Assessment of resource nexus-related challenges and opportunities in the context of the European Green Deal

Background report for the EEA Briefing “Applying a ‘resource nexus’ lens to policy: opportunities for increasing coherence”

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1 Introduction

This background report examines European Green Deal policies from a resource nexus perspective, identifying relevant challenges and opportunities associated with particular transition pathways foreseen in the European Green Deal. The background report functions as a supporting document to the EEA briefing on these topics entitled “Applying a ‘resource nexus’ lens to policy: opportunities for increasing coherence”. A brief overview of the European Green Deal as well as the resource nexus is included in this introduction to familiarise all readers with the relevant concepts.

Section 2 of this report characterises existing interactions among the nodes of the EEA’s resource nexus framework (i.e. water, energy, food, land, materials, and ecosystems). Particular emphasis is placed on interactions yielding synergies and trade-offs between resource uses. Considerations of climate and health are also incorporated in the characterisation. Key synergies and trade-offs are identified based on a literature review of publications on the interactions between two or more of the relevant natural capital components (nodes of the resource nexus).

Section 3 characterises European Green Deal policies related to three topics—food, mobility and energy—that have a particularly high resource nexus relevance. In total, nine policy areas are identified as particularly relevant and were considered as case-study candidates. These policy areas are: bioenergy; grid infrastructure and renewables installation; building renovation; organic farming and pesticides; fertilisers; pollinators; electric vehicle batteries; sustainable and smart mobility; and hydrogen for transport.

The remaining sections consist of three case studies that examine particular European Green Deal policies and related transition pathways, characterising challenges and opportunities from a resource nexus lens. These case studies provide a more in-depth examination of resource nexