4: California's credit contributions schedule for years 2019 to 2023.

EDU Category	% Contribution in years 2019 to 2022	% Contribution in years 2023 and subsequent
Large Investor-owned Utility	67%	67%
Large Publicly-owned Utility	35%	45%
Medium Publicly or Investor-owned Utility	20%	25%
Small Publicly or Investor-owned Utility	0%	2%

California Air Resources Board (2022e).

Other EV incentives in the 2018 update included credit generation opportunities for the owners of publicly accessible EV charging points, with the caveat that, to generate credits, the charging points must be able to service at least two of the main three types of EV chargers (CHAdeMO, SAE CCS, and Tesla) and have a minimum 50 kW capacity.

CCS projects were also included as potential credit generators under the 2018 LCFS update. Fuel producers who capture on-site CO_2 and sequester it either off or on site are eligible, as well as projects which employ direct-air capture technologies to sequester CO_2. Net CO_2 sequestered can be used to adjust the carbon intensities of associated fuel pathways, potentially representing a reduction in CI for alternative fuel producers if utilised. Associated credits will, however, be invalidated if the sequestered CO_2 is leaked or otherwise released before 50 years post-injection, and all sites must be monitored for 100 years to ensure proper sequestration and maintain financial instruments (e.g., insurance) which would cover the cost of any remedial responses required (Cal. Health & Saf. Code Tit. 17 § 45480 et Seq., 2018).

The 2022 Scoping plan and future updates

The reporting and scoping plan requirement in AB 32 continues to impact the implementation of the LCFS, as CARB assesses all programmes and regulations to ensure compatibility with California's 2045 net zero emissions goal. The 2022 scoping plan is currently in progress and is the first update since the 2017 plan, bringing about the largest changes to the LCFS. The plan is subject to a series of public hearings and workshops and touches nearly every area of California's economy. Emphasis continues to be placed on decarbonising transportation and driving innovation in new technologies, fuels, and applications. The draft scoping plan (unofficial and not yet approved) suggests that the LCFS has met expectations thus far and encourages a strengthening of standards to drive innovation, particularly in the biofuels market and to help meet the net zero 2045 goal. Other proposed updates include integrating the opt-in industries and providing capacity credits for hydrogen and electricity projects to support heavy-duty fuelling (California Air Resources Board, 2022a).

8.3.5 Evaluating the LCFS's impact

Compliance

CARB has been relatively positive regarding the ongoing results of the LCFS, touting near 100% compliance rates, beginning in 2015. In a press release from May 2016, CARB Chair Mary D. Nichols said, "this programme is succeeding: California has a thriving market for new low-carbon fuels (…) the Low-Carbon Standard is fully delivering on its promise to drive innovation" (California Air Resources Board, 2016). For the 2015 compliance period, CARB found that the programme had a 98% compliance rate — of the 52 registered entities selling high-CI fuel, only one ended up with a shortfall of credits. High levels of compliance followed in 2016 and 2017, with CARB reporting 100% compliance and no credit shortfalls for both reporting periods (California Air Resources Board, 2018a, 2018b). Concerning enforcement, between 2017 and 2021, CARB reached ten settlement agreements, totalling just under USD 3 million, the majority of which was appropriated to the state Air Pollution Control Fund and directly used for emissions reduction projects (California Air Resources Board, 2018a, 2019b, 2022c). Other penalties assessed included mandatory mitigation programmes and "supplemental environmental projects" to be completed by the violators (California Air Resources Board, 2021a).

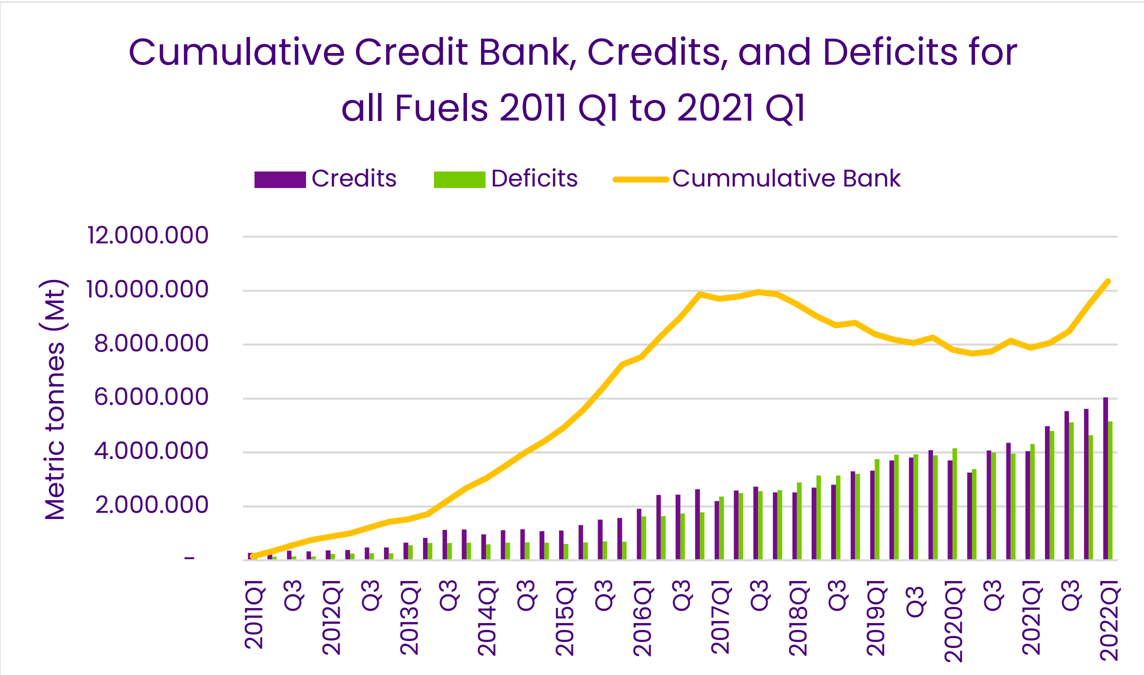
The high level of compliance and relatively small value of settlements is additionally seen through the overall levels of credits and deficits generated through the programme. Back-loading CI increases seems to have allowed the industry to over-comply in the initial stages of the LCFS more easily, building up a bank of credits which can be retired to meet compliance obligations. In the first quarter of 2011, over 275,000 credits were generated, indicating an equivalent amount of emissions avoided due to the production of fuels below the target CI. CARB reported the highest number of credits in the fourth quarter of 2016, a total of 2.6 million. Credit bank growth between 2014 and 2015 can be partially attributed to a court-ordered freeze of the CI standard due to ongoing litigation and questions about the LCFS's legal standing regarding Californian state law and the US Constitution (Witcover, 2018). Strengthening targets from 2017 onwards has reduced the growth of the oversupply of credits.

Trading and price

Credit trading started relatively slowly, mainly as Regulated Parties often opted to bank credits to ease future compliance in the early stages of implementation. Credit prices in the market are determined by available supply relative to demand and consider the expected marginal cost of compliance relative to the uncertainty of bringing alternative fuels to the California market. Trading kicked off in earnest in 2013 when it increased from less than USD 30 to almost USD 90 for credit. After a decrease to between USD 25 and USD 30 in 2014 and early 2015, it exceeded USD 130 in 2015. Since 2018, the credits traded close to the soft cap of USD 200, introduced in 2016, indexed to inflation year on year (Hu & Chen, 2019; Witcover, 2018). Prices peaked in February 2020 at USD 206, before falling to USD 125 in May 2022 (California Air Resources Board, 2022j).

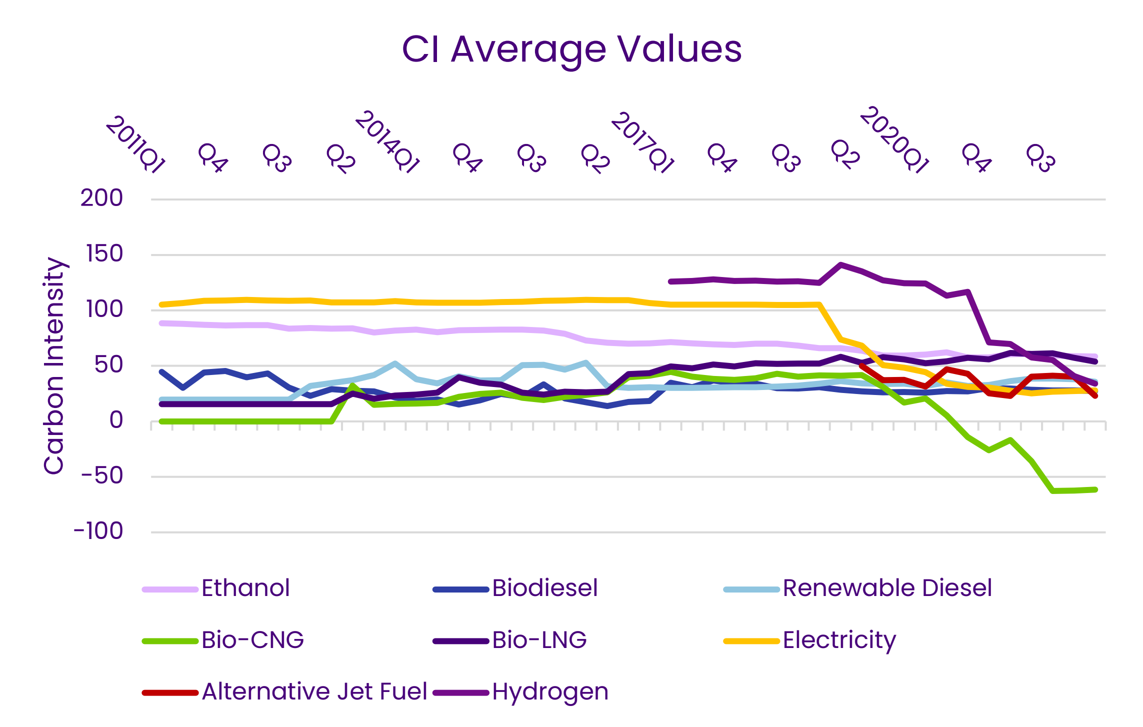
Whereas compliance with the monitoring and credit/deficit scheme has been quite successful, CARB has faced several challenges concerning attaining the actual CI reduction target. The 2018 downgrade of the 2020 target to a 7.5% reduction rather than 10% was driven by the fact that reduction goals stagnated in the early stages of the programme between 2013 and 2014. This stagnation was due to a series of lawsuits and judicial orders halting enforcement of the LCFS until a clear judgement could be made (Pettit, 2013; Sabin Center for Climate Change Law, 2022). Additionally, CARB's quarterly data show that, despite increasing reduction targets, most fuel types did not see significant decreases in average CI until late 2018, three years after reduction targets were unfrozen. While CARB remains optimistic about achieving the 2030 targets, progress will likely continue to be incremental, as shown in **Figure 8.5** and **Figure 8.6**.

Figure 8.5: California's total credits and deficits from 2011 to 2021.



Source: California Air Resources Board (2022j).

Figure 8.6: Average Carbon Intensity values from 2011 to 2021.



California Air Resources Board (2022j).

Uptake of alternative fuels

The share of alternative fuel energy in transportation covered by the LCFS increased from 6.2% in 2011 to 10.1% in the first quarter of 2018. Estimates from CARB calculated that, from initial enforcement to the first quarter of 2022, alternative fuels had replaced nearly 83 billion litres equivalent of petroleum diesel (California Air Resources Board, 2019a). A look at the sources of credit generation indicates that, although ethanol remains the dominant fuel, production of other alternative fuels continues to grow. Relative to fossil sources, biomass-based fuels increased production, including bio-methane and biodiesels. Electricity as a transportation fuel saw significant growth under the LCFS scheme, accounting for 10% of all credits in 2016 and growing to 22% of credit generation in the fourth quarter of 2021 (California Air Resources Board, 2022j).

Growth in alternative fuels has been connected to the incentives of the LCFS, particularly as requirements become more stringent. In the case of renewable natural gas from non-fossil feedstocks, including municipal solid waste and wastewater, landfill gas, and livestock manure, the LCFS has been shown to trigger substantial quantities of production, and approaches a relatively high level of market efficiency (Scheitrum, 2020). Cellulosic ethanol remains a significant source of fuel. Still, it has remained steady at the 10% blend level, above which significant infrastructure changes would need to be made to allow continued blending of ethanol with petrol (Hoekman & Broch, 2018).

Estimates from California's annual GHG inventory suggest that, without biofuels, emissions would be 17 $MtCO_2e$ higher in 2019 than measured, likely a direct result of the LCFS (California Air Resources Board, 2021b). Research conducted by CARB as part of the 2022 Scoping Plan update found that the LCFS "is a key driver of market development for renewable diesel and its coproducts, (...) and an analysis of their [other regulations] respective contributions to market development, and interviews with industry representatives and independent experts, point to LCFS as a more important factor in market development" (California Air Resources Board, 2022a).

The expansion of the LCFS to include more EV incentives in 2018 has proved successful, particularly with regard to EV adoption. By May 2022, 18 months after its inception, the Clean Fuel Reward programme issued over 250,000 rebates, totalling around USD 320 million to customers purchasing plug-in electric vehicles. CARB estimates that 21.2% of the rewards went to underserved communities, 10% to low-income communities, and 10% to otherwise disadvantaged communities. Over 90% of the EV market in California participates in the programme (California Air Resources Board, 2022h).

Due to the long-term nature of CCS projects, the success of the CCS crediting programme is still unclear; however, several new projects have been announced following the update (Veogele, 2021). Concerns exist about the 100-year liability and monitoring requirement under the LCFS, which critics argue dissuades CCS project development. Other concerns have been raised about the LCFS CCS protocol, which includes a long permitting process, in addition to already lengthy federal permitting, which CCS proponents argue contribute to the low number of projects put into action (Wickersham, 2021). Whether the potential for credit generation is enough to spur an increased number of CCS projects remains to be seen and should be carefully monitored in the coming years.

8.3.6 Discussion

The California LCFS crediting system demonstrates how such a crediting system can work towards better accelerating investment into electro-mobility. The case for the combined emission standard and crediting system for the EU is that it offers a means of harmonising the investment and distribution of financial resources in electric vehicle subsidies and changing infrastructure. The LCFS offers an opportunity to include various actors in the framework of one policy instrument. This especially applies to the installers of electric charging stations which, under the European framework, have different rules applied to them depending on the member state. Rewarding charging station installations with credits that could later be sold on the market would allow for a more harmonised approach. The number of credits received could be determined by the electricity sold annually for EV charging. While only electricity coming from renewables should be accounted for, a multiplier could be used if the electricity used was generated and stored at the property. Compared to the current system of a one-time payment for the installation of charging stations, such a model would reward charging stations that have the biggest impact on emissions. The investors would determine the speed of charging in a way that would maximise their utilisation.

8.4 Case study 2: Dual credit policy in China

In recognition of its growing transport emissions, China has become one of the first developing countries to embarked on policy measures to rake in emissions from their passenger cars. This case study examines China's Dual Credit Policy that sets emission standards for carmakers and establishing a credit trading system. Section 8.4.1 is an overview of the country's emission trends and economic market of electric vehicles. Section 8.4.2 expands into the evolution of China's policy development, the evolution of the Dual Credit Policy and its component policies, how it functions, and what the implications have meant for manufacturers and the market of cleaner vehicles. Section 8.4.3 examines how the crediting system works, and Section 8.4.4 discusses the lessons learnt from China's experience that are applicable to the EU.

8.4.1 Context and background

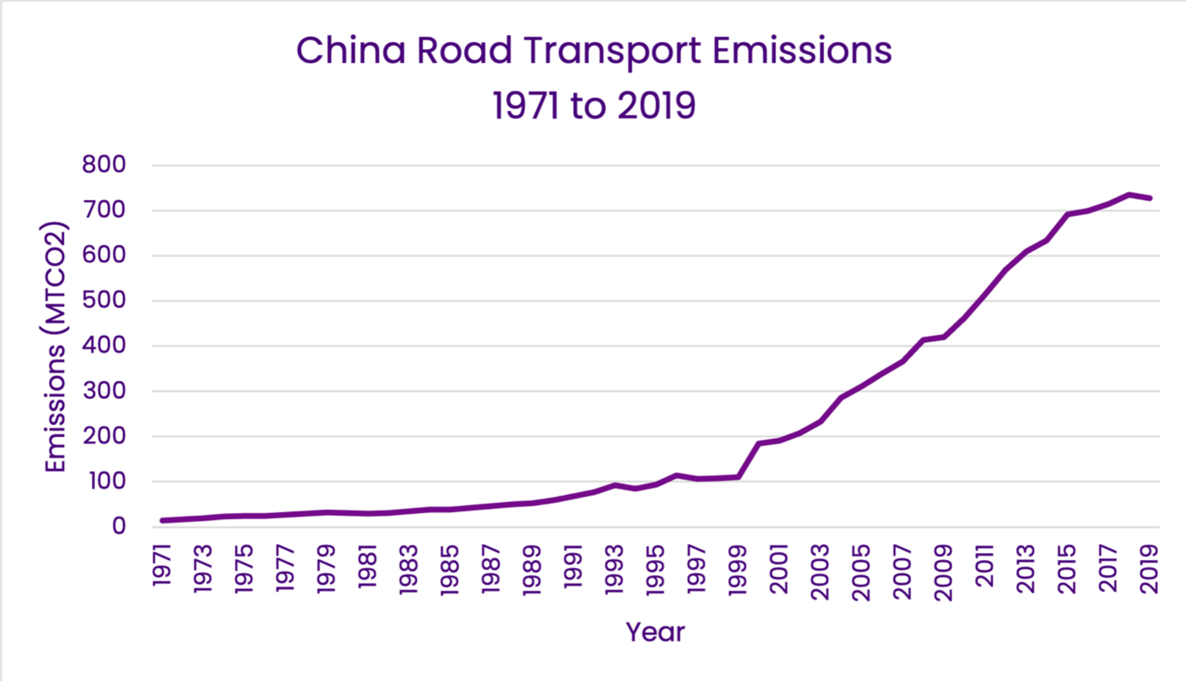
China is one of the world's faster growing economies, with one of the largest populations. The rapid growth experienced in the last few decades has resulted in an increase in vehicle ownership and, consequently, in its transport sector emissions. China accounts for a bullish EV market globally. China accounts for the world's largest fleet of EVs, amounting to 7.8 million in 2021, 3.3 million of which were sold in 2021 alone. For much of the 2010s, China's policies made it the global leader in EV sales, easily outpacing the US and Europe. However, as of 2020, Europe (including Norway) surpassed China and in 2021, the European EV market share accounting for 17% of sales, compared to 16% in China. When looking deeper though, China still leads with the sales and fleet share of BEVs relative to PHEVs compared to Europe. Shares of ECVs that were fully electric (i.e., BEVs) in 2021 were about 80% in China but only 55% in Europe (IEA, 2022c). This distinction between the proportion of BEVs and PHEVs is crucial in order to achieve the decarbonisation goals of road transport. As reported by Transport & Environment (2022), PHEVs are markedly less reliable than originally anticipated as an alternative to cut emissions given that the lion share of kilometres driven have been using fuel and not electric.

China has shown it is an experienced and serious global contender in the race of transport electrification. Existing policy targets in China have centred around a crediting system combining the improvement of fuel consumption efficiency and the enhanced production of electric vehicles. In fact, China's fuel efficiency requirements are some of the most stringent in the world, and consequently, as a result of strict fuel standards, improvements in fuel efficiency have occurred. At the same time, the electric vehicle and low-emission vehicle market has boomed over the past decade thanks to several policies. We have structured the case study to provide an overview of China's transport sectors emissions and the socio-economic trends that have affected the light duty passenger vehicle sector.

Emissions from the passenger transport sector in China

In 2020, China announced its goal of carbon neutrality by 2060, with emissions peaking before 2030. Over the past decade, transportation-related CO_2 emissions increased to 10% of China's total carbon emissions, and it is the third largest emitting sector behind industry and energy generation (Peng & Li, 2022a). Although smaller, in proportion, to other countries, transport emissions in China are growing. The situation is worsened by the impact of cars on air pollution, especially with ozone (O_3) and PM2.5, which became one of the main drivers of policies aiming to move away from combustion vehicles (Stanway & Xu, 2022). This has been the case in large cities. For example, transport accounts for an estimated 65% of all emissions in Shenzhen and up to 45% of particulate matter in Beijing (California Climate Institute, 2020). Nationally, emissions from road transport remained relatively low with little increase for much of the 20th century, but have risen dramatically since the turn of the century (**Figure 8.7**). Apart of socio-economic reasons explaining these trends, for most part China's road vehicle fleet has largely been made up of small, less emitting two-wheel vehicles. China's improving economic circumstances meant not only more vehicles on the road but an increase in the share of passenger cars and LDVs. As of 2019, road transport emissions stood at 728 $MtCO_2e$ (IEA, 2021c).

Figure 8.7: Emission trends of China's transport sector from 1971 to 2019.



Note: In 2019, emissions reached 901.4 MtCO2e *Source:* IEA (2021).

Electric vehicle market in China

Light duty vehicles (LDVs) remain the primary form of passenger transportation, and the Chinese fleet is expected to grow at least until 2050. This presents a significant challenge to decarbonisation and opportunities for low and zero-emissions vehicles (Callahan, 2022). The Chinese automobile market is the largest in the world, with over 26 million cars sold domestically or exported in 2021, up 3.8% year on year from 2020 (Marklines, 2022). Although traditional internal combustion engine (ICE) vehicles dominate the market, new energy of vehicles (NEV) continues to grow significantly. In 2018, 1.1 million NEVs were sold — an increase of 80% in comparison to 2017, with 4.2% of all new cars being electric (SIPA Center on Global Energy Policy, 2022). The first half of 2019 saw continued growth, with 50% greater sales than the same period in 2018. June 2019 was a particularly successful month, where EVs represented 8.5% of all vehicle sales, partly due to a subsidy cut, which likely motivated some to move their purchases forward. Sales then continued at a slightly slower rate than the first half of the year (SIPA Center on Global Energy Policy, 2022).

Despite NEVs continuing to make up a smaller share of new vehicle sales than other regions, China continued to lead the EV market in 2020 and 2021, accounting for half of the global growth in those years. There were 3.3 million EVs sold in 2021, more than in any other country, bringing the EV fleet total to around 7.8 million (IEA, 2022c). The projected NEV sale in 2022 is estimated to reach up to 6 million units (Bloomberg Hyperdrive, 2022) with

593,000 sold in July, an increase of around 120% over the same period in 2021 and accounting for approximately 26% of the new auto sales market that month (Zhang, 2022).

China developed a strong EV industry, with sales mixed between established domestic automakers, start-ups, and joint ventures with foreign auto manufacturers. Prominent actors in the Chinese EV market are Tesla, BYD (affiliated with Toyota in the EV market), SAIC Motor, SAIC-VW, SAIC-GM-Wuling, and NIO. BYD is the major player, with 160,000 units sold in July, up 280% year on year, and has overtaken Tesla as one of the largest NEV automakers in China, with most of its sales in the Chinese market. The one-time market leader, Tesla, sold 28,217 units in July 2022, a 64% drop from June due to a scheduled shutdown in its Shanghai manufacturing hub to upgrade the factory in anticipation of future production jumps to accommodate growing demand (Stanway & Xu, 2022). The VW Group also has a significant market share, delivering 22,215 EVs in June 2022, up 50% year on year as part of its joint ventures with SAIC and FAW (Chu, 2021). Additionally, many start-ups make inroads domestically and internationally, with the three largest (Peng, Li Auto, and NIO) totalling approximately 17% of the market share (F. Chen, 2022; Chu, 2021).

The price gap between conventional vehicles and NEVs in China continues to shrink and the median price of an EV is around 10% more than a comparative conventional vehicle. Whereas the global sales-weighted average price of BEVs in 2021 was EUR 34,000, and EUR 49,000 for a PHEV, these numbers are skewed downward by the Chinese market, according to analysis conducted by IEA (2022). Chinese NEVs typically have lower production costs, such that small and medium models have an advantageous market position domestically, reducing the sales-weighted average BEV cost to around EUR 26,000 and EUR 38,000 for a PHEV (IEA, 2022c).

8.4.2 Policy Development

The following section describes the evolution of China's policies and regulation. It first describes China's shift in strategy to promote EVs to the devising of the robust Dual Credit Policy, with its component parts, the CAFC and NEV regulation. The section outlines the requirements faced by manufacturers as well as the technical details on the functioning and calculations of the crediting system.

Promotion of EVs before 2017

China promoted alternatives to combustion engines at the turn of the century. While the instruments changed, contrary to many other countries, there has been continued support for electric vehicles. Firstly, during the tenth Five-Year Plan (FYP) of 2001 to 2005, the Ministry of Science and Technology (MOST) instituted an Electric Vehicle Key Project under the National High-tech Research and Development Programme, the so-called "863

Programme" (Peng & Li, 2022b). The policy aimed to promote research and development (R&D) in new energy vehicles, including EVs, HEVs, and FCVs (Peng & Li, 2022b). Between 2004 and 2008, the Automobile Industry Development Policy was declared, aiming to stimulate the coordinated development of the automobile industry (Peng & Li, 2022b).

Between 2009 and 2013, the government focused on fiscal policy. In 2009, it began subsidising the purchase of electric vehicles for public and government fleets, to expand the new energy market. After that, in 2013, electric vehicle subsidisation favoured individual car buyers (Hart et al., 2018; Peng & Li, 2022b). These subsidies were directly imbursed to manufacturers, depending on vehicle sales and registration (Hart et al., 2018).

The thirteenth FYP, for the years 2016 to 2020, included the goal of advancing China's low-carbon transport by promoting electric vehicles. Subsidies for new energy vehicles have been revised by the government and were initially expected to be gradually reduced and eliminated by 2020 in favour of non-monetary incentives. However, the policy has been extended through 2022 in a bid to keep the auto market growing as the wider economy slows in reaction to the COVID-19 pandemic (Hart et al., 2018; Reuters, 2022). For this purpose, an interim management regulation for CAFC and NEV Credits has been proposed by China's Ministry of Industry and Information Technology (MIIT) for public comment on September 22 2016 (Cui & He, 2016).

Introduction of the Dual Credit Policy

The Dual Credit Policy (DCP) was introduced the MIIT in September 2017, and included two elements: the CAFC and the NEV regulations (Cui, 2018; Peng & Li, 2022b). The DCP was the enhanced version of California's Zero Emission Vehicle (ZEV) mandate (Cui, 2018) and was created to foster the development of new energy vehicles and to substantially relieve the demand for government financial support. The role of the DCP was to facilitate and stimulate the market uptake of EVs and set out standards for fuel consumption. The CAFC element investigates and employs energy-saving technologies, while the NEV element advocates new energy vehicles (Peng & Li, 2022b).

The CAFC element sets a 2025 target on fuel consumption limit of for 4 l/100km (equivalent to 95 gCO_2e/km for all passenger cars manufactured or imported into China for ICE and NEVs. Additionally, NEVs must comply with 12 kWh/100km energy consumption limit by 2025 (Xue & Liu, 2022).

NEV Mandate

The Chinese NEV mandate constitutes regulating, calculating, and trading CAFC and NEV credits, and formally entered into force on April 1 2018 (Z. Chen & He, 2021; Cui, 2018; Peng & Li, 2022b). The MIIT defines NEVs as battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), as well as fuel cell electric vehicles (FCVs) (Z. Chen & He, 2021). Through this policy, the Chinese government intended to facilitate manufacturing 2 million BEVs and PHEVs by 2020 (State Council 2012), with NEV sales forming 7% of the market for all vehicles in 2020, 20% in 2025, and 40% in 2030 (F. Zhao et al., 2019).

The DCP targets passenger cars irrespective of their fuel type and applies to all businesses engaged in the Chinese market, both domestic and importers (Cui & He, 2016). The integrated policy intends to promote NEVs and grant the prevailing fuel consumption regulations greater compliance flexibility (Cui, 2018; Cui & He, 2016). According to MIIT, this programme will reduce fuel consumption by 35.5 million tonne, equivalent to 114 million tonne of CO_2 emissions, and establish a market for more than 5 million NEVs combined, from 2016 to 2020 (Cui & He, 2016).

All car manufacturers with annual production or imports of at least 50,000 passenger cars must adhere to both CAFC and NEV regulations. Small-scale businesses (less than 50,000) are only required to satisfy CAFC targets. However, the annual volume limit is decreased to 30,000 in the final rule compared to the interim proposal. All car manufacturers must adhere to CAFC regulations, but larger businesses (those importing or producing 50,000 or more conventional internal combustion engine vehicles annually) must also satisfy CAFC and NEV targets (Cui & He, 2016). Moreover, manufacturers, with the exception of eligible small-volume companies, must accomplish mandated targets for NEVs as a percentage of newly produced conventional fuel passenger cars in a given year (Z. Chen & He, 2021).

Corporate Average Fuel Consumption (CAFC) management

The CAFC element sets out requirements to lower the fuel consumption in passenger cars. In essence, the dual credit policy allows manufacturers to use excess NEV credits to compensate for deficits in CAFC credits, enhancing compliance flexibility, to comply with the predetermined annual requirements on credits for auto manufacturers (Cui, 2018). All car manufacturers are required to satisfy certain annual CAFC requirements, considering their fleet composition. Each company's CAFC targets are based on China's mandatory passenger vehicle fuel consumption standards. The CAFC target for a vehicle-producing company is based on sales weighting of each model's fuel consumption standard (**Table 8.5**). The model's fuel consumption is predetermined by national standard GB 27999-2014. Additionally, the same approach applies to calculating actual CAFC credit (Z. Chen & He, 2021). If a corporation both manufactures and imports cars, its CAFC target, and actual CAFC performance should be measured separately for domestically manufactured versus imported vehicles (Cui & He, 2016).

For a particular calendar year, an auto manufacturer producing or importing N passenger cars determines its actual CAFC value (A_{CAFC}), target CAFC value (T_{CAFC}), and annual CAFC target (R_{CAFC}) as follows:

$$A_{CAFC,j} = \sum_{i=1}^{N} (A_{FC,i,j} \times \frac{V_{i,j}}{\sum_{i=1}^{N} (V_{i,j} \times W_{i,})})$$

$$T_{CAFC,j} = \sum_{i=1}^{N} (T_{FC\ i,j} \times \frac{V_{i,j}}{\sum_{i=1}^{N} V_{i,j}}$$

$$R_{CAFC,j} = T_{CAFC,j} \times R_j \times AF$$

Where:

$A_{FC,i}$ is the actual fuel consumption of model i in year j;

$T_{FC,i}$ is the target fuel consumption of model i in year j;

V_i is the annual production or import amount of model i in year j;

W_i is the number of super-credits given to model i in year j;

R_i is the annual target ration in year j;

AF is the adjustment factor for small-volume manufacturers or importers (Cui & He, 2016).

* NEVs and "energy-saving vehicles" yield credits so-called "super-credits", which were expected to decline between 2016 to 2020 (Cui & He, 2016).

Table 8.5: Fuel consumption target standards.

Curb Mass (kg)	**Fuel consumption target (l/100km)**			
	Phase 3, 2012-2015		Phase 4, 2016-2020	
	Regular Cars	Special Cars (≥3 rows)	Regular Cars	Special Cars (≥3 rows)
≤750	5.2	5.6	4.3	4.5
750-865	5.5	5.9	4.3	4.5
865-980	5.8	6.2	4.3	4.5
980-1090	6.1	6.5	4.5	4.7
1090-1205	6.5	6.8	4.7	4.9
1205-1320	6.9	7.2	4.9	5.1
1320-1430	7.3	7.6	5.1	5.3
1430-1540	7.7	8.0	5.3	5.5
1540-1660	8.1	8.4	5.5	5.7
1660-1770	8.5	8.8	5.7	5.9
1770-1880	8.9	9.2	5.9	6.1
1880-2000	9.3	9.6	6.2	6.4
2000-2110	9.7	10.1	6.4	6.6
2110-2280	10.1	10.6	6.6	6.8
2280-2510	10.8	11.2	7.0	7.2
2510+	11.5	11.9	7.3	7.5

Source: Cui & He (2016).

New Energy Vehicle (NEV) Regulation

The second element of the Dual Credit Policy is the requirement to fulfil certain quotas in terms of the share of NEVs in the overall number of cars sold. However, due to multipliers, the annual percentage goals do not represent the share of NEVs in the total number of cars sold. Since the multiplier is always higher than one, the share of NEVs sold is always lower.

The NEV credits were initially designed for two years, aiming for 10% of the market for conventional passenger vehicles in 2019 and 12% in 2020, as shown in **Table 8.6**. Depending on features such as electric range, energy efficiency, and rated power of fuel cell systems, NEVs earn a certain number of credits. The maximum credit limit for each vehicle is six (Cui, 2018).

Table 8.6: NEV target percentages by year as part of Phase One of the policy.

Year	2016	2017	2018	2019	2020	2021
Percentage Required	-	-	8%	10%	12%	Formulated separately

Source: Cui & He (2016).

When a qualified auto manufacturer produces or imports NEVs, it generates credits. The credits are multiplied according to the annual counted-up manufacture or import volume of each NEV type and the technology mix of its fleet (Z. Chen & He, 2021; Cui & He, 2016). Importantly, each NEV type receives a unique per-NEV score (**Table 8.7**). Per-NEV scores are only assigned to NEVs that fulfil minimum electric-drive range parameters, vary by technology, and remain unchanged during the regulation term (Cui & He, 2016).

The following equation is formulated to calculate the NEV credit:

$$A_{NEV,i} = \sum_{i=1}^{N} (C_i \times V_{NEV,i,j})$$

Where:

$A_{NEV,i}$ is the NEV score for model i;
C_i is the per-vehicle NEV score of model i;
$V_{NEV,i,j}$ is the annual production or import volume of NEV model i in year j.

Table 8.7: Per-vehicle NEV scores.

Per-Vehicle NEV score for NEVs with variable driving range in electric mode					
NEV Type	Range ≥ 50 km	80-150 km	150-250 km	250-350 km	350+ km
BEV	-	2	3	4	5
PHEV	2	-	-	-	-
FCV	-	-	-	4	5

Source: Cui & He (2016).

By applying weighting variables, CAFC credits can be banked and carried forward up to three years to support CAFC compliance in the future (Cui & He, 2016). If the actual CAFC score is greater than the target for a particular year, the surplus credits can be sold to other manufacturers. If a car manufacturer fails to meet the quota requirement, it can cover the deficit by using banked CAFC credits, transferring CAFC credits from affiliated companies, or acquiring NEV credits from other businesses (Cui, 2018). However, it should be noted that the credits are not carried backwards, meaning that manufacturers are not authorised to borrow future credits for a given year and credits are only transferable among shareholders and associated companies (Cui & He, 2016).

Between the initial proposal and implementation, the MIIT made several changes to the NEV Mandate, including a one-year delay in mandatory NEV credit requirements, beginning in 2018, with tighter exemption criteria for small-volume manufacturers, stricter technical thresholds on speed and e-range for NEV credit qualification, variable per-vehicle credit for battery electric vehicles (BEVs) based on e-range, higher per-BEV credit based on electric efficiency, and variable per-vehicle credit for fuel cell electric vehicles (FCVs) (1).

The final rule tightened the exemptions for small-volume manufacturers, decreasing the threshold for exemption from an annual production and/or import volume from <50,000 vehicles to <30,000 vehicles. With regard to credit eligibility for NEVs, the final rule increased the qualifying electric range from ≥80 km for BEVs to >100 km, with a required maximum speed ≥100 km/h. The electric range threshold requirement for FCVs was increased from ≥250 km to ≥300 km. Eligibility thresholds for PHEVs remained the same.

Looking more specifically at the adjustments made with regard to NEV credits, MIIT adjusted the calculation for per-vehicle NEV credit such that:

BEV:

$$BaseCredit(BC) = (0.012 \times R_e + 0.8)$$

$$Final\ Credit = (BC \times EC)$$

PHEV:

$$BC = 2$$

$$FinalCredit = (BC \times EC) \leq 2$$

Fuel-Efficient Vehicles (FEVs):

$$BC = 0.16 \times RatedPower$$

$$FC = BC \times RP \leq 5$$

The maximum per-vehicle NEV credits were reduced overall and the technical requirements for determining credit value (such as electric range and rated power) were tightened, decreasing the number of credits earned through the production of NEVs.

Following the implementation of the updated rule in 2018, the MIIT immediately announced the technical details for Phase Two (also, "the 2020 rule"), with enforceability beginning 1 January 2021. Phase Two set longer-term expectations for the NEV market and responded to accounting challenges and circumstances which came to light only after the implementation of the credit-trading market. The headline update was the one to the NEV credit percentage targets, setting the 2021, 2022, and 2023 targets at 14%, 16%, and 18%, respectively. Looking towards the credit market, of particular concern was the potential for a credit supply-demand imbalance. In 2019, manufacturer surpluses totalled 4.17 million NEV credits and deficits were only 0.86 million NEV credits. One reason for the NEV credit surplus is that technology advancements led to an increasing number of long-range BEVs, which were given higher relative value under the 2017 policy. The MIIT lowered the credits given to BEVs with long electric range, and Phase Two encourages energy-efficient EV models instead. Phase Two additionally increases the carry-forward period for NEV credits to three years, at a 50% discount. Under the 2017 policy, NEV credits generated in 2019 could be carried out for one year; however, as of 2020, the three-year allowance applied if (1) the average fuel consumption of conventional fuel vehicles of a company is no higher than 123% of the CAFC target, or (2) a company only produces or imports NEVs.

The Phase Two update created a new fuel-efficient vehicle (FEV) category for NEV credit calculation to encourage fuel efficiency gains. FEVs are considered conventional fuel vehicles that meet China's weight-based fuel consumption standard on a per-vehicle basis. Each year, FEVs are those with a lower fuel consumption level for their vehicle weight, or those with fuel consumption below the annual standard curves. From 2021, each FEV is counted as 0.5 conventional fuel passenger cars when calculating a manufacturer's total vehicle production volume upon which the NEV credit percentage targets apply. This multiplier is reduced to 0.3 and 0.2 for 2022 and 2023, respectively. Other ICE vehicles are considered under the 2020 rule, which seeks to promote vehicles using methanol and alternative fuels, and MIIT emphasised the necessity of diversifying fuel types through promoting methanol and alternative fuels vehicles, beginning in 2019. These vehicles are included in the category of conventional fuel vehicles in the 2020 policy.

Compliance

According to the DCP, in order to accomplish compliance, prior-year deficits in CAFC and NEV must be closed out by the end of the current year (Cui & He, 2016). Manufactures in need of achieving compliance have several effective solutions they can follow highlighted in **Table 8.8**.

Table 8.8: DCP compliance pathways.

<table>
<tr><th></th><th>CAFC credit</th><th>CAFC deficit</th></tr>
<tr><td>NEV credit</td><td>In compliance</td><td rowspan="2">Use banked CAFC credits
Use banked NEV credits
Transfer CAFC credits from affiliated firms or shareholder firms
Purchase NEV credits from other firms</td></tr>
<tr><td>NEV deficit</td><td>Out of compliance, purchase NEV credits from other manufacturers and/or importers</td></tr>
</table>

Source: Z. Chen & He (2022).

The MIIT will issue warnings to automakers who do not properly report the required CAFC and NEV data and will refuse to grant "type approval" for new models that do not satisfy their specified fuel efficiency requirements. Additionally, until the recalculated CAFC based on the MIIT's investigative findings and the amended production plan comply and can compensate for its NEV-credit deficiency, the manufacturing of several current high fuel consumption models will be suspended. Significant offenders will be labelled as "deceitful companies" and blacklisted in the enterprise credit information management system, and the public will be kept informed by MIIT and other related bodies about their status (Cui, 2018; Cui & He, 2016).

There are several occurrences that could lead to the imposition of the sanctions, including if the data related to the fuel consumption and NEV credits for the vehicles are not disclosed and/or conflict with the inspection findings from the MIIT. Another one is if there is a contradiction between vehicle manufacturing or import numbers with the actual totals. The invalidity of the CAFC and NEV credits reports that have been submitted, and violating the automakers' promises are also mentioned as factors. Eventually, the company is required to comply with the timelines for submitting CAFC and NEV credits reports; so, in case of any missing deadlines, they will be subjected to the sanctions (Cui & He, 2016).

Monitoring and Reporting

The MIIT monitors the NEV systems. Monitoring entails developing a management system so that different regulatory organisations can track credit information provided by automakers, examining and confirming the CAFC and NEV data that automakers submit, and setting up a system for addressing public complaints (Cui, 2018).

The MIIT monitors the CAFC and NEV credits through several mechanisms. It requires commitment letters from automakers, along with deterring, blacklisting, and notifying other regulatory agencies of deceitful companies, as well as establishing a system for public complaints about automakers. Furthermore, MIIT collaborates with other agencies to build an inspection and monitoring system that includes random inspections of the CAFC and NEVs of automakers and makes the results available to the public (Cui & He, 2016).

When automakers provide the necessary reports, for CAFC and NEV, two reports are to be submitted to MIIT. One is the pre-report that, among other specified information, must include the projected target CAFC value, CAFC value, CAFC credits, and NEV credits. It must be delivered by 20 December of each year for the following year. The second report for a given year needs to be submitted by 1 February of the following year and includes the target CAFC value, the actual CAFC value, the CAFC credits, the NEV credits, and the strategy for employing the various credits (Cui & He, 2016).

By March 20 of each year, the MIIT will publicly release CAFC and NEV compliance and credit information for all companies, enabling the public and automakers 20 working days to scrutinise and comment. Moreover, by July of each year, the MIIT, in collaboration with the appropriate regulatory authorities, verifies the information and reports and releases the "CAFC and NEV Credits Accounting Report for Passenger Vehicles" for the previous year (Cui & He, 2016). The Accounting Report includes data on the vehicles manufactured and imported, actual fuel efficiency ratings for each model, summaries of CAFC and NEV credits and deficits generated the previous year for each manufacturer, and the numbers and amount of credit transactions and reports that have been approved by the MIIT, and is published in the form of an annual Accounting Report.

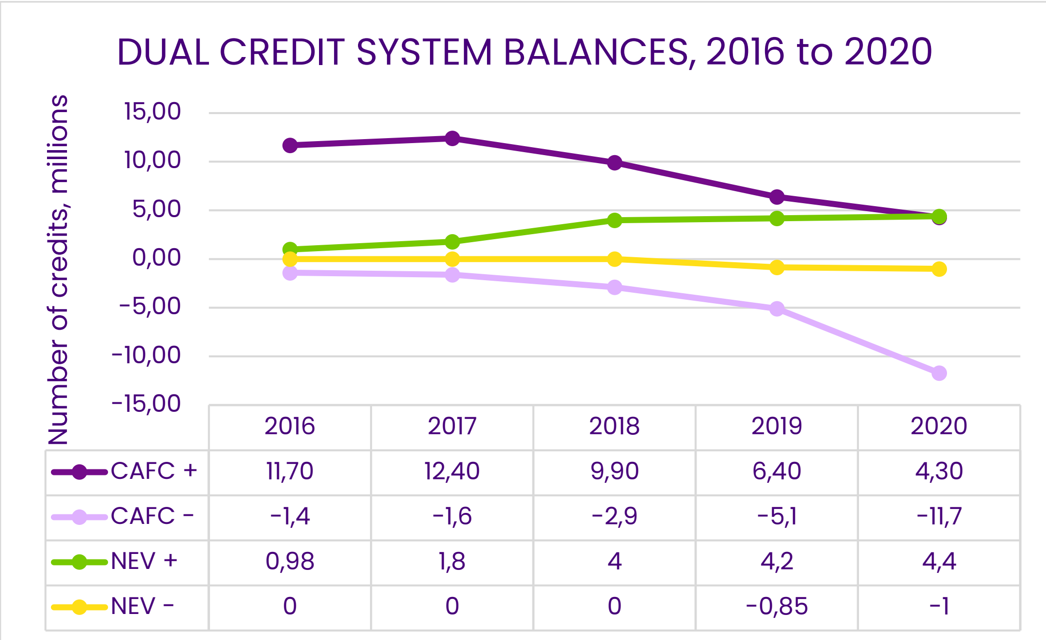
Any company possessing CAFC and NEV credits must submit a compliance plan to MIIT within 20 working days of the Accounting Report's publication, outlining the number of credits the company intends to transfer or purchase, towards becoming compliant. Additionally, they are requested to attach the formal agreement on either transferring or acquiring the credits to the compliance plan. The MIIT is responsible for adjusting CAFC and NEV credit according to compliance plans and agreements, using an online credit information platform. In this regard, it is important to note that the actual transactions are not supervised by the MIIT, which does not operate as a broker in the credit trading (Cui & He, 2016).

8.4.3 Evaluation of the Dual Credit Policy

Since 2017, the MIIT has released annual credit reports, detailing the overall number of positive and negative CAFC and NEV credits in the market, as well as the manufacturers which meet or fail to meet the standard set. From 2016 to 2018, the positive NEV credit score increased significantly, but the rate of growth stalled in 2018; whereas, between 2019 and 2020, negative NEV credit balances grew. At the same time, the number of positive CAFC credits fell after peaking in 2017, and negative balances grew significantly, particularly in 2020 as car manufacturers pivoted towards less efficient but higher priced, and therefore more profitable, medium and large SUVs and crossover vehicles as part of their COVID-19 recovery strategy (KrAsia, 2022; Sun, 2020).

As CAFC standards and NEV percentage targets strengthened, the number of firms in compliance with the mandate dropped. Manufacturers that produced mainly combustion vehicles continued to generate significant negative CAFC credits and failed to produce enough NEV credits without having to purchase extra credits in the market (KrAsia, 2022). Initially priced at around RMB 250 to RMB 300 (EUR 36 to EUR 50), credit prices rose due to scarcity in the market, first to RMB 1000 and then settling between RMB 2500 and RMB 3000 (EUR 360 and EUR 433).

Figure 8.8: Balancing trends of the number of credits available through the Dual Credit System from 2016 to 2020.



	2016	2017	2018	2019	2020
CAFC +	11,70	12,40	9,90	6,40	4,30
CAFC -	-1,4	-1,6	-2,9	-5,1	-11,7
NEV +	0,98	1,8	4	4,2	4,4
NEV -	0	0	0	-0,85	-1

Source: KrAsia (2022).

Due to the increase in the price of the credits, EV manufacturers and importers to China benefitted significantly from the mechanism (**Figure 8.8**). Tesla in China earned EUR 1.52 billion in from credit sales in 2020, whereas the company made EUR 697 million in profit — without credit sales, Tesla would have seen another year of losses in China. NIO generated 200,000 credits in 2020, worth up to RMB 600 million (EUR 86 million). On the other side of the market, companies with large, traditional combustion engine vehicle sales (such as FAW-VW, SAIC-VW, Dongfeng Motor, GAC-Honda, and SAIC-GM) generated significant credit deficits and have sought to set up subsidiaries focused on credit-generating activities, indicating a potential shift towards greater NEV development as a result of the mandate (Kennedy, 2020).

The policy accelerated China's move away from combustion vehicles. Modelling from the National Transportation Research Centre at the United States Department of Energy suggests that the market shares of BEVs and PHEVs with the policy constrains implemented through the Dual Credit policy is larger than it would be without such policies in place, estimating a 2023 market share of roughly 16% for NEVs, versus around an 8% market share in a business-as-usual scenario (Ou et al., 2020). In addition, the modelling suggests that the market share growth rate for EVs (BEVs and PHEVs) is higher under the updated Dual Credit policy than under the old NEV policy and the business-as-usual scenario, which have relatively low growth rate expectations for 2021 to 2023. Under the updated policy, modelling forecasts a PHEV and BEV market share of 11% in 2023 (Ou et al., 2020).

Looking specifically at NEV development and sales decisions from one firm, SAIC-GM-Wuling, it has developed one of the most successful EV models in the Chinese market within the structure of the NEV mandate. Yearly, SAIC-GM-Wuling produces nearly 1.6 million traditional ICE vehicles, mostly microvans known domestically as "breadbox cars", which generate deficits. To address the deficit and mandated credit-ratios, SAIC-GM-Wuling faces a decision — purchase credits at roughly RMB 3000 each (EUR 432), or increase NEV manufacturing (Chu, 2021). SAIC-GM-Wuling announced the Wuling Hongguang MINI EV, with models priced between RMB 28,800 (EUR 4145) and RMB 38,800 (EUR 5584) (Jiang, 2020). Media estimates suggest that SAIC-GM-Wuling likely earns a profit margin of around EUR 13 per vehicle, accounting only for parts and labour. If shipping, taxes and associated costs are included, it suggests that the suppliers of the MINI EV are likely losing money by continuing production (Tang, 2021).

However, accounting for credit generation and non-compliance penalties avoided by manufacturing EVs, SAIC-GM-Wuling is estimated to earn over EUR 140 per vehicle, with the MINI EV adding an estimated EUR 548 million in NEV credit value in 2021 (Chu, 2021; Tang, 2021). Although the decision to produce the MINI EV is not entirely attributable to the NEV mandate, SAIC-GM-Wuling did admit that high NEV credit prices did influence the decision (Kang, 2021). Since then, the MINI EV has become the most popular EV model in China, with over 500,000 units sold since June 2020. In December 2021, the Wuling Hongguang MINI set an all-time monthly sales record for EVs in China with over 50,000 units sold, outpacing Tesla's Model 3 by over 10,000 units (KrAsia, 2022).

Although the policy is still relatively early on in its implementation, it can already be seen that it had a significant impact on research and development in NEV technologies. It also facilitated increasing the efficiency of combustion vehicles. In essence, the credit market may act as an offset for some of the R&D costs associated with the increasing technological and production standards mandated through the Dual Credit policy. Firms with strong technological backgrounds may react to the stepwise standards increases by expanding their R&D investments to maintain their leading position in the market. However, those companies without a solid technological background are likely to forge increased connections in the industry, establish affiliates, and trade credits, creating a more dynamic R&D structure based on capital flow (X. Li & Xiong, 2021). There are already indications that, during the initial phases of the Dual Credit policy, the scale and intensity of R&D conducted by NEV firms increased, likely as a function of the strong signalling and expectation adjustments brought on in the capital market by the introduction of the mandates (X. Li & Xiong, 2021; Liu et al., 2022).

However, accountability and compliance continue to be challenging, as penalties for non-compliance are still somewhat opaque and actual enforcement remains questionable. Companies that had failed to meet their obligations were not publicly identified until 2021, and even then, financial or legal penalties remain unclear (Z. Chen & He, 2022). Without strong penalties, the Dual Credit approach may cause an incentive for producers to not improve the efficiency of their conventional vehicles because they can draw on credits generated by EV imports and sales. Therefore, companies may be incentivised to focus on NEV development at the cost of fuel efficiency improvements in conventional vehicles.

8.4.4 Discussion

The DCP, with its combined mechanism of reducing average car emissions by increasing stringency of fuel standards and the use of a crediting system, has shown its effectiveness to drive automakers to produce and/or import more electric vehicles in China. Crediting has shown that Chinese car companies investing in EVs can record successful profits from credits earned, while forcing companies producing higher-emitting models to pivot. The benefit of the DCP is that, while it has made a strong impetus on the growth of EV production, it has also facilitated research and development into more low-emission vehicles. This has allowed growth into new markets. In a nutshell, the Chinese crediting system acts as a checks and balance system within the automakers' circle that self corrects and trends towards zero and near-zero emission vehicles. This offers the EU an approach for the market to set the pace of innovation, while at the same time, foster greater cooperation between car companies and research and development companies and institutions.

Ensuring compliance through strict penalties and timely public identification of non-compliance was a key pitfall of the DCP initially. However, through revisions, the responsible authority will send early warnings to car manufacturers for not submitting the necessary CAFC reports and any designs of new models failing to comply will be suspended from the market. China's approach in dealing with excessive cases of non-compliance is to blacklist them as "deceitful companies". This is one way to inform the public in their purchasing decisions. A similar system of traffic-lighting, that is more adapted to the EU, could be another solution.

8.5 Lessons for the European Union

Since their introduction, California's LCFS and China's DCP became increasingly complicated. Growing complexity was mostly a result of the need to calculate emissions intensities of different fuels and the crediting of various charging options. However, the LCFS and DCP have five elements which can be of interest to the European policy-makers. **Table 8.9** below offers a summary of the similarities and differences in the California and China regulations.

Table 8.9: Features of China's NEV Credit Regulation vs California's ZEV Credit Regulation.

Features	China's NEV Credit Regulation	California's ZEV Credit Regulation
Associated with CAFC/CAFE:	Yes	No
Scope:	Nationwide	California & nine other states
Applicable manufacturer:	Production of traditional cars per year more than 30,000	Average sales of traditional cars in the previous 3 years more than 4500
Credit proportion requirement:	2021: 14%; 2022: 16%; 2023: 18%	2018: 4.5%; 2019: 7%; 2020: 9.5%; 2025: 22%
Encouraging vehicle:	BEV/PHEV/FCV	PHEV/BEV/FCV
Credit trading:	Free trading	Free trading
Expiry date:	Allowed to be carried over annually	Allowed to be carried over annually
Punishment:	Administrative punishment: suspension of production	Financial punishment

Source: Peng & Li (2022b).

Firstly, both the DCP and LCFS introduced annual interim targets to send clearer signals to automakers and the markets on the state of progress they should be achieving, effectively reducing the risk of delayed action on missing the long-term goals.

Secondly, the instruments open the possibility of including other technologies and could also encompass different modes of transport. It could not only include credits for hydrogen for heavy-duty transport, but also provide credits for the development of low-carbon fuels for aviation and maritime use. Also, operating railway connections by private companies and the development of infrastructure for cycling could be rewarded with credits. To ensure stability, such a broad coverage of credit recipients should also be accompanied by an inclusion of all actors selling fossil fuels and decreasing emissions intensity. The latter could be adapted to what is technically possible. At the same time, governing bodies should exclude biofuels that are not fulfilling strict environmental criteria from the mechanism. Furthermore, the funding for the development of low-carbon alternatives comes from the proceeds of the producers of emissions-intensive fuels. This constitutes a significant difference compared to the funding of the charging infrastructure in the EU member states, which is currently subsidised from public resources. While some of these resources come from fuel taxation, the funding development of low-carbon alternatives in the transport sector may be decreased due to austerity measures. Shifting the funding from public resources towards the private sector — as is the case for the LCFS and DCP — would pose the risk of the budget drying up, as the consumption of fossil fuels decreases. However, in such a scenario, the need for funding low-carbon infrastructure would also decrease as the market reaches maturity.

While California experienced overall good compliance with the regulations, China, on the other hand, did not initially experience this, requiring the development of a labelling tool to inform the public of greenwashing to influence their purchase decisions towards lower or zero-emission carmakers.

Finally, if introduced at the European level, the instrument could facilitate harmonising the coordination of efforts and thus the speed of decarbonisation in different countries. This would result from investors moving to regions with less saturated markets, such as with fewer charging stations, but with significant potential for their development. In addition, countries or regions that cannot afford the high cost of subsidies for charging or low-carbon infrastructure could still benefit from the flow of investments from the sale of credits, driven by fossil fuel consumption in wealthier EU member states.

Evidently, the EU has started heading towards a similar direction. As of July 2021, the Commission released a new proposal as part of the 'Fit-for-55' packages to revise the EU ETS and include road transport, as well as buildings, together in a separate ETS system that operates adjacent to the pre-existing. While the proposal is still in the pipework of institutional approval procedures, the Directive would see the start of emission trading covering vehicles start from 2026, with this year representing the baseline from data acquired through the ESR (European Commission, 2021d). The proposed system is composed of two key features; firstly, allowances will only be distributed by auctions. Secondly, the Commission proposed that the revenues generated from the trading scheme be re-investment by MS back into measures that support climate actions, with a quarter of revenues be diverted into the newly established Social Climate Fund to support the just transition for vulnerable groups (ICAP, 2022). Compared to other parts of the world, the EU's tack towards road vehicle credit trading is still in its nascency, as so the experience, both success and failures, can be adapted accordingly by the EU as it tests the dynamics of its new proposal.

However, in 2022 the EU proposal is still in on-going political and technical negotiations between the European Parliament and Council over the final text have the potential to limit the effectiveness of the crediting system. For example, the Californian LCFS crediting system accommodates both residential and non-residential charging in the generation of credits (Kelly & Pavlenko, 2020). At present, the proposed amendments from the EP would exclude private households from the crediting system until 2029. Additionally, while the EP wishes to accelerate the initiation of the permit issuing, auctioning, and surrendering of allowances a year earlier than proposed, effectively initiating the process from 2024, the Council wishes to delay the start of the process to begin auctioning and surrendering of allowances from 2027 and 2028, respectively (Killick et al., 2022). Given the urgency of the climate crisis, accelerating this procedure, especially since the EU is late to the game with road transport crediting, will be crucial. As both case studies from California and China have shown that the effectiveness of their measures require a degree of trial and error, adjustments and updates for the policy to reach the evolved forms they are in today If the EU were to delay such procedures further will risk falling behind in targets.

8.6 Conclusions

Considering the EU's ambition to become the world's first climate-neutral region, stronger targets and policies in one of its most polluting sectors, transport, are needed. This ambition has become increasingly necessary in light of rising fuel prices as a consequence of the pandemic and Russia's war in Ukraine. As it is currently in the process of drawing up sectoral proposals to achieve its Green Deal goals, now is an opportune moment to learn from the successes in California and China.

While the systems developed by California and China are not perfect, they offer insights into how the EU can strengthen its already robust regulatory framework to meet its long-term goals. For the EU, the California case highlights the need for harmonisation of crediting, to accommodate multiple stakeholders across the EU. This will allow for inter-operability of the crediting system designed to use revenues to reinvest into the electrification and alternative fuel markets. The growth of the electro-mobility sector is heavily reliant on the simultaneous expansion of renewable energy resources. Therefore, a crediting system would benefit the promotion of charging stations which source or develop renewable sources of energy.

In the initial years of the DCP, little compliance was seen by manufacturers, especially with stricter standards introduced. However, as the credit market adjusted, with the price of credits increasing due to scarcity in circulation, a shift in the manufacturing industry was seen. EV manufacturers racked up higher profits, while less fuel-efficient automakers recognised the need to change direction.

The case studies presented here should be approached with some caution, and further adaptions would be required before implementation in the EU. For example, while the EU has existing fuel standard regulations, they are riddled with loopholes that provide exemptions to manufacturers from meeting average emissions reductions targets. This, in turn, jeopardises the likelihood of meeting targets set for 2025 and beyond. The checks and balance system using a crediting market should be looked into further as a means to avoid such issues from arising.

Caution must also be taken when considering the adaptation of such mechanisms to the EU's framework. This is most evident in the framework separation of the EU ETS and ESR. Although crediting offers an excellent option to accelerate private investment towards lower-carbon fuels, technology and electric vehicles, further research will be needed to understand how such a dual system can operate at a technical level in the EU's framework.

Lastly, the case studies presented here offer some empirical evidence of investment trends and emission standards. However, given that both policies are continuously evolving and that markets change, close supervision should be kept of updates coming from California and China.

9. Archetype 8: Decarbonisation of the building sector

9.1 Introduction

The building sector has a significant and often underestimated impact on climate change, both in terms of energy it consumes as well as at all stages of construction. The operation and construction of buildings produce 38% of all energy-related CO_2 emissions. To address this problem, several studies agree that emissions from buildings must be halved by 2030 to put the sector on track to net zero carbon by 2050 and achieve the Paris Agreement long-term 1.5ºC goal (United Nations Environment Programme, 2021).

For the European Union, the building sector is responsible for 36% of emissions and 40% of the energy consumed (European Climate Foundation, 2022). Therefore, achievement of the EU's emissions reductions goals for 2030 and reaching climate neutrality by 2050 requires radical action in this sector. However, decarbonisation of the building sector has been made difficult by the complexity and diversity of the sector, and the number of actors involved. The building stock is quite diverse, with a wide range of intended uses, across varying environments and with varying technical requirements to meet zero-carbon goals (Climate Action Tracker, 2022a). An additional problem in decarbonisation of the sector is the high upfront investment cost necessary to carry out renovations. The necessary resources are not always available to the homeowners, or they are not willing to take the risk without being sure about the reduction of the energy costs.

This poses a significant opportunity loss as building renovation can, in most cases, generate significant savings — both in terms of emissions and money — compared to the baseline energy consumption, especially keeping in mind the current high energy costs. To take advantage of this potential, more targeted policies are needed that will target the challenges slowing down the renovation rate. A more active role of the government is essential to make the transition to more sustainable buildings a reality. This concerns not only reductions in energy consumption in the buildings, but also the life cycle emissions of the buildings engrained in the materials used for construction. Clear policies that support innovation in terms of energy consumption, integration between different forms of energy through smart electrification, and low carbon construction materials are essential to reduce emissions from the sector at the rate compatible with the EU emissions reductions targets. The policy targeting the decarbonisation of the building sector should also simplify the access to funding for buildings renovation.

This report presents some of the interventions that could offer some lessons for the EU's policy framework, facilitating decarbonisation of the building sector. The case studies focus on mitigating the challenge of high upfront investment for the energy renovation and facilitating a coordinated approach to decarbonisation of whole neighbourhoods.

The case studies presented here are based on desk-research and expert interviews. We identified important explanatory factors with the help of grey literature and academic publications. In addition, we analysed official policy documents as well as media reports. These helped to identify the relevant actors, institutions, policies, and processes. Next to desk-research, we conducted three semi-structured interviews with the stakeholders involved in the development of the policies investigated and discussed the repercussions and lessons learnt during a workshop with European stakeholders.

The collected information was then used to develop a comprehensive narrative that describes and explains the Property Assessed Clean Energy programme as well as the Ithaca Green New Deal building decarbonisation effort. Based on the case studies, interviews, and the workshop, general lessons for the EU were drawn up.

The report proceeds as follows. Section 9.2 develops the case study selection further by discussing the relevance of proper financing instruments and comprehensive planning for decarbonisation of the building sector. Section 9.3 presents the case study of the Property Assessed Clean Energy (PACE) instrument as a tool to facilitate decarbonisation of the building sector. Section 9.4 presents the case study on building decarbonisation regulation and financing, looking at a municipal-level programme which took a comprehensive approach to building decarbonisation. Section 9.5 presents some lessons for EU policy-making, and the last section concludes.

9.2 Why consider PACE and the Ithaca Green New Deal as case studies?

The decarbonisation of the building sector is critical in the EU's transition efforts, and in decreasing dependence on fossil fuels. In order for the EU to achieve its climate goals, the building sector is projected to require at least a 60% reduction in emissions by 2030 and become totally carbon neutral by 2050. As of 2022, the EU is not on track to achieve this goal, with buildings accounting for 40% of all energy consumption (European Climate Foundation, 2022).

Due to the long lifetime of the building stock, decreasing the energy demand of already constructed buildings is critical, and can be achieved through energy renovation, targeting key efficiency upgrades. In the EU, the energy renovation rates are quite low, ranging between 0.4% and 1.2%, depending on the Member State and the depth of those renovations (such as the intensity of the changes made) (Ipsos Belgium & Navigant, 2019). To increase the renovation rates, in October 2020 the European Commission published its Communication and Action Plan, aimed at triggering a "renovation wave" in the EU, specifically attempting "to at least double the annual renovation rate of residential and non-residential buildings by 2030" (European Commission, 2020c). An annual renovation rate of 3.5%, through electrification and deployment of heat pumps, would allow the EU to halve its energy consumption in the building sector by 2050, and would result in much higher GDP growth rates (European Climate Foundation, 2022).

When seeking to increase renovation rates, it is critical to understand the drivers of renovations as well as common hurdles. The decarbonisation of the building stock faces challenges at both individual and structural levels. On the individual level, it requires connecting property owners with financial resources, sector knowledge, and construction know-how in order to complete a project. And that only applies when the property owner is motivated to instigate a renovation. In many cases, the buildings that are in the greatest need of energy efficiency improvements are the least likely to have owners with access to the time and money needed to implement such projects. For individuals with fewer financial resources, barriers to energy efficiency improvements are particularly pernicious (Carlander & Thollander, 2022). However, studies considering the issue in the United States and Europe show that financing programmes have significant potential to improve savings and energy usage, but that financing options are key (Environmental Defense Fund (EDF), 2018; Jakob, 2007; World Green Building Council, 2022).

At the same time, building renovation is increasingly an expensive and complicated process due to COVID-19-related hold ups in the supply chain, and due to inflation in both materials and labour (Hanson, 2022). Energy efficiency renovations typically include improvements to heating and/or cooling systems, and prices for HVAC materials are up 15% to 20% year-on-year for 2022, compared to an average year-on-year increase of only 2% to 4% (JastMedia, 2022). There is also concern that direct, but short-term, subsidies could result in a boom-and-bust for the construction companies which brings the risk of unsustainable business practices that threaten sector capacity in the long run (S. Richardson, personal communication, September 2022).

Box 9.1 Decision-making for energy renovation

The literature examining individual homeowners' decision-making around home energy efficiency improvements is relatively robust and generally conclusive (Carlander & Thollander, 2022; d'Hebermont et al., 2020; Ipsos Belgium & Navigant, 2019). When looking at individual decisions, obstacles to decision-making can generally be understood as either structural, which change the broader context of the individual's decision, or internal/psychological, which have to do with the individual's cognition or mindset. As with many decision-making contexts, this delimitation applies to the individual's choice to seek (or avoid) energy-saving renovations on their home (d'Hebermont et al., 2020).

Key structural barriers to energy renovation decisions at the individual level are costs and financing. As above, the cost of energy-efficient building practices and renovations as well as lack of financial resources is a (if not the most) significant structural barrier to energy renovations (Klöckner & Nayum, 2016). A study of the energy efficiency investments of private homeowners in Switzerland found that the tax burden (as a proxy for household income) was a clear predictor of energy-investment decisions (Jakob, 2007). At the same time, perceived potential savings in energy costs, in addition to income, were found to be a good predictor of whether or not a homeowner would opt to spend funds on energy efficiency improvements (Klöckner & Nayum, 2016). Concerns about returns-on-investment were critical, with many homeowners wary that lower-than-expected returns would make the decision to renovate financially tenuous (Carlander & Thollander, 2022).

On the other hand, there are barriers which affect the individual's mindset and decision-making process, such as the lack of reliable or credible information, previous experiences with renovation and contracting, and the perceived inconvenience of home renovations — particularly if a landlord is involved (Ástmarsson et al., 2013; Klöckner & Nayum, 2016). Access to technical knowledge, confidence in that information, and procurement are often beyond the average property owner (S. Richardson, personal communication, September 2022). Flat owners in collective housing organisations in France, Switzerland, and Spain were found to be more likely to decide to move forward with energy efficiency renovations if they had knowledge of national and local support programmes which would assist with planning and completing projects (Beilan et al., 2011). The lack of clear information has other, somewhat more pernicious, impacts on decision-making, as some homeowners held a certain amount of scepticism about the benefits of energy renovation, particularly as a result of contradictory and conflicting commentary in the public sphere (Klöckner & Nayum, 2016).

Another critical challenge to decision-making with regards to energy renovations is the landlord-tenant dilemma, which occurs when the interests of property owners and tenants diverge. Questions of who pays, what approach to take, and even if the renovation is necessary, all extend the process and even just the prospect of involving one's landlord can have a significantly chilling effect (Ástmarsson et al., 2013).

Looking past barriers and on to the specific triggers which may motivate someone to instigate energy efficiency improvements, individuals often do not weigh potential energy savings particularly heavily (Beilan et al., 2011; d'Hebermont et al., 2020; S. Richardson, personal communication, September 2022). In most cases, individuals were motivated to improve the energy efficiency of their home as a result of a change that directly impacted on their day-to-day comfort. This could include, for example, a water heater, broken windows becoming draughty in the winter, or moving to a new home in which other renovations are already required (Carlander & Thollander, 2022).

Considering the multifaceted nature of energy renovation and financing building decarbonisation, the Property Assessed Clean Energy (PACE) programme, introduced in the United States to help individual homeowners fund energy renovations, offers a viable option as a case study because it attempts to address key financing and information barriers for both residential and commercial properties, while offering a novel financing structure. The barriers to building renovation that the PACE programme attempts to address are barriers seen in the EU — information gaps, lack of technical skill, and upfront costs (d'Hebermont et al., 2020). In the United States, the PACE programme seeks to overcome the cost hurdle of energy renovation and provides key tools to assist with coordination and information gaps. At the same time, by packaging energy renovation loans as securable assets, the PACE programme also offers a mechanism to overcome the barriers set by financial institutions. PACE is interesting because it engages with both residential and commercial properties, whereas many programmes target one or the other (Rose & Wei, 2020).

Looking from well-established programmes to programmes and policies at the cutting edge of building decarbonisation, the Ithaca Green New Deal comes up naturally as a case study. As the one of the first municipalities in the country to establish a decarbonisation mandate, Ithaca is set apart as an experiment and case study into municipal policy, supporting decarbonisation (Lamb, 2021a). This presents a critical addition to this archetype, not only looking back at already implemented policy, but forward to building decarbonisation policy as it develops. The relative newness of the Ithaca Green New Deal also means that the literature has yet to be fully developed, presenting a key opportunity to not only examine new policy decisions, but also to set the stage for future inquiry.

Box 9.2: Building renovation and investment

Industry estimates find that just under EUR 100 billion in assets were traded in the European residential sector in 2021, a record number. Investment in 2021 was 45% higher than in 2019, the previous record year. As inflation continues to creep upwards and bond yields continue to be quite low, investment in housing grows. As a growing asset class which is perceived to be a better long-term investment than other options, money is likely to continue to flow into the residential sector (Knight, 2022).

At the same time, financing continues to be a key concern for all actors involved in energy renovations and can be the main barrier or trigger for renovation, but in a deeply complex regulatory environment with convoluted materials supply chains, it cannot be the only consideration (d'Hebermont et al., 2020). In order to successfully integrate the components of energy renovation on a building-by-building level, local and municipal authorities are key, due to their role in addressing financial regulation, markets, and homeowner and resident engagement.

9.3 Case study 1: Property Assessed Clean Energy (PACE)

The first case study looks into the US development of the Property Assessed Clean Energy, or PACE, as a means to funnel investment towards the decarbonisation of the building sector. Section 9.3.1 starts by introducing the case study and begins by considering the background of the development of the PACE programme, looking into the building sector in the United States both before and after the 2008/9 housing and financial crises. opening the discussion around what the programme is about. Section 9.3.2 goes into the detail of the policy development, from the domestic need to decarbonise buildings and the subsequent adoption of a policy and financing structure needed to fund this large investment. Section 9.3.3 evaluates the impact PACE has had on investment across the US, particularly of its two components, Commercial and Residential PACE. Finally, Section 9.3.4 closes the case study by discussing the EU version, EuroPACE as a project.

9.3.1 Context and background

The case for PACE

The development of the PACE programme in the United States was prompted by a series of interconnected challenges, from rising emissions, an ageing and increasingly inefficient housing stock, a complex and difficult-to-navigate regulatory environment, and a lack of financial incentives to address any of the above challenges.

Buildings in the US continue to make up a large proportion of the country's energy demand, but energy demand has trended downward (U.S. Environmental Protection Agency, 2020). Following a discussion of the broader context, the case study then turns to examine local-level drivers of climate action and building decarbonisation. Even with support at the federal level, municipal action is required to implement significant changes to the building stock due to the regulatory structure of the building sector.

Subsequently, the case study examines the key actors within the PACE financing model, looking into the motivations and interactions of each. Critical to understanding the PACE programme is understanding the interactions between local government, the property owners, and financiers, and the way the programme creates new incentives for each actor to move forward with energy efficiency improvements. A discussion of the specifics of financing each loan follows, considering the impact of liens on the financing structure, as well as on individual homeowners.

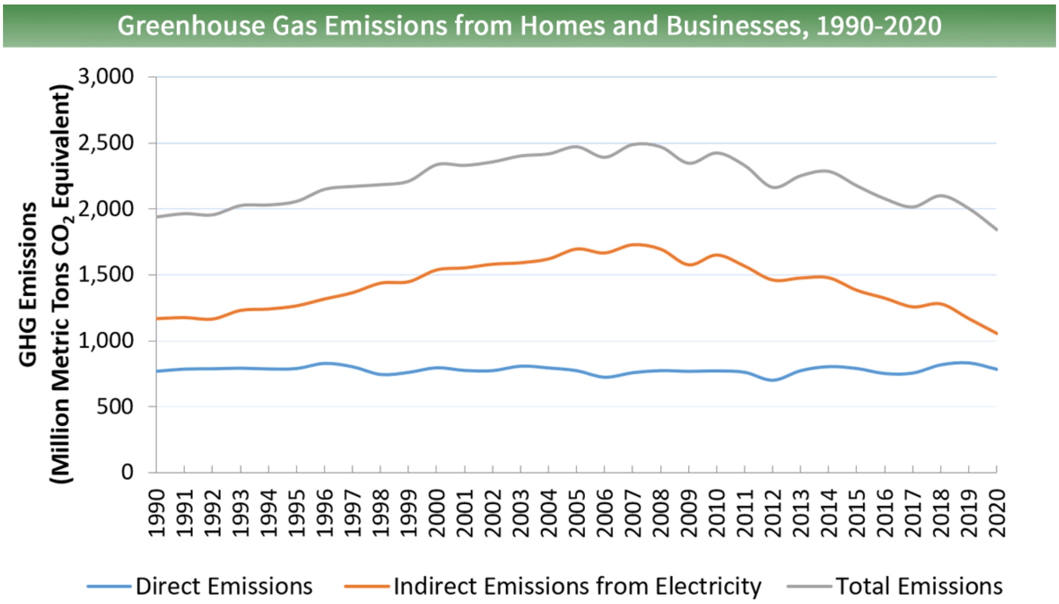
Having examined the PACE model itself, the case study then investigates its impact on both residential and commercial properties, looking at the successes and drawbacks that became apparent as the programme matured. Finally, potential lessons for the EU are considered, including a discussion of the EuroPACE programme and potential applications to the EU's building decarbonisation effort.

The building sector in the USA before the introduction of PACE

Between 1990 and 2005, the median age of owner-occupied housing units in the United States increased, with approximately two-thirds of owner-occupied homes being built before 1980, and over 40% of the owner-occupied stock being built before 1970 (N. Zhao, 2015). By 2005, the average home was over 30 years old, with ageing appliances, insufficient insulation, and inefficient gas piping. At the same time, the average size of housing has trended upwards, contributing to a rise in emissions from the building sector from the late 1990s through to the present day.

Energy consumption from buildings in the United States has accounted for almost 30% of all carbon emissions since the turn of the century, through both direct and indirect emissions (Cleary & Palmer, 2021). While this was less than in the EU, where emissions from the sector amount to around 36%, the per capita emissions from this sector in the United States are much higher (Center for Climate and Energy Solutions, 2018; European Commissison, 2020). The decades-long lifetimes of buildings, particularly housing units, mean that buildings built after 2000 are likely to still be in use in 2040 and beyond, and in need of updates to meet emissions reductions requirements and to improve energy efficiency (Fuller et al., 2009).

Figure 9.1: Commercial and residential emissions between 1990 and 2020 in the US.



Source: U.S. Environmental Protection Agency (2020).

As the total carbon output in the US continued its upward trend, eventually peaking in 2007, increased importance was placed on energy efficiency and decreasing fossil fuel dependence at all levels of the building sector (**Figure 9.1**). This was complicated by the fact that the building sector is regulated at nearly every level of government within the United States, leading to a complex mix of regulation, building codes, and zoning requirements, impacting both new builds and renovations. Federal, state, and city-level building codes all interact in a complex environment which can be challenging to understand, particularly for homeowners seeking to renovate or update their homes. A 2001 study from the California Integrated Waste Board found that the customer-led nature of key services like architecture, construction, and contracting meant that if the building owner was not aware of energy-efficient options or incentives, they were unlikely to be suggested or implemented due to a lack of information and intimidating regulatory structure. This resulted in lower renovation rates and higher energy consumption, resulting in much higher overall energy consumption. At the same time, builders were financially disincentivised to advocate for additional green building practices beyond what was legally mandated, as the long-term accrual of environmental incentives generally only applies to the final owners of the building, not the builders, contractors, or developers.

The low levels of energy-specific home renovations also resulted from the fact that, prior to the collapse of the housing market in 2008, the mortgage market and financial institutions backing up the building sector were fairly adverse to any sort of energy efficiency improvement financing or mortgage structure (Davis, 2001). In 1999, the residential mortgage market contained 13 million mortgages, but fewer than one-tenth of 1% of those loans contained an energy efficiency clause or requirement. Studies of the mortgage market in the early 2000s argue that the energy efficiency loan market was deeply underserved because loan providers did not understand the true market potential and were not educated in the right area to develop a new business model to focus specifically on energy-related loans for new buildings and renovations (Fuller et al., 2009). At the same time, energy efficiency-focused loans were complicated contractually, increasing average closing time on house purchases, and decreasing potential profits for lenders, real estate agents, and construction firms.

Decarbonisation of the building sector since the 2008 housing crisis

The 2008 to 2009 housing and financial crises had significant impacts on the housing stock and housing decarbonisation efforts in the United States. The American Recovery and Reinvestment Act (the Recovery Act) signed by President Obama in February 2009 was an unprecedented stimulus bill which included significant funding to support building decarbonisation and energy efficiency improvements for residential, commercial, and public properties. Funding was distributed through a variety of financial and policy instruments including both direct funding and tax incentives (Office of Electricity, U.S. Department of Energy, 2022). The clean energy sector received USD 90 billion in funding, which was split across multiple sectors, with roughly 51% going to renewable energy and energy efficiency measures.

A key programme benefitting from the Recovery Act in terms of energy efficiency measures was the Weatherization Assistance Program (WAP), which received USD 5 billion in extra funding (Varro, 2020). Originally instituted over 40 years ago, WAP is the largest federal-level energy efficiency and home improvement funding mechanism. WAP aims to provide funding for energy efficiency improvements for owner-occupied low-income households in order to decrease energy use and associated costs for those households. The programme provides grants and coordinates with over 700 related organisations to provide basic improvements such as insulation, duct work, and energy-efficient heating and cooling systems (U.S. Department of Energy, 2022c). In addition to the extra funding, WAP rules were changed to increase the income eligibility threshold and allow higher average spending per project (Varro, 2020).

Other regulatory changes in the Recovery Act included updates to the Residential Clean Energy and Energy Efficiency Tax Credit, providing an additional USD 10 billion in incentives for homeowners to improve energy efficiency. The eligible deduction was also expanded to equal 30% of qualifying investments. In addition, the Energy Efficiency and Conservation Block Grant Program was also expanded by USD 2.6 billion, to be sent to state and local government entities for efficiency retrofits and buildings and facilities improvements (Varro, 2020). In total, over USD 27 billion was allocated for energy efficiency improvements in the building sector, including funding for further R&D in the field.

The Recovery Act had a significant impact on the state of the building sector, with direct funding continuing through 2015 and regulatory changes implemented, which are still in place today. The WAP spent a majority of its Recovery Act funding by 2013, with an estimated 28 TWh of energy saved between 2009 and 2019 due to the efficiency improvements on over 800,000 buildings (Varro, 2020). Elsewhere, the Smart Grid Investment Program installed 16 million smart meters in public and private buildings between 2009 and 2016. Between 2009 and 2010 alone, over 13 million residential energy efficiency tax credits were claimed under the Residential Clean Energy and Energy Efficiency Tax Credit (Varro, 2020).

9.3.2 The main drivers for the introduction of the PACE scheme

In this section, the main drivers and key actors participating in the policy-making process that resulted in the adoption and implementation of the PACE scheme are discussed. As noted earlier, the building sector is challenging due to the multi-layered governance structures which regulate construction, remodelling, and energy standards.

First, this section discusses action at the local level to decarbonise buildings, including an overview of initiatives taken by local leadership, including the U.S. Conference of Mayors, and the international political and legal environment which enabled that action. Next, an overview of the policy development process is presented, along with an outline of the policy mechanism itself, including key actors and the actual process of applying for a PACE loan. Section 3.3 concludes with an outline of the financing structures which make the PACE programme unique, including a brief overview of industry reactions to the programme.

Local action to decarbonise the building sector

The George W. Bush administration's decision not to ratify the Kyoto Protocol was met with disappointment at the state and local level. Prior to the Bush administration, states had already emerged as the most proactive public actors in US climate policy. This accelerated under a federal government opposed to reducing GHG emissions in any meaningful way (Rabe, 2007). California exemplified this trend, with the state passing a suite of policy initiatives aimed at reducing GHG emissions. For instance, Governor Arnold Schwarzenegger passed the Global Warming Solutions Act (Assembly Bill 32, or AB 32) in 2006. AB 32 pledged California to limiting 2020 emissions to 1990 levels, strengthening the state's position as a national leader in climate policy (AB 32, 2006).

Simultaneously, ambition existed at the local level to engage with GHG mitigation. In March 2005, nine mayors, representing over 3 million Americans, signed an agreement to take definitive action to reduce their emissions in their cities (Griscom Little, 2005).[37] This culminated in the signing of the Mayors Climate Protection Agreement three months later (Benton-Short & Short, 2013). The Agreement committed participating cities to take the following three actions:

- Urge their respective state governments and the federal government to reduce GHG emissions by at least 7% below 1990 levels by 2012, in line with what was suggested for the United States under the Kyoto Protocol.
- Urge the US Congress to establish a national emissions trading system.
- Strive to meet or beat the Kyoto Protocol targets through measures such as anti-sprawl land-use policies, clean energy, and promoting energy efficiency in building code requirements (The U.S. Conference of Mayors, 2005).

The push for climate action among local governments was largely a result of their closeness to citizens, who often advocated for much stronger climate legislation. This was the case in Berkeley, a city near San Francisco. In 2006, Berkeley voters endorsed an 80% reduction in emissions by 2050. This vote eventually led to the adoption of the Berkeley Climate Action Plan in 2009 (City of Berkeley, CA, 2009). Berkeley voters' support for strong climate action translated into proactive local government policy.

Around the same time as Berkeley voters showed their support for significant emissions reductions, a group of homeowners had petitioned the city to have all their utility lines placed underground. This was achieved by the city paying the upfront cost, which was then repaid incrementally by the homeowners through their property tax bill (DeVries, 2013). The mayor at the time, Tom Bates, and his chief of staff, Cisco DeVries, promoted applying a similar model to clean energy and energy efficiency installations, thereby setting in motion what ultimately became PACE (DeVries, 2013).

Policy adoption and development

Within this same framework and to meet the emissions reductions targets, Assembly Bill 811 (AB 811) was approved on July 21 2008 (Levine and Ball, 2008). AB 811 was essential because it provided a new financing option for permanent renewable energy and energy efficiency improvements on developed properties. By authorising cities to establish programmes that offer the opportunity to finance renewable resources secured by contractual property assessments to fund these improvements, AB 811 provided property owners with financing alternatives when available financing and costs of such improvements might otherwise be prohibitive. On this basis, property owners could finance voluntary energy

[37] As of 2022, 1,066 mayors have signed the Mayors Climate Protection Agreement (The U.S. Conference of Mayors, 2022)

efficiency renovations covered by loans from their local municipalities that could then be repaid through a property tax assessment rather than a traditional loan payment.

This was the basis for the creation of the Property Assessed Clean Energy (PACE) programme which allowed homeowners to invest in energy efficiency, renewable energy improvements, or water savings without upfront payment. The programme started in 2008 in Berkeley, California. Since then, it has been applied in different versions in 38 US states. The programme applies to both residential and commercial properties. It is composed of state laws and federal guidance from the Department of Housing and Urban Development (HUD) and the Internal Revenue Service.

In the programme, a special tax assessment is made on the estate owner's property tax bill in lieu of traditional mortgage or debt repayment schemes. In this way, the owners can make investments without needing the high initial capital required for purchases. As a special assessment, the responsibilities remain linked to the property where the improvements were made and not to the owner. Investments are to be repaid through energy savings generated by the building upgrades, usually over a 10 to 20-year period. The main requirements and necessary conditions are established in each state according to local legislation between the owner, the contractor, and the municipality.

The programme is applied in commercial buildings (C-PACE) and residential buildings (R-PACE). For each type of project, rules and legislative arrangements are needed to enable the renovation actions to be carried out.

Key actors and stages of the PACE programme

The main actors involved in the programme can be classified as private or governmental, and they interact during different stages of the programme (**Figure 9.1**). First, the state legislature needs to allow the county or city to create a type of assessment district. Second, the state adopts technical standards, manuals, procedures, and local specifications based on nationally accepted standards. The property owners voluntarily sign up for financing and installation of energy or water projects on their property. They can choose the service providers that suit the project type and prices better. Capital providers can be from various sources and need to be registered officially in order to provide the financing for the property owner.

Figure 9.1: Main actors involved in the PACE structure.

In addition, other actors are involved in monitoring and supporting the programme, such as consumer protection and transparency groups as well as external energy auditors. The Trade Promotion Authority (TPA) ensures that all financial, technical, and legal requirements are met during the programme.

Eligible projects include investments that improve roofing, wall and window insulation, solar panels, and changes in lighting, air conditioning and heating, among others. One condition for eligibility as a PACE project is that the investment must remain in the property. An example of an investment that cannot be financed would be a household appliance such as a fridge or washing machine. Due to the nature and variety of proposed projects, the Project Developer will be required to assess, on a case-by-case basis, the compatibility of potential clients with the programme's characteristics.

Projects include different stages and phases. The typical stages are described below:

- **Application.** The process of obtaining resources through the programme begins when a landowner applies for funding.
- **Evaluation.** Once an application has been received, the programme representatives will work with the landowner or their representatives to gather the necessary elements to verify its eligibility. As part of this verification process, third parties are contracted to conduct energy audits, seismic or windstorm risk assessments or other studies, as appropriate, to determine the eligibility of the subproject. Once all elements have been received, reviewed, and approved, the programme representative will issue a term sheet outlining the terms under which

programme financing will be provided and other conditions precedent to closing. The homeowner may choose to sign the term sheet and proceed with underwriting the debt, negotiate the items on the term sheet, or decline to participate in the programme.

- **Approval**. Once the homeowner has signed the term sheet, all pending and necessary verification tasks will be performed to obtain final approval from the Program Administrator for the proposed financing.
- **Documentation.** Once the financing is approved, legal counsel will draft the various legal documents evidencing the structure and terms of the financing.
- **Closing.** Once the financing documents have been formalised, the contracts establishing the relevant tax lien are registered with the public land registry of the locality where the property is located.
- **Post-closing.** After payment of all fees, issue costs and capitalised interest, the remaining funds will be available to the owner. Upon completion of the installation of the sub-project(s), the owner must file a completion deed, as specified.

Financing of the investment

The PACE programmes are financed in two main ways: via bonds and through direct funding (**Figure 9.3**). These methods can vary depending on whether the property being renovated is commercial or residential. State and local law determine what financial entities are allowed to participate in PACE funding while establishing the legal framework under which PACE bonds are issued. PACE districts, land secured legal entities, are granted the right to issue PACE bonds and foreclose on delinquent PACE assessed properties. These limited obligation improvement bonds ("revenue bonds") are often, but not always, sold to a PACE administrator, a third party responsible for executing the PACE programme. The PACE administrator then uses the bonds to finance improvement projects. Once bond volume becomes sufficient, administrators can securitise the PACE bonds and pass them along to the secondary market, providing cash flow to invest in purchasing more PACE bonds (Bellis et al., 2017).

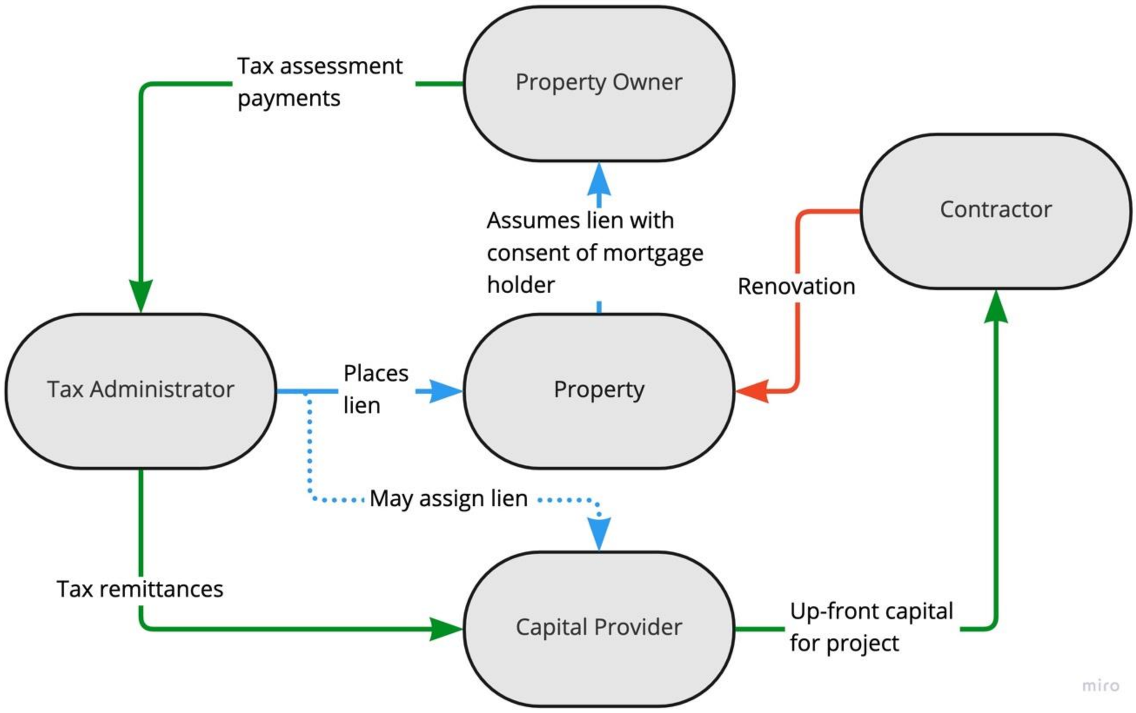
The loans that administrators or other lenders approve are issued with no money down and paid back through assessments in the form of a line item on the property tax of the building. Repayment plans can range from five to thirty years and carry a range of interest rates. Because the loan is only repaid through specific property tax assessments, debtors pay only once or twice a year with their normal property tax bill. To secure the loan, the local government places a lien on the property, granting them the right to foreclose on the property to recover funds should the loan become delinquent. This also means that, unlike most other loans, a PACE loan lives with the property rather than the individual. Securing the loan through a lien dramatically changes the typical criteria lenders gauge potential debtors.

Instead of looking at credit score or ability to pay, PACE lenders look at how much equity a debtor has in the building and how consistent they have been with their property tax payments. This issue is especially pertinent to residential PACE customers in low-to-middle income areas who may be persuaded to sign on to PACE loans that they cannot reliably pay for. In California, concerns about consumer protections and the potential for unsound lending practices had led to some PACE reform. The state now requires household income to be considered when assessing a candidate's application for a PACE loan.

As part of the PACE programme, governments are responsible for the placing of liens on the borrower's property and the collection and remittance of funds back to the lender from the PACE property. Should the borrower become unable to pay their property tax bill and become delinquent, the lien allows the lender to hold the property in question in lieu of payment. Governments often place senior liens on participating PACE properties, meaning that should the government need to recover funds, it has priority in reimbursement, even over mortgages. This controversial aspect of the programme has led Fannie Mae and Freddie Mac, two of the nation's largest secondary mortgage owners, to advise against providing mortgages to buildings with PACE liens.

The timing of when the liens are placed and when funds are disbursed to the service providers (contractors) varies from state to state and can create significant issues. Some states hold funding until the project has been completed, forcing contractors to either front the total cost of the renovation or the building owner to secure bridge funding. Either of these things may be exceedingly costly or impossible, reducing the use of PACE. Other states refuse to place a lien on the building until the project is completed. This can make certain investors nervous and dissuade investment in PACE projects (Leventis et al., 2018).

Figure 9.2: Structure and flow process of PACE.



Source: Reproduced from Leventis et al. (2018).

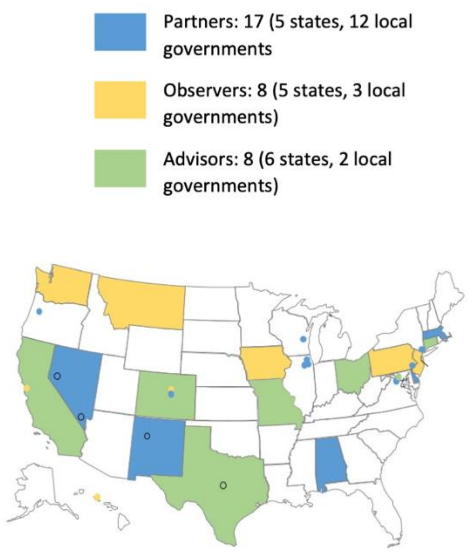
Commercial PACE programmes (C-PACE) are funded both with limited obligation improvement bonds (revenue bonds) as well as direct funding from a variety of lenders. Direct funding for commercial projects has increased over the years in large part due to the additional costs associated with the issuance of bonds. When bonds are employed, to minimise the proportion lost to fees they are typically for projects that exceed USD 500,000. Single-issue bonds can be produced for large individual projects, or many smaller projects can be pooled together and funded through a single bond issuing. The pooling process can significantly delay funding as the issuer must first gather a requisite project volume before disbursing any funds. C-PACE loans are secured through senior liens, but because of the much larger amounts of money involved, PACE lenders typically have better relationships with mortgage providers, which helps assuage concerns around the lien (C-PACE Alliance, 2019; Leventis et al., 2018).

Residential PACE (R-PACE) programmes are funded primarily through bonds, mainly because the amounts being lent are not large enough to attract private sector interest and appear risky. The Department of Energy advises that states develop loan loss reserve programmes to protect lenders from missed payments and help reduce the risk of investing in PACE (U.S. Department of Housing and Urban Development, 2016). The only state to follow this advice, California, had, as of 2017, never actually used funds from it. Other issues include the hesitancy of mortgage lenders to approve loans for homes with a PACE lien. This hesitancy is exacerbated by an unsteady message from the Federal Housing Association (FHA) that in 2017 announced it would no longer insure new mortgages on homes with PACE assessments. This was reversed in 2021 but came with new regulations surrounding how the liens are structured (U.S. Department of Energy, 2022b).

9.3.3 Evaluating PACE programme's impact

There are currently PACE-enabling legislation and legislatures in 33 states and the District of Columbia (**Figure 9.3**). Commercial PACE (C-PACE) programmes are active in 20 states plus the District of Columbia, whereas R-PACE programmes are offered in California, Florida, and Missouri (U.S. Department of Energy, 2016b). California continues to be the state with the highest investment, fallow by Ohio and Minnesota (PACENation, 2022).

Figure 9.3: Distribution of the thirty-three states and actors participating in the C-PACE programme.



Source: PACENation (2022).

Since the beginning of the programme, its impacts on the environment, economy and beneficiaries have been evaluated. There is a majority agreement that the benefits of the programme outweigh the negatives (Oliphant et al., 2020).

Although the benefits vary from state to state, the main results include increased investment in energy efficiency and renewable energy generation projects such as solar, increase in new green jobs, environmental benefits, reduction of greenhouse gases, reduction of carbon intensity in buildings, economic and energy savings, among others.

Commercial PACE

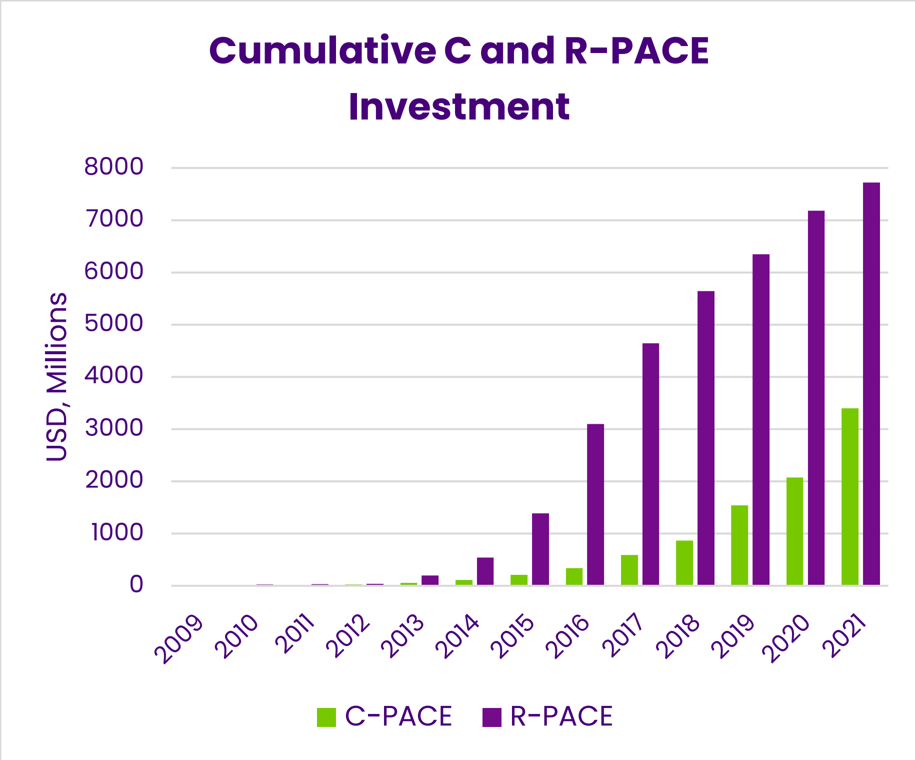
Despite the economic impact of the pandemic in the USA, data have shown that the Commercial-Property Assessed Clean Energy loan programme (C-PACE) was used in businesses heavily affected by the pandemic, such as hotels and entertainment venues. In fact, the hospitality sector has used C-PACE financing the most so far, followed by office and retail, according to trade organisation PACE Nation (Lydersen, 2021).

After a continued increase since 2018, the combined investment in renovation driven by the PACE programme amounted to USD 3.4 billion. In total, from 2009 to 2021, there have been 2760 commercial projects funded under this project and over 42,000 job-years created. Considering the type of projects from the total, 55% represent energy efficiency, 17% renewable energy, and mixed projects account for 15%, and resiliency for the remaining 3%. Nationally, 14% of the investment is approved for new construction, showing that there is still a preference for renovations and improvements in existing buildings (PACENation, 2022).

Residential PACE

Uncertainty in the mortgage market and the underlying property assessment have made it difficult for homeowners to sell their homes, forcing them to lower their asking price to compensate for the remainder of the PACE loan incurred by the new homeowner. Although the loans are smaller and face many difficulties, R-PACE programmes nationally have a much higher loan volume than C-PACE (**Figure 9.7**). This is despite R-PACE programmes only operating in three states: California, Florida, and Missouri.

Figure 9.7: Cumulative annual investment (in USD millions) of C-PACE (green) and R-PACE (blue) programmes.



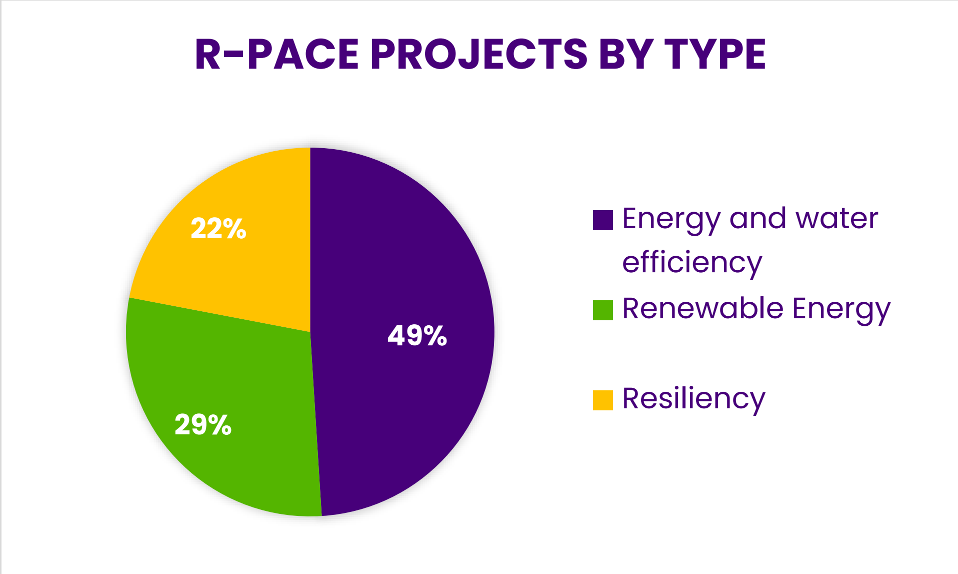
Source: PACENation (2022).

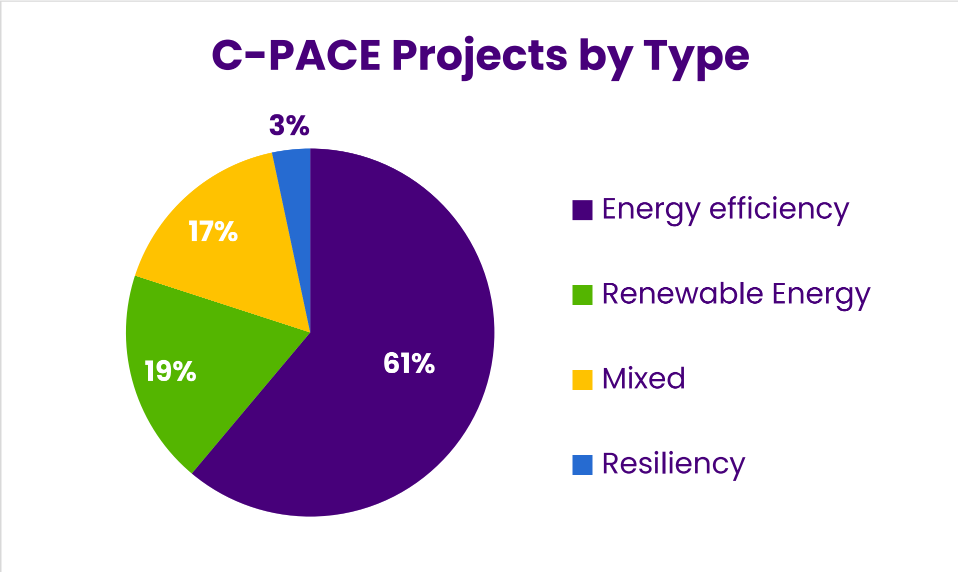
After a rapid increase, investment in residential construction under the PACE programme reached USD 7.7 billion. More than 323,000 home upgrades have been completed in PACE states. Although the residential programme is only available in three states, the number of investments exceeds the number of commercial investments. This has resulted in the creation of approximately 117,000 new jobs per year (PACENation, 2022).

In terms of preference by type of project, the distribution corresponds to 49% energy and water efficiency, 29% renewable energy, and 22% resilience (**Figure 9.**). For residential PACE, investments for resilience are considered to prepare buildings for events such as earthquakes, hurricanes, floods and other extreme events.

A recent study that analysed the R-PACE programme in California from 2009 to 2017 found that PV produced large reductions in grid electricity consumption, with an average of 69% of household consumption. According to calculations, all projects installed before 2019 would generate annual reductions in electricity consumption from national grid by 506 GWh because of solar PV. In addition, gas savings are estimated at roughly 58 GWh, which is equivalent to the consumption of 4700 households for gas, and 74,000 households for energy efficiency and PV energy (Deason et al., 2022).

Figure 9.8: Distribution of project types across the C-PACE and R-PACE programmes.





Source: PACENation (2022).

Despite the programme's successes, key elements of the programme have been criticised for creating unintended negative consequences for low-income households. Due to a lack of understanding of the programme's financial implications and/or a poorly executed initial energy audit, unnecessary investments are often made that do not achieve sufficient cost savings (Polsky et al., 2021). This is revealed to cause tax increases that some homeowners cannot afford and consequently places their property at risk of foreclosure. In some instances, contractors have acted with malicious intent. If elements of this programme are to be replicated sustainably, these issues must be addressed, with one potential solution being its application only to commercial buildings or excluding low-income households, which are then addressed via a separate programme.

9.3.4 Discussion

The use of on-tax financing tools in general, and PACE-style programmes in particular, to finance energy efficiency and renewable investments in Europe could bring similar benefits to those already observed in the US (UpSocial, 2021). This has already been identified by the EU, and a pilot scheme was developed within the framework of an EU programme.

The EuroPACE project lasted three years and was financed by the European Union in the framework of the Horizon 2020 programme. Between March 2018 and August 2021, it supported the renovation of housing and commercial buildings in the city of Olot in Spain, with an investment of EUR 1.87 million, resulting in the avoidance of 196 MtCO_2e and the creation of new jobs (CORDIS, 2021).

The programme goal was to make home renovation simple, affordable, and reliable for their owners, bringing effective and affordable financing through people-centric implementation. The programme had three main pillars:

1. Market study and feasibility analysis within the EU.
2. Development of EuroPACE in Girona, running the first programme in the city of Olot.
3. Assessing the possibility of scale to the rest of Europe, sharing the results and developing programmes in four European cities.

The project carried out a study covering the EU countries, in which the suitability for implementing the EuroPACE programme was assessed by employing a scoring system. According to the results, the most adequate were Austria, Belgium and Romania, and the least adequate in the list were Croatia, Malta and Cyprus. An important finding was that there is a great variety between countries and even more so between municipalities. In addition, the market is highly different between all states.

The main element in the programme's design was adapting the financing scheme to municipal taxes (a mechanism known as on-tax financing) and was modelled after the PACE programme implemented in the United States (CORDIS, 2021; UpSocial, 2021). After multidisciplinary analysis and advocacy with various institutions, a legislative change was achieved that facilitated decarbonisation of the building sector in each region the programme was implemented. There are many differences between EU countries in terms of local legislation, so if legislation is to be implemented, it must be adjusted per country to enable it to work properly.

Finding a legal solution to implement a programme like PACE could be a challenge to move any on-tax financing structure forward within Europe. However, the EuroPACE model represents a significant step towards overcoming this hurdle because it has already built a model for implementation in the EU, conducting feasibility research and implementing changes to tax legislation in its pilot areas using the PACE model adapted to EU circumstances (CORDIS, 2021).

The PACE programme as implemented in the United States offers further evidence for the success of the PACE model in supporting building renovations. The EuroPACE programme, which was modelled after the American PACE programme, saw short-term success as well (CORDIS, 2021). PACE as implemented in the United States shows that it is possible to shift the financial outlook of the building sector into the longer-term, making energy renovation loans an attractive portfolio asset in the private sector and offering surety to the public sector that on-tax financing can be successful. The PACE programme highlights the critical role that local governments play in de-risking private finance, and how public-private cooperation is key to developing financing mechanisms which work for building decarbonisation projects (Rose & Wei, 2020; World Green Building Council, 2022).

Both of the US and European PACE models highlight that policies addressing financing in the building sector need to be flexible in order to address the situation in each state, town, or region where the model is being implemented. As part of a suite of policies, PACE financing models have the potential to help overcome the financing barrier and push the renovation rate upwards. The success of the EuroPACE pilot programme and the ongoing results from the PACE programmes in the United States signal that this model can be helpful in developing policies to meet the EU's decarbonisation goals.

9.4 Case study 2: the Ithaca Green New Deal programme

In the second case study selected, the Ithaca Green New Deal from the US was chosen for the strong emphasis the plan had to accelerate the decarbonisation of buildings at a city and municipal level intervention, despite slower action at higher level of administration. It is of special interest for the city's ability to try developing a funding mechanism to make the costly transition financially feasible. The case study opens with Section 9.4.1 which introduces what the Green New Deal is and how it came to fruition as well as discussing the investments it resulted in. Section 9.4.2 explains the policy development centred around the funding needs and design, structure, and phases, which are then evaluated in Section 9.4.3. Lastly Section 9.4.4 closes with a discussion and extraction of the lessons learn from Ithaca's experience.

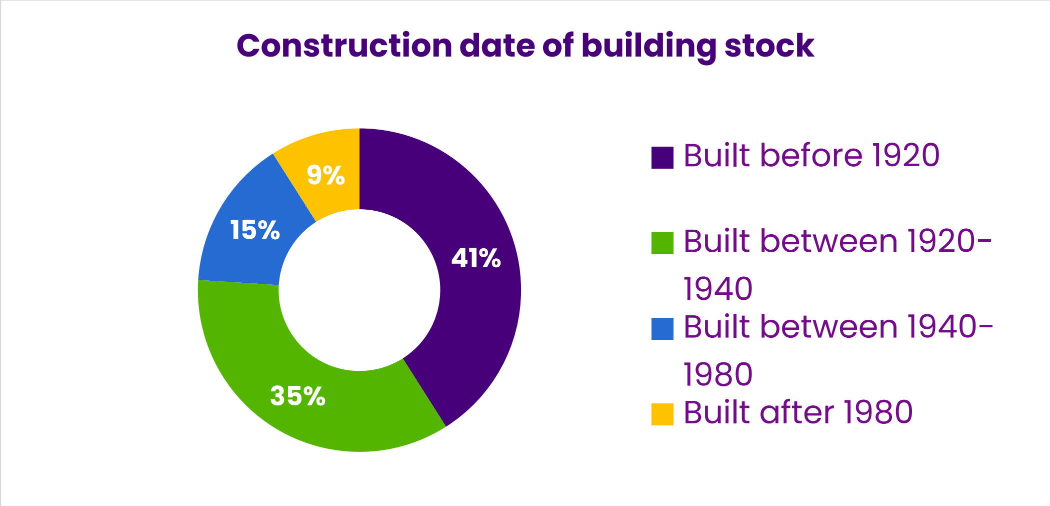
9.4.1 Context and background

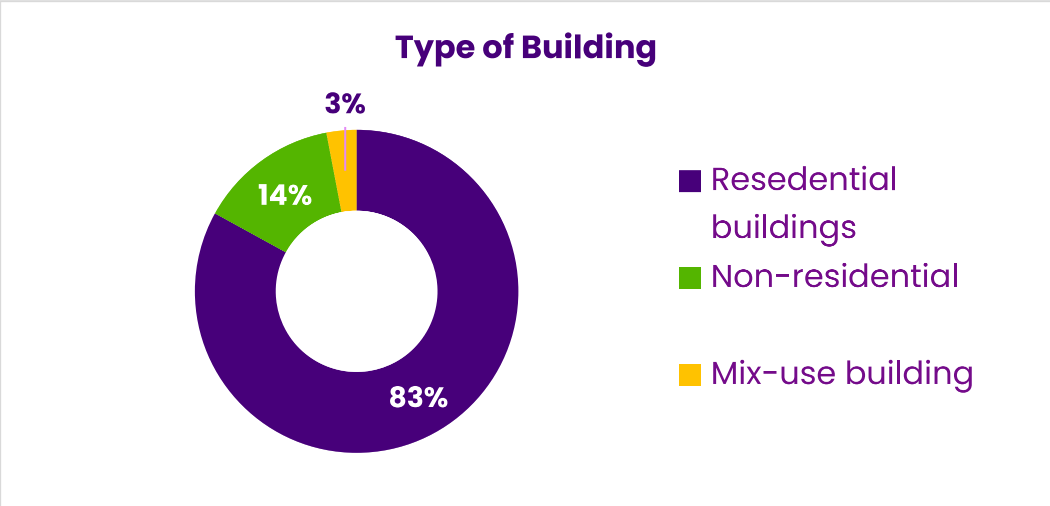
Ithaca's building sector circumstances

The city of Ithaca is located in New York State, about 360 km northwest of New York City. Many of the city's 6000 buildings are nearly a century old (**Figure 9.7**); 41% of Ithaca's buildings were constructed before 1920, and 76% were built before 1940, the majority of which (83%) are residential, whereas only 14% are commercial (Department of Planning and Development, Sustainability Office, 2021). Almost all lack efficient building envelopes and rely on traditional, inefficient heating and cooling systems. As a result, buildings account for 40% of the city's annual GHG emissions (Rosenbaum, 2021a).

In 2019, the Ithaca's Common Council approved the Ithaca Green New Deal (IGND) which pledged the city towards completely decarbonising by 2030. To achieve this goal, the city government adopted the Energy Efficiency Retrofitting and Thermal Load Electrification Program (EER-TLE) in November 2021. The bill authorises the use of USD 100 million in investor commitments to begin retrofitting its building stock (Sustainability Office, Department of Planning and Development, 2021).

Figure 9.4: Breakdown of building type and construction date in the building stock.





Source: Department of Planning and Development, Sustainability Office (2021).

Typically, undertaking these retrofits is solely at the expense of the property owner. Greater energy efficiency, especially in the building envelope and heating, ventilation, and air conditioning (HVAC) system, can significantly lower monthly utility bills (Gulati, 2012). However, the upfront costs act as a deterrent to many property owners, even if they would save money over time. In the US, some additional forms of finance exist, such as the PACE mechanism described in earlier section, but they require a lien on the home and may have prohibitively high interest rates.

The introduction of the Ithaca Green New Deal

The Ithaca Green New Deal was proposed within a national context, where the Green New Deal (GND) was firmly on the political agenda. Reminiscent of Franklin Roosevelt's New Deal, which was a series of policies and public projects that stimulated the US economy in the

1930s, the GND aimed to cut emissions while creating jobs and stimulating the economy (Friedman, 2019). Although the bill failed to pass Congress due to widespread Republican opposition, it contributed to the national conversation around climate action and equity and empowered advocacy groups, such as the Sunrise Movement, to push for greater change in their localities (Friedman, 2019).

Sunrise Ithaca, comprised mainly of high school students and young adults, advocated for the GND in Ithaca through protesting and raising community awareness (Aguirre-Torres, 2022a). Ithaca was already one of the most liberal communities in a reliably liberal state, but the national conversation around the Green New Deal opened space in the discourse for advocacy groups, like Sunrise, to push for more aggressive climate action.

In 2019, former Mayor Svante Myrick announced a Green New Deal package for Ithaca that committed the city to climate neutrality by 2030, while advancing equity for Ithaca's economically and socially disadvantaged population. At that time, Ithaca was the first city in the United States to commit to climate neutrality on such an aggressive timeline (Olick, 2022).

Although the city lacked a concrete action plan, the adoption of the Ithaca Green New Deal (IGND) provided the stimulus required for the city to begin generating ideas and attracting individuals willing to help achieve the climate neutrality by the 2030 goal. However, efforts were stymied for much of 2020 as the city government coped with the public health and economic crises brought on by the COVID-19 pandemic. The pandemic, which disproportionately created hardship for disadvantaged groups, highlighted the central place that equity and social justice would have to take in the IGND. In 2021, the city refined its articulation of the programme, describing it as:

> "a people-first, socially driven economic strategy, seeking to elevate social capital and to guarantee equity, justice and sustainable prosperity to all members of the community. It represents the City of Ithaca's response to climate change and social injustice; a new global imperative demanding urgent action, collaboration and the democratisation of community engagement." (Department of Planning and Development, Sustainability Office, 2021).

To realise this vision, the city created the Director of Sustainability position and, in March 2021, hired Luis Aguirre-Torres. Aguirre-Torres, an entrepreneur with a background in electrical engineering, had experience working on climate issues with the Obama administration and earlier with the Schwarzenegger government in California. Ithaca's Office of Sustainability is contained within the larger Department of Planning and Development and is primarily responsible for shaping the implementation of the IGND, which resulted in the EER-TLE programme (Sustainability Office, Department of Planning and Development, 2022). Large policy decisions need to be approved by the Common Council, an elected body presided over by the mayor and populated by ten representatives across Ithaca's five wards. The

Common Council rarely generates new policy proposals for the IGND, acting instead as an approving body (Town of Ithaca, NY, 2022).

Decarbonisation of the building sector was an essential component of achieving climate neutrality by 2030. In order to be effective in facilitating voluntary retrofits while advancing climate and economic justice, funds needed to be offered broadly, to have low interest rates, and to stay off the balance sheets of municipalities (Aguirre-Torres, 2022b).

9.4.2 Policy development

Programme funding

The City of Ithaca has an annual budget of USD 80 million, far too small to finance a programme that was projected to cost around USD 600 million (Aguirre-Torres, 2022b). Municipalities frequently finance projects they cannot afford outright through the issuing of bonds. However, it is illegal in the State of New York for municipalities to issue revenue bonds — bonds whose returns are tied to a particular entity, such as a toll bridge. General obligation bonds are available, but these bonds are guaranteed by the income of the municipality rather than the income generated by a particular project, making it more difficult to minimise liability for the issuer and potentially placing the city's credit rating at risk (Aguirre-Torres, 2022a).

Green banks, which are financial institutions established by some governments to help fund green energy initiatives, are a potential funder for small to mid-sized municipalities with limited means to execute capital-intensive projects. However, they were unable to fund Ithaca's renovation programme. The New York Green Bank (NYGB) was originally established to fund solar projects and considered heat pumps and other housing upgrades as a separate asset class that they could not account for. The NYGB also hesitated at dividing the retrofits in stages, arguing that the entire city would have to be ready for retrofitting all at once for it to be feasible (L. Aguirre-Torres, personal communication, June 27, 2022).

Private finance was a third option for covering the costs of the IGND. It offers a much greater level of flexibility in how the funds are managed, opening opportunities for incentives and risk-mitigation strategies to lower the cost of capital to a workable rate. However, typically, loans to individual property owners for retrofits are deemed risky, which makes them more expensive in the long term and gives them the potential to undermine the equity aspect of the IGND (L. Aguirre-Torres, personal communication, June 27, 2022). In exchange for higher rates, private financing can shift liability away from a government or other entity.

By including the entire Ithaca building stock in the project and pursuing other risk-mitigation techniques, Ithaca was able to secure USD 150 million in initial project commitments from two firms, BlocPower and Alturus. BlocPower is based in Brooklyn, NY, and is a technology company that specialises in energy efficiency retrofitting for residential homes. It offers its retrofits as a lease with no upfront costs and never places a lien on the home, making the retrofit process more accessible. BlocPower is financially backed by large investment firms, such as Goldman Sachs and Microsoft's Climate Innovation Fund (BlocPower, 2022).

Alturus is based in Boston, MA, and is a financing company that works with larger, corporate entities to identify and develop sustainable infrastructure projects. Similar to BlocPower, Alturus's project financing is based on off-balance sheet financing that allows large companies to commit to sustainable infrastructure projects without adding to their debt load. Alturus is partnered with Generate Capital, which has provided it with USD 600 million to deploy energy efficiency, on-site generation and storage solutions for its customers (Garcia, 2020).

Securing the investments of BlocPower and Alturus required risk-mitigation strategies beyond the portfolio diversification offered by committing the entire building stock. A major development in Ithaca's access to private capital was the establishment of a loan-loss reserve programme with the New York State Energy Research and Development Authority (NYSERDA). A loan-loss reserve programme protects lenders against late or missing payments, which greatly reduces the risk of investment in individual homes — a practice traditionally deemed risky. This is particularly important for a company like BlocPower whose primary income stream is lease payments (L. McNevin, personal communication, June 22, 2022). Should this income stream be disturbed, the company may face difficulty making interest payments, which could make it more difficult to get funding in the future. The loan-loss reserve is also essential for carrying out Ithaca's climate justice vision as it helps improve the credit risk profile for those that would not normally qualify for a loan (Eclipse & Davis, 2022).

On the basis of the cooperation between the City of Ithaca and private sector companies — primarily BlocPower and Alturus — with additional assistance from the State of New York and charitable funds, a public-private partnership was created, referred to as EER-TLE. The programme is primarily administered by BlocPower which was awarded the contract to act as programme manager by the Common Council of Ithaca (Walton, 2021). As programme manager, BlocPower receives and handles the capital being used to fund EER-TLE improvements. Funding comes directly from investors such as Goldman Sachs and Microsoft, who expect to be repaid with interest. Tasking the programme manager with handling the capital, removes liability from the city's balance sheet, reducing the risk that Ithaca is suddenly saddled with debt. The programme manager is also responsible for managing the various contractors required to execute the retrofits, negotiating bulk purchasing agreements with manufacturers, and communicating with the broader constellation of private companies aiding in the running of the programme (Department of Planning and Development, Sustainability Office, 2021).

The programme manager is legally bound by terms and agreements established by the City of Ithaca. Simultaneously, it maintains its responsibility to private investors to ensure favourable returns that compensate them for the use of capital while still creating profit for the company (L. McNevin, personal communication, June 22, 2022). To ensure that Ithaca is meeting its climate justice promises and obligations, the city has adopted Justice 50. This pledges 50% of all economic, social, and environmental benefits of the EER-TLE to go to disadvantaged and low and moderate-income (LMI) communities. Justice 50 has been operationalised by using demographic data to select homes for retrofitting priority and by creating a large enough loan-loss reserve to accommodate everyone who seeks out retrofitting.

To further lower costs, Ithaca and its private partners were able to take advantage of a wide range of incentives sprinkled throughout the state government, federal government, and utility companies. Utility incentives, such as heat pump rebates, greatly influenced project feasibility (L. McNevin, personal communication, June 22, 2022). Their ability to lower costs allowed more buildings to be retrofitted with the available capital. The City of Ithaca also offers incentives, e.g., paying BlocPower for every 200 homes they electrify, but that amount is small compared to the income they receive from lease repayments (L. McNevin, personal communication, June 22, 2022).

Functioning

The Ithaca EER-TLE programme addresses energy inefficiencies and fossil fuel dependency within the city's building stock in an attempt to drastically reduce emissions from the building sector and comply with Ithaca's 2030 goal of city-wide carbon neutrality (**Figure 9.8**). The EER-TLE programme aims to be accessible to all Ithacan residents and is dedicated to extending the benefits of carbon neutrality to disadvantaged communities.

Before any retrofitting is undertaken, the property will first be assessed by BlocPower or Alturus and then a recommendation will be made to the property owner. Special emphasis is placed on replacing gas appliances, installing heat pumps in the place of using inefficient, fossil fuel using HVAC systems, and addressing the building envelope, but other retrofits may include:

- Installation of energy recovery ventilation systems.
- Efficient and automated LED lighting.
- Electrical panel and installation upgrades.
- Load flexibility, grid-interacting, advance control systems.
- Solar PV and on-site energy storage systems.

- Bi-directional electric vehicle charging systems.

The city anticipates the cost of retrofitting for most residential building owners to be in the range of USD 3000 to 25,000. USD 5000 to 100,000 is expected for commercial building owners. (L. Aguirre-Torres, personal communication, June 27, 2022).

The city intends for the entire building stock to be assessed and retrofitted in two phases:

- **Phase 1:** 1000 residential and 600 non-residential units, with emphasis on LMI (low-to-moderate) communities.
- **Phase 2:** 3500 residential and 900 non-residential units, with emphasis on LMI communities.

Phase 1 accounts for the initial USD 150 million raised by private equity to fund the project. Should the EER-TLE programme hit its intended benchmarks, there is contract language in place for BlocPower and Alturus to increase their capital commitments by a combined USD 150 million, placing the total for the initial round of funding at USD 300 million. Retrofitting the entire city is expected to cost around USD 600 million, and so Ithaca will need to negotiate additional funding as it progresses through Phase 2 of the programme rollout.

The costs associated with the purchase and installation of all retrofitting materials are initially paid by the programme manager who then leases the improvements to the property owner. Leases are repaid monthly over ten to fifteen years at interest rates kept low by Ithaca's risk-mitigation strategies and supplemented with philanthropic support. For LMI communities, Ithaca hopes to provide retrofit financing with an interest rate that is close to zero percent. This will be made possible with a government fund that matches philanthropic donations and can be directly applied to property owners' lease payments. Aguirre-Torres estimates this fund would have to grow to around USD 13 million in order to cover all LMI residents in Ithaca (Eclipse & Davis, 2022).

Ithaca also plans to offer a loan and cash payment option to better serve the various needs of the full range of property owners. Some might prefer the ability to pay off a loan in fewer, larger instalments than commit to a ten to fifteen-year lease. Loans also include the possibility of paying for the principal of the loan up front, an option most leases do not have. Leasing may also have tax implications for Limited Liability Companies (LLCs) who own multiple properties, a common occurrence in the landlord-dominated residential housing market.

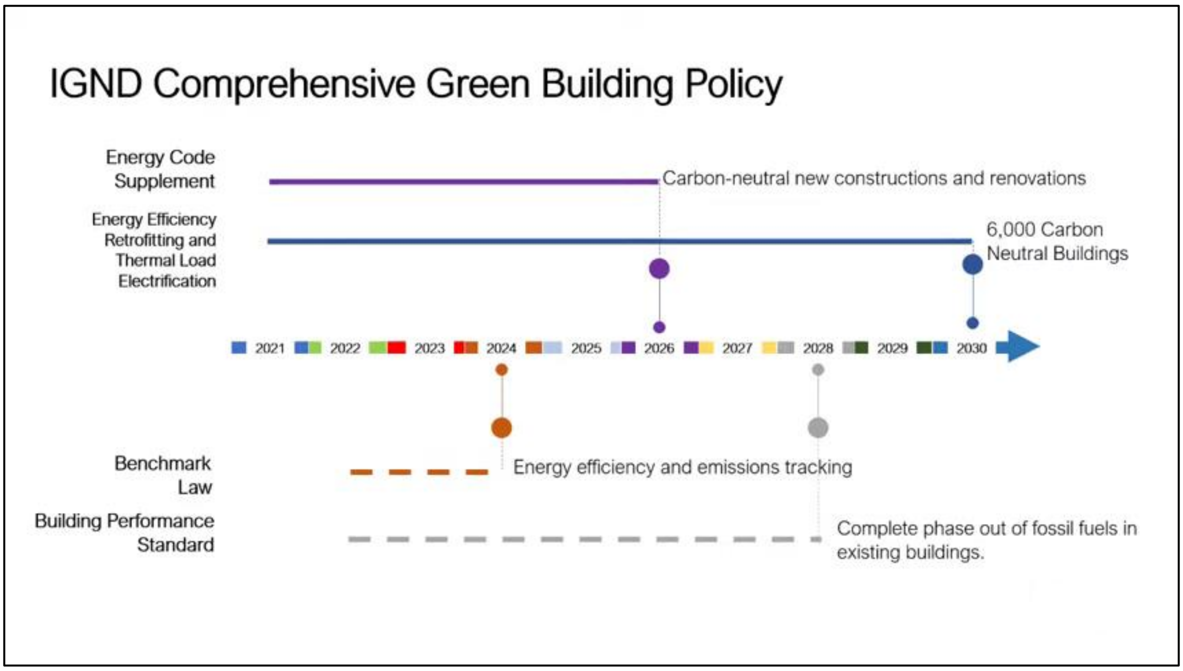
Unlike PACE, the lease/loan is not secured with a lien. The loan lives with the borrower and, in the case of a property sale, the debt burden would have to be transferred to the new owner. If this is not done, the initial borrower continues to be responsible for repayment (L. Aguirre-Torres, personal communication, June 27, 2022). BlocPower also cannot reclaim heat pumps or other materials used in the retrofit should a borrower become late or delinquent on their repayments. This leaves the loan essentially unsecured, a risk very few lenders would undertake without the robust risk-mitigation framework Ithaca has developed.

Ithaca plans to have most EER-TLE programme borrowers pay their leases back "on-bill". Instead of having to manage a separate bill, the monthly payment for the retrofit loan will appear as a line item on the utility bill. The programme anticipates that the increases in energy efficiency (especially from building envelope interventions and heat pumps) will result in savings that equal or exceed the monthly loan repayment. This will clearly show the customer the savings they have reaped from the programme and add a level of convenience that lowers the chances of non-payment and makes the programme more accessible.

However, because the City of Ithaca does not provide utility services itself, it will have to formulate a Community Choice Agreement (CCA) with the local utility, New York State Electric and Gas, to pursue on bill repayment. CCAs are legal agreements that empower municipalities to purchase energy for their residents outside of the traditional utility — for New York, this is a state-owned utility monopoly that typically has the first right to supply energy in its established region. CCAs allow municipalities greater choice on where their energy comes from. Ithaca hopes to use this new liberty to purchase green energy, moving them towards their climate neutrality goal (Jordan, 2022). As Ithaca would take on the traditional role of utility provider (most likely through a third-party servicer) it would be responsible for collecting payment, empowering it to add retrofit repayment charges directly to the bill. Depending on energy prices, this may be slightly more expensive or slightly cheaper than the original utility system, regardless of which, Ithaca will have to pay a fee for using the state utility's electricity infrastructure.

For residential properties CCAs are "opt-out", meaning that once the CCA goes into effect the entire residential building stock is enrolled unless they deliberately chose not to join the CCA. Commercial properties are "opt-in", meaning that the City of Ithaca will have to work with each small business owner to enrol their property in the CCA and thus be eligible for on-bill retrofit financing. Large commercial and industrial spaces are not allowed to join a CCA. For them to receive on-bill repayment, Alturus is working with a third party to help administer the billing. CCAs in New York State also have fairly strict rules concerning their use within disadvantaged communities. Ithaca will have to prove to the state that these communities are better off under the CCA or they will be flipped back to the state utility and a different repayment model will have to be worked out (L. Aguirre-Torres, personal communication, June 27, 2022).

Figure 9.5: The Ithaca Green New Deal building policy timeline of targets and benchmarks.



Source: Crandall (2022)

In order to maximise the effectiveness of the EER-TLE programme and achieve carbon neutrality within the building stock, the City of Ithaca plans to adopt a series of additional regulations to help incentivise energy efficiency retrofits and electrification. In May 2021, the city introduced the Ithaca Energy Code Supplement (IECS), an update to the existing energy code, which creates the phased introduction of climate neutral construction requirements for new buildings and major renovations. Buildings constructed after May 2021 will have to emit 40% less than NY state law requires. This will increase to 80% by 2023, and finally require all new buildings constructed after 2026 to be climate neutral (Lamb, 2021b). The Office of Sustainability is currently developing a benchmark law that would require the tracking of emissions within buildings, starting with the commercial building stock (Crandall, 2022). New building performance standards are expected to follow, allowing the city to fine buildings that do not meet the new standards. These performance standards would promote a phased approach, getting progressively more stringent until total climate neutrality is achieved.

9.4.3 Evaluating Ithaca's renovation push

Likely challenges

The EER-TLE programme's financing is predicated on reducing the cost of capital and taking advantage of economies of scale to reduce material costs. The programme's initial funding is secured, but rising interest rates or commodity prices, or tight labour markets could threaten

Ithaca's ability to acquire the further funding necessary to complete the project. Private equity is particularly sensitive to economic fluctuations and is often unwilling to invest in projects perceived to be risky in times of economic uncertainty. Current global supply issues are contributing to high levels of inflation, discouraging investment and increasing uncertainty. This makes it more difficult for Ithaca to secure additional funding at affordable interest rates, endangering the success of the programme.

The ongoing energy crisis has significantly increased natural gas prices, leading to increases in electricity costs in localities where it is a significant part of the energy mix. Upstate New York receives 26% of its electricity from natural gas production (US EPA, 2021) and the New York Public Service Commission has warned customers to expect an increase in their electricity bill of about 12% (CBS New York, 2022). Almost 18% of heating energy in New York is produced using fuel oils (Sönnichsen, 2021) which have not experienced such intense price increases, and this may discourage individuals from electrifying their properties, as any cost savings are diminished as electricity prices increase relative to heating oil.

Committing all 6000 of Ithaca's buildings to the programme was a necessary step in order to achieve favourable investment terms and advance the climate neutral goal, but in order to complete all the retrofits by 2030 it will require a trained workforce much larger than that which Ithaca can provide. Without a sufficient workforce, the programme might be slowed down considerably, delaying action and endangering Ithaca's ability to meet its 2030 goal. This includes workers all along the skill spectrum — from window installers to heat pump and solar technicians and even to municipal building inspectors (many of whom retired without replacements during the pandemic). BlocPower is currently working closely with other cities in the region to create a job development corridor that would train new workers and give them work experience in Ithaca doing retrofitting (L. Aguirre-Torres, personal communication, June 27, 2022).

There is also an intense need for in-depth and reliable data concerning socio-economic, demographic, and building stock information (L. McNevin, personal communication, June 22, 2022). This includes which buildings house LMI residents, which buildings are fuelled with gas and which with oil, and, more elementary, how many buildings there actually are. Having these data available allows companies like BlocPower to, using software, assess additional costs that might not be initially visible and develop a workable plan that has fewer surprises and roadblocks. A lack of these data makes it very difficult to achieve aggressive retrofit goals and few cities, including Ithaca, have this information in hand before contacting BlocPower.

74% of Ithaca's residents are renters (De Socio, 2022b), setting up an incentives dilemma between landlords and tenants. Many landlords do not live in Ithaca and some not even in the US (a significant share of housing in Ithaca is owned by Thai investors) (L. Aguirre-Torres, personal communication, June 27, 2022) making it difficult to contact them and persuade them to undertake retrofits on their buildings. When the landlord is not responsible for utilities payments, there is no incentive to pass savings realised from lower energy demand on to tenants. Some utility billing arrangements have the landlord paying for natural gas use and the renter charged with electricity use. In this instance, once a residence is electrified, an additional burden is placed on the tenant.

One way to address this would be for the city to help negotiate a new scheme. Should the renter already be paying the full utility bill (moving the cost savings incentive of retrofitting from the landowner to the renter) there may be opportunities to structure the lease agreement in a way that creates savings for the renter, but still compensating the landlord. This could be done through a rent increase or an agreement whereby both tenant and landlord contribute to repayments for leased energy efficiency equipment. In affordable housing, where the management company frequently pays the utility, there is the possibility for a rent reduction scheme based on electricity consumption. This variety of utility payment structures amongst renters challenges the ability for Ithaca to pass along the economic benefits to all residents, particularly those in disadvantaged communities, who are primarily renters. Solutions may exist, but currently they primarily centre around person-to-person negotiations, which may strain the programme's capacity and slow down the overall pace of project execution.

In order to further incentivise landlord participation, the Office of Sustainability has floated a tax abatement that could be placed on participating properties for two years while being coupled with a hold on new property value assessments for a couple more years, further extending the savings. By the end of the incentive period, landlords should have higher value property, lower utility costs, and have saved several years' worth of tax payments (L. Aguirre-Torres, personal communication, June 27, 2022). Ithaca also has regulatory tools it could use to ensure decarbonisation in its rental properties. It could draw on the already planned roll out of building emissions standards for commercial properties and mandate that no residence can be rented until it has reached a desired standard. This is well within the city's jurisdiction and mirrors how they plan to manage commercial spaces. This strategy worked well in Boulder, CO, where non-compliancy went from 37% to 14% after the mandate was put in place (Climate Analytics, 2022b).

9.4.4 Discussion

The programme has an intended start date of December 2022 so, at the time of writing, results with regards to energy demand and emissions impacts remain unclear. At the same time, the passage of the IGND itself represents a sea-change in the environmental movement in the United States and demonstrates potential strategies for other cities that wish to implement a decarbonisation plan. When discussing the passage of the IGND, Aguirre-Torres highlights how much of the progress was community driven (Shivaram, 2021). Beginning as a letter-writing campaign started by university students and pushed forward by youth advocacy groups like the sunrise movement, the IGND is a community affair (Lamb, 2021a). In a country where climate advocacy remains overwhelmingly white, Aguirre-Torres finds that having a whole-community-driven project like the IGND sees electoral success while at the same time, working with BIPOC-driven organisations like BlocPower, represents a "social restructuring" of the movement which may make implementing similar programmes more appealing and achievable to cities around the country (Shivaram, 2021).

Investigations of policy-making at the municipal level find that inherent barriers to innovative policy at the local public sector level include lack of budget, risk-averse cultures, and fear of experimentation due to being in the local public sector (Boyle et al., 2021). As the first municipality within the United States to take on a 100% decarbonisation mandate, the IGND could serve as a model to help other municipalities overcome those hurdles and implement their own GND-style mandates. The IGND offers an example of a novel funding mechanism which overcomes the issue of inflexible and underfunded city budgets by partnering with private equity, and is likely to act as a model for other cities (Rosenbaum, 2021b). Simply by being the first to implement such a plan, Ithaca goes a long way to reassure policy-makers around the country and provide a template for future action (Walton, 2022).

Looking to the IGND as a model for other municipalities, many expect the policy to be a test case for other cities, and the IGND's passage and progress has been closely watched at national and local levels (Shivaram, 2021). The decarbonisation effort has attracted close scrutiny in the local media in Rochester, NY, where local civil society members spoke at length about using Ithaca as a model for decarbonisation and the ways they could adapt Ithaca's plan to fit Rochester (Dawson, 2022). Amherst, MA, adopted a "Climate Action Adaptation and Resilience Plan" in June 2021, with language based explicitly on the Ithaca Green New Deal and climate goals (DuMont, 2022). While not as ambitious (Amherst's carbon neutrality goal is 2050, rather than 2030 as in Ithaca), it does represent an important step of setting municipal priorities with regards to climate action (Energy and Climate Action Committee, 2021). Amherst's Energy and Climate Action Committee has been consistently reviewing updates from Ithaca at their bi-weekly meetings, paying close attention to the development of the building decarbonisation efforts (Energy and Climate Action Committee, 2022).

Beyond the opportunities for learning lessons and building confidence in other municipalities, the IGND is already supporting technological developments, which may be more broadly applicable. Of particular interest is the ongoing development of software which uses machine learning to estimate retrofitting costs and future energy grid loads on a building-by-building level. In partnership with Cornell University's Environmental Systems and Circular Construction Labs, Ithaca hopes that the development of this building-by-building map will help to translate IGND goals into actionable data. Creating a so-called "digital twin" of Ithaca, the map and software will help the city identify electrification priorities and more efficiently allocate funding (De Socio, 2022a). Felix Heisel and Timur Dogan, the two architecture professors at Cornell behind the software hope that after building the map of Ithaca, both the software and lessons learnt can be sent on to other cities as they seek to decarbonise buildings at scale (De Socio, 2022a).

9.5 Lessons for the European Union

Decarbonisation of the building sector in the EU is slowed down by a number of barriers that build on each other. While the EU is well ahead of the United States both in terms of emissions intensity of its buildings stock as well as the complexity of its legislative framework, it can still learn from the PACE programme and Ithaca's approach to decarbonisation of the whole town to deal with these barriers.

The PACE system creates an opportunity to deal with the challenge of high upfront funding. The repayment of the loan should be made possible by the much lower energy bills resulting from the efficiency improvement. As a result, in a perfect situation, the combined costs of energy and repayment after the renovation should be equal or, preferably, lower than the energy costs before the renovation. After the loan is repaid, these costs decrease significantly. This approach makes it easier for property owners to deal with the financial barriers which slow down the renovation rate.

A contentious point of the PACE programme is the fact that the loan remains linked to the property where the improvements were made, instead of to the owner. As a result, the mortgage rate increases could also increase the risk of foreclosure. However, the improvements in efficiency, or installation of solar panels or a heat pump, tend to increase the value of the property as well, especially during times of high energy prices.

However, as mentioned in the case study, the PACE scheme has also been rightly criticised for creating negative consequences for some homeowners for whom the reduction of energy costs did not compensate the investment costs either due to poorly executed initial energy audit or unnecessary investments that may not achieve sufficient cost savings. Also, annual payments may constitute a significant burden to many property owners. These drawbacks would constitute less of an issue in the EU due to the much higher energy cost. Replacement of the annual payments with monthly ones would also make it easier to repay the loan with savings resulting from lower energy bills.

An additional lesson learnt from both case studies is the creation of an equivalent of a one-stop-shop, which allows homeowners to gain a better understanding of what measures can be implemented to increase a building's energy efficiency. In many cases, homeowners are not familiar with the existing options to reduce their energy consumption and their rate of return in terms of decreasing energy costs. Such one-stop-shops for home renovation targeting emissions reductions could address this knowledge gap and facilitate procurement of services. However, to avoid the problems witnessed in some cases of implementation of the PACE scheme, these advisory services should be provided by independent and trusted bodies, which would also facilitate execution of contracts and provision of funding. The lower the bureaucratic effort, the higher will be the uptake of the programme.

The form of the support for home insulation does play an important role. While PACE and IGND are financed mainly through loans, in the EU many homeowners may expect grants that cover some portion of the investment needed. However, the scope of the funding needed to decarbonise almost the complete buildings stock on the continent makes such an approach challenging in terms of duration as the amount reserved in the country's budget may run out after some months, resulting in a boom-and-bust trend for the construction industry (S. Richardson, personal communication, September 2022). To ensure financial sustainability of the support schemes that target home insulation, a combination of loans and grants should be found, with the share of the former in total financing decreasing steadily as economies of scale decrease the costs of the necessary equipment (e.g., energy-efficient windows, heat pumps, and solar panels). and the availability of the specialised workforce further decreases the costs.

While there are numerous sources of funding for home renovation in different EU member states, their functioning differs significantly in terms of scope, bureaucratic effort, and the level of support. The aforementioned problem of the resources running out within a matter of months requires the applicants — in most cases the property owners — to familiarise themselves with new requirements and application processes. This constitutes an additional non-financial barrier that discourages some property owners from initiating the application process. One of the main advantages of the PACE scheme is its recognisability: in the US states in which it has been implemented, property owners mostly know what to expect and how to apply in order to benefit from the programme.

In the EU, a support scheme for home renovation that could function according to similar criteria, using similar application processes, but with some differences regarding the balance between the grants and the loans, could reduce the bureaucratic effort of the property owners and the construction companies. However, such a pan-European programme would have to have clear criteria about which elements are harmonised and which can differ between countries, and even regions, using it. One of the variable elements could be the balance between the (preferential) loans and the grants in total investment cost. This balance could be influenced by the source of funding which could be coming from European, national, regional, or even private sources.

Learning from Ithaca's ambitious goal of decarbonising the whole town, such a programme could in fact make it much easier for ambitious communities to implement such a goal than was the case for Ithaca, which had to rely mostly on private funding. Instead of developing in a public-private partnership like the EER-TLE programme from the beginning, such cooperation could be developed within the framework of a European equivalent of the PACE programme, adapted to the European circumstances. Such a programme could benefit from a more balance mixture of public and private funding than was the case for Ithaca.

An often-ignored aspect of decarbonisation of the building sector is the emissions life cycle (S. Richardson, personal communication, September 2022). While replacing emissions-intensive materials, such as cement and steel, with low-carbon alternatives, would constitute a very small additional cost to the overall cost of construction or renovation, construction companies and property owners are lacking an incentive that could encourage them to take the life cycle of emissions of the buildings into consideration. For the few who do take this aspect into consideration, due to the lack of economies of scale, such materials are not available or only available at small quantities and high costs. A European equivalent of the PACE programme could mitigate this issue by introducing criteria that could make the level of support (e.g., the balance between the preferential loan and the grant) dependent on the uptake of low-carbon materials. A pan-European requirement of this type, the stringency of which could increase over time, could create the necessary market that would facilitate investment in their manufacturing.

9.6 Conclusion

Buildings continue to account for a high proportion of energy demand and emissions in the European Union, and this sector would need to contribute to overall emissions reductions in order to meet EU climate objectives. As the Russian invasion of Ukraine has led to increased pressures on fossil gas supplies in the EU, decreasing reliance on fossil gas in the building sector has become even more prescient. Additionally, with the launch of the European Commission's "Renovation Wave" initiative, strategies to decarbonise the building sector have come under renewed scrutiny as the Commission seeks to push the low renovation rate higher. The PACE programme and Ithaca Green New Deal offer compelling case studies in building decarbonisation, and this report has considered the implications of both.

Both case studies emphasise how challenging decarbonising the building sector can be due to the multi-layered regulatory environment, the large number of actors, funding concerns, and complex supply chains. These case studies have emphasised, however, that a core barrier to increasing the renovation rate is relatively simple — access to capital. Both case studies show that, regardless of the specific funding model, increasing homeowner access to capital to fund energy renovations up front will help move building decarbonisation efforts forward.

Although certainly not examples of perfect building decarbonisation policy, both the PACE programme and Ithaca's plan for the decarbonisation of the building sector offer a number of lessons that can accelerate decarbonisation of the EU's building sector. However, these lessons must be viewed with caution. The EU and its member states have an established legislative and financial framework that could facilitate the decarbonisation of the building sector. While its impact varies across member states, it allowed the EU building sector to become much more energy-efficient than the US equivalent.

At the same time, the variety of the support mechanisms for renovations targeting energy efficiency, combined with their ad hoc and short-term character in many EU member states, undermines their potential to reduce emissions from the building sector at a rate necessary to meet the EU 2030 and 2050 goals. It also makes it challenging to develop a construction industry and to educate the work force needed to fully decarbonise the EU's buildings stock by 2050 at the latest. Finally, the CO_2 emissions engrained in the building materials are rarely accounted for in the support mechanisms.

An EU programme, understood as a set of set of criteria and streamlined application and implementation process, offers the potential to mitigate these issues and increase the effectiveness and efficiency of the funding for energy efficiency in the building sector. The participation in the programme could be voluntary, as was the case in the United States. After all, the existence of an established application process and criteria could potentially save regions, communes, or even some countries the effort of "reinventing the wheel". More importantly, it would save the companies and the property owners the effort of having to learn yet another application process, with its accompanying paperwork. Channelling some of the available streams of funding through a programme that could be more recognisable all over the EU would also create the opportunity for larger flexibility of construction companies. Knowing the "rules of the game" in the framework of the programme across different EU countries and regions would allow them to support the homeowners in applying for the funding and potentially apply for the funding themselves. This could mitigate the challenge of the insufficient workforce, which constitutes the bottleneck for renovation in many EU member states.

10. Conclusions

Moving from incremental to transformative change in terms of the decarbonisation of its economy will have ripple effects well beyond the EU's energy sector. As realised during the ongoing energy crisis, energy dependency and high costs of imported fossil fuels have an impact on the quality of life of EU citizens, through high inflation rates and energy poverty. At the same time, the impacts of climate change on the EU became very clear, resulting in droughts, heat waves, and flooding.

The challenges of energy dependency and climate change can only be solved by moving towards renewable energy sources and decreasing the consumption of energy through energy efficiency. After incremental improvements of its policy framework, the EU needs to shift the gears of the transformation. Learning from the experiences of other countries and regions may help to reduce emissions, by stimulating innovation to transform the material base of our economy, rolling out the infrastructure for a resilient, climate-neutral economy, shifting investment and finance, and achieving integration of different sectors.

10.1 Stimulating innovation

There are some technologies that have the potential to help the EU decrease its dependency on fossil fuels and reach climate neutrality by 2050. Many need to be mainstreamed and commercialised, while others are yet to be developed. This requires different kinds of innovation.

Large-scale innovation is needed in many energy-intensive industries, including manufacturing materials and chemicals such as steel, plastics, ammonia, aluminium, and cement. Due to their technological processes, such projects require significant investment before the economic benefits materialise. Such investments are risky due to the novel character of the low-carbon alternatives to the existing high-emission manufacturing technologies. Public support for such investments is essential. Whether it is granted in the form of preferential loans, loan guarantees, or grants, the support needs careful consideration and adapting to the specific situation. Some grants could be needed for projects essential for decarbonisation, not to generate proceeds, but to repay a loan, even though they may reduce the number of projects that could benefit from the funding. At the same time, preferential loans or loan guarantees may be needed for projects that cannot be built using exclusively private funding due to potential risks for the lender and the resulting higher interest rates.

The US Department of Energy Loan Program demonstrates that preferential loans and loan guarantees may be an effective tool in the deployment of novel technologies. While in some cases the instrument was used to shore up industries affected by the 2008/2009 economic crisis, especially the car manufacturing industry, it has also led to the development of the solar and wind energy industries in the US. Most of all, it was one of the main drivers of Tesla's success in deploying Model S, with significant knock-on effects for the electric vehicle industry well beyond the US. Undoubtedly, the programme experienced some setbacks but, overall, the potential to instigate innovation, especially in areas very close to commercialisation but not fully realised, has been rather underutilised. This potential can be very well realised in the EU, especially at the time when high interest rates could be a barrier to innovative large-scale projects.

At the same time, many existing small-scale innovative solutions, that could significantly reduce emissions or help increase the flexibility and resilience of a decarbonised energy system, are not used in practice. This results from path dependencies — a situation in which certain technological processes were chosen in the past and are still being used, despite the availability of more efficient and lower-emissions opportunities. Adherence to these suboptimal solutions is caused by the high upfront costs of investments, lack of knowledge, and insecurity about returns on the necessary additional investments.

The SBIR and STTR programmes adopted in the US are a major step in mainstreaming new technologies, even if only a small portion of those apply to climate innovation. While the first two stages of the programmes focus on developing innovation by small and medium-sized enterprises — in the case of the STTR, in cooperation with research institutes — the third stage focuses on their commercialisation. Some aspects of these programmes, especially the comparatively unbureaucratic application process, focus on driving cooperation between small and medium sized-enterprises and research institutes, and the commercialisation and mainstreaming of the innovation, providing useful lessons for the EU's innovation framework. While some of these aspects are present in different innovation funding streams, they could be strengthened, especially against the backdrop of the ongoing energy crisis, in which low-carbon innovation, if mainstreamed, could significantly reduce energy consumption.

Decarbonisation of different sectors of the economy may also spur innovative business models. Electricity trading, so far the domain of large electricity utilities, may now also be mainstreamed, creating an opportunity for prosumers or energy cooperatives, as is the case for the participants in Australia's Virtual Power Plants and Community Battery networks. They can earn or save money not only by generating electricity, but also by shifting their energy consumption. They may also contribute to grid flexibility by integrating different sectors, e.g., transport and heating, through smart electrification. The US Low Carbon Fuel Standards allowed Tesla Motors to earn money from carbon credits long before it sold its first cars. Supermarkets and restaurants can earn credits that need to be purchased by oil companies, by installing charging stations.

This shows that innovation is an essential part of decarbonisation, not only as its driver, but also as its enabler. However, it requires an adequate policy framework and public funding to help the move away from the existing path dependencies. Climate-positive innovation impacts not only emissions reductions but also spurs new business models, economic growth, and reduces energy dependency. Public support for innovation should not be perceived as a cost, but as a smart investment.

10.2 Infrastructure for a resilient, climate-neutral economy

The nature of an infrastructure that will enable the EU to achieve climate neutrality is very different from that designed and constructed in the post-WWII era, when entire economies were powered with polluting fossil fuels. The rise of the personal vehicle that accompanied global economic growth has led to higher public investment in road infrastructure relative to railways. Centralised electricity generation led to the construction of electricity grids that did not have to take into account the variability of renewables and decentralised electricity generation. Reliance on imported fossil fuels gave rise to very expensive infrastructure projects in the form of pipelines, oil and gas terminals, and coal ports.

The clean infrastructure of tomorrow looks different: rail takes on a more important role in passenger and freight transport, with a greater number of high-speed connections across EU member states. The increasingly urbanised demographic landscape underscores the need for this transition, as higher population density makes rail both more efficient and financially viable. Increasing the share of renewables will still require high voltage transmission lines but with the focus on connecting areas with different energy sources that could complement each other. In addition, lower voltage electricity distribution grid will have to be strengthened to make it possible to accommodates the significant increase in electricity generation, especially with variable renewable supplies. Charging stations for electric vehicles will become commonplace and will steadily replace petrol stations. The need for gas or oil pipelines will decrease but in the future many might be replaced by pipelines transporting hydrogen or CO2.

These massive changes in the nature of the infrastructure, some of which will only be fully utilised decades from now, will require long-term, forward-looking policies and planning that takes into consideration different trade-offs. Such policies need to provide certainty to investors financing infrastructure development, and need to persuade consumers, who may be sceptical about cleaner transport and energy solutions, to embrace them.

The need for this integrated, long-term approach is best evidenced by Australia's Renewable Energy Zones, which demonstrate the need for planning grid infrastructure alongside renewable energy plants, especially when they are located far from demand centres. Likewise, a future that is reliant on variable renewable energy sources requires infrastructure that allows people and businesses to 'keep the lights on when the sun is not shining, and the wind is not blowing'. This comes in the form of procurement mandates for energy storage systems, and policy frameworks that allow for community batteries. Risk-averse investors, on the other hand, will not provide capital for projects without certainty that they will not be derailed by complex permitting processes. Finally, decarbonisation of transport cannot be achieved without incentivising consumers to make the switch from combustion vehicles to either rail or electric vehicles, or without providing greater convenience. Japan's HSR and through-train services demonstrate this, as do the reduced north-south train travel times in Switzerland due to newly constructed tunnels. Aggressive construction of EV charging infrastructure in Norway was part of a series of policies convincing citizens to make the switch from polluting vehicles.

10.3 Shifting investment and finance

One of the main challenges of moving away from a fossil fuel-powered economy to one relying almost exclusively on renewables and energy efficiency is the high upfront investment that this transformation entails. Funding such investments is challenging especially in the situation of high interest rates for loans. But after the investment was made, the running costs of renewables are very low and energy efficiency measures result in significant reductions of energy costs.

Public funding can drive decarbonisation of the economy in four ways: (1) by partly covering initial costs of projects necessary from the climate change mitigation perspective, to make them commercially viable, (2) by funding development of infrastructure needed for a low-carbon economy, (3) by supporting citizens and companies in dealing with the high upfront costs of investments needed for emissions reductions, and (4) by leveraging private funding to facilitate the mainstreaming of certain technologies. In many cases, these different goals may be achieved with one stream of funding.

Many low-carbon, innovative solutions, e.g., green steel installations, low-carbon cement, or the production and generation of hydrogen, are not commercially viable when forced to compete with fossil-powered alternatives. Public funding is essential to drive the commercialisation of these low-carbon solutions. The EU's Innovation Fund, like the US Department of Energy Loan Program, is essential to realise such projects. However, the scale and character of the funding, e.g., whether the funding is provided as a grant, loan guarantee, or preferential loan, depend on the project. Considering the significant level of funding needed for the transformation that will later result in correspondingly higher savings, public resources should be spent carefully, and windfall profits need to be avoided. This will increase the number of beneficiaries of public support and spur innovation.

As mentioned in the previous section, moving to a low-carbon economy will require significant changes to the infrastructure developed over more than a century. This will require tremendous spending from both government and private investors. While it will also generate savings in the long term, it is necessary to keep the goal of climate neutrality clearly in sight. This means that, even if many projects will not be profitable in the coming years or even decades, they may still be necessary to implement. The development of railways is one example. While certain expensive infrastructure projects in Switzerland could be difficult to justify from the economic perspective of a specific train connection, they fit very well into the strategy of moving away from road (and air) to rail, and establish Switzerland as an important element of Europe's railways architecture. The same applies to Japan, where several train connections are operated despite the need to subsidise them, due to the long-term vision of decarbonising the transport sector.

As mentioned in Chapter 9, the high upfront cost is one of the main barriers to investment in energy efficiency measures in the housing sector. Yet, such investments would not only reduce CO2 emissions but would also, in most cases, pay for themselves many times over, bringing the additional benefits of reducing energy poverty, job creation, and reduced energy dependency. The PACE programme adopted in many US states and the, for example, city of Ithaca's Green New Deal are successful cases where this challenge of the high cost of upfront investments has been mitigated. Despite some justified criticism of the PACE programme, the idea of replacing upfront investments with period repayments (e.g., annual or monthly) that could be covered from reduced energy costs, could accelerate decarbonisation of the building sector, which remains challenging because of those high costs.

Finally, public funding may leverage private funding, especially when it allows reaching the economies of scale that will make certain technologies commercially competitive. This is the case for subsidies granted for the purchase of electric vehicles or storage systems. As a result, the governments may increase the amount for climate action manifold. Rewarding installation of storage in South Korea with additional certificates, or carbon credits for installations of charging infrastructures in the framework of the LCFS, is an example of successful funding.

While the total amount of capital that is required to transition the EU to climate neutrality by 2050, is monumental, it can be decreased by eliminating barriers, and facilitating the harmonisation and simplification of planning, application, and administrative processes that may otherwise inflate the costs of projects and measures. Long-term targets, as in the case of China's DCP, increase investment safety and reduce the costs of finance for private companies. Shifting funding from fossil fuel investments, driven by phase-out policies, as was the case in Norway and Vancouver, Canada, could also open a significant source of additional funding that could be used for energy transformation. Finally, some of the funding may come from additional charges imposed on fossil fuel companies, as in the case of the LCFS.

10.4 Achieving integration of different sectors

A zero-carbon future in the EU will be one in which the division between sectors, often determined by different fuels, will, to large degree, disappear. Decarbonisation through electrification is the most feasible and appropriate means to move away from fossil fuels, especially for sectors such as transport and building. However, the greater demand for electricity brought about by electrified heating and cooling systems, and electric vehicles, will need to be satisfied by an increasing number of renewable energy plants to avoid shifting these sectoral emissions to the power sector by using polluting fossil fuel plants. Integrating these disparate sectors is key to ensuring successful decarbonisation, while also making the most of the existing infrastructure, most of all by allowing all sectors — from households, to grid operators, to electricity market participants — to play a role in generating and storing electricity, as well as in load-shifting.

Households have an increasing role to play in the integration of various sectors, as they not only consume electricity for the heating and cooling of their homes, but are increasingly able to generate electricity of their own, using solar PV. To avoid the curtailment of excess solar power production, residential batteries, virtual power plants, and electric vehicles can be used to store this excess power, to be utilised when renewable power generation is lower, as demonstrated by case studies from Australia. By integrating electricity consumers and their generation and storage capacity into the grid, the resulting demand shift to periods of higher demand and lower renewable generation means that polluting, peaker plants are no longer required.

Meanwhile, to address the challenges that large-scale renewable developments face, integration into the electric grid has been shown to be successful, as seen with the concept of Renewable Energy Zones in Australia. REZs would designate areas close to existing transmission lines for renewable energy investments. By taking advantage of sector-coupling, demand-shifting, and co-siting different kinds of renewables, e.g., solar, wind, and bioenergy, REZs could function as a stable and, to some degree even dispatchable, source of electricity.

The existing electricity systems will be complemented with storage systems and infrastructure, allowing for the integration of different sectors. Storage has been key for several countries; South Korea has invested heavily in subsidising storage energy systems, resulting in a rapid growth in storage capacity; however, this has not necessarily meant that renewables make up a significant proportion of its energy mix. California, through policy changes that delegate the responsibility to utility companies to integrate an increased storage capacity in the network, has allowed renewable energy capacity to grow significantly. Australia's community batteries have made it possible to connect and integrate entire neighbourhoods to the grid and have helped regulate the electricity imbalances faced by the grid, using prosumer-to-prosumer exchange. This integration is also vital to grid operators and electricity market participants: with procurement mandates, or the provision of community batteries, additional and costly grid expansions are avoided. By fully utilising the decentralised nature of rooftop solar by using community batteries, the local distribution infrastructure is fully utilised, and less generation capacity is required to serve neighbourhoods.

An important part of this electricity system will be electric vehicles, that will not only consume electricity but will, in some cases, also be used to increase the flexibility of a grid that is highly reliant on variable sources of energy. As electric vehicles replace combustion engines, the charging infrastructure becomes more commonplace, further allowing households to participate in electricity markets by charging their cars when electricity demand is low and powering the grid when it is high. Heat pumps that will replace fossil fuel heating will provide additional flexibility for the electricity grid.

10.5 The EU's "Man on the Moon" moment

Driven by the climate and energy crisis, the EU is about to accelerate the transformative change away from fossil fuels and towards clean sources of energy. Through investments in energy efficiency and heat pumps, it will also significantly reduce energy consumption, making its economy and households more resilient for future crises.

In its "Man on the Moon" moment, as described by the European Commission President, Ursula von der Leyen, the EU can and should use the experiences of other countries and regions. Over the last three decades, the EU developed one of the most comprehensive policy frameworks aimed at climate change mitigation of any country or region. However, not all of its elements worked as expected and, in most cases, they only resulted in incremental change. The ongoing negotiations that should result in, not only accelerating EU's emissions reductions, but also moving away from imported fossil fuels much faster than initially planned, create an opportunity to integrate some lessons learnt from other countries and regions.

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11. Appendix – Other Renewable Energy Zones

With the Central-West Orana REZ furthest along in the development process and acting as a blueprint for other REZs, NSW has committed to developing a further four REZs, in New England, South-West, Hunter-Central Coast, and Illawarra (EnergyCo NSW, 2022b). These zones are set to follow the same development path as the Central-West Orana REZ and are at varying stages of development.

The New England Zone is intended to deliver 8 GW of renewable energy, with over AUD 10 billion in projected private sector investment and 2000 jobs in construction and operation. It was formally designated in December 2021, in line with AEMO's 2020 ISP, and the Government of NSW has officially earmarked AUD 78.9 million to support its development. The New England REZ is notable for its pumped-hydro storage potential, which is critical for successfully integrating variable renewable energy into a fragile NEM. It is set to facilitate increased interconnection and trade between NSW and Queensland. The New England Registration of Interest (RoI) process ended in 2021 with over 80 entities indicating interest, totalling over 34 GW of installed capacity, indicating a high level of interest from private industry. Assessment of fundamental infrastructure needs within and outside of the REZ is underway, with EnergyCo coordinating between community stakeholders, generators, and transmission operators (EnergyCo NSW, 2022a).

The South-West Zone is at a similar development stage but slightly smaller than the Central-West and New England zones, with an intended capacity of 2.5 GW. EnergyCo projects the South-West Zone will bring just under AUD 3 billion of private investment to the region and around 2000 construction jobs. The South-West Zone was particularly chosen because of its high-quality wind and solar resources, in addition to its proximity to Project EnergyConnect, which is developing a high voltage transmission line connecting the states of South Australia, NSW, and Victoria (ElectraNet, 2022). Other transmission network upgrades identified will connect several substations in Victoria and NSW, in addition to connections to substations outside of the proposed area of the REZ. Transmission upgrades are subject to change based on attracted generation, and the RoI process concluded in 2021 with 49 RoIs registering 34 GW, significantly higher than the 2.5 GW of intended capacity. The South-West REZ has not yet been officially declared, as EnergyCo is considering public feedback on the draft declaration, but the final statement is expected in 2023 (EnergyCo NSW, 2022c).

The Hunter-Central Coast REZ is unique among the NSW REZs for its proposed inclusion of offshore wind projects, pumped hydro, and battery projects to support the development of traditionally energy-intensive industries. The region is home to hydrogen, ammonia, and metal production industries, a key port, and other heavy industries. In early 2022, the RoI process attracted a significant response from the industry with 40 GW and over AUD 100 billion of pledged interest, comprised of 24 solar PV projects, 13 onshore and seven offshore wind projects, 35 large-scale batteries and eight pumped-hydro proposals. The official designation of the Hunter-

Central Coast REZ was expected in mid-2022, following consultation with regional stakeholders and industry.

The final REZ in NSW's current portfolio is proposed to centre in Illawarra, taking advantage of existing dams to develop pumped hydro, offshore wind resources, and potential demand for hydrogen projects in the future. In a similar manner to the Hunter-Central Coast regions, Illawarra has significant heavy industry and mining and is economically vulnerable to the decarbonisation of the energy sector. As such, NSW seeks to use the designation of the REZ to build resilience and shift dependence away from fossil fuels. Illawarra already has two GW offshore wind projects in the proposed pipeline to connect to existing infrastructure, and EnergyCo and TransGrid are currently assessing further infrastructure upgrades. The RoI process for Illawarra closed in July 2022. Based on the submitted proposals, EnergyCo will reassess the exact geographic scope of the REZ and begin assessing transmission projects in the region. The official designation is expected at the end of 2022 (Young, 2022).

The state of Victoria has begun the development process for several REZs, following the pilot balloon of the Central West Orana REZ. It dedicated AUD 540 million to support network investments for six REZs (Department of Environment, Land Water and Planning, 2022). Similarly, Victoria established REZs in line with AEMO's ISP, and is going ahead with the development of these REZs concurrently. Regulatory development is occurring on multiple levels as Victoria also fleshes out the exact development approach which would ensure coordinated development of transmission and generation projects and balance community considerations specific to Victoria (Government of Victoria, 2022). For this purpose it introduced VicGrid, a new agency within the Department of Environment Land Water and Planning, which would plan and lead investments and the development of VREZs; however, the exact roles and powers of VicGrid are still to be determined (Energy Networks Australia, 2021).

In coordination with AEMO, the Victorian Government identified 20 projects to support REZ development — nine near-term and 21 longer-term. Stage One near-term projects are focused on delivering network upgrades to support system strength and capacity concerns that would threaten future generation development and can be delivered on a shorter timeline without significant inquiry or community consultation. Procurement for Stage One upgrades was expected to begin in 2022 Q2, with AEMO responsible for tendering.

Development of REZs is ongoing in the state of Queensland too, with three candidate zones identified. The Government of Queensland received a significant number of submissions during the RoI process for the three zones, with 192 proposed projects, totalling around 6 GW of capacity, comprised of a mix of solar PV, wind, and biomass generation (Carroll, 2020a). In addition, the Government dedicated AUD 145 million to the development of the REZs and published an initial technical discussion paper open for community and industry comments. Work on a new substation has begun in the Northern QREZ, which is estimated to bring in up to 500 MW of capacity, mostly through wind generation (Government of Queensland, 2022). Industry advocates and interest groups have noted that, as it stands, Queensland's REZ development framework lacks the targeted ambitions seen in Victoria and NSW and is without a definitive target for renewable generation capacity. Others note that the sheer size of the areas identified as REZs may be counterproductive when it comes to project planning for industry stakeholders (RE-Alliance, 2021a; Solar Citizens, 2021).

About the project

4i-TRACTION – innovation, investment, infrastructure and sector integration:
TRAnsformative policies for a ClimaTe-neutral European UnION

To achieve climate neutrality by 2050, EU policy will have to be reoriented – from incremental towards structural change. As expressed in the European Green Deal, the challenge is to initiate the necessary transformation to climate neutrality in the coming years, while enhancing competitiveness, productivity, employment.

To mobilise the creative, financial and political resources, the EU also needs a governance framework that facilitates cross-sectoral policy integration and that allows citizens, public and private stakeholders to participate in the process and to own the results. The 4i-TRACTION project analyses how this can be done.

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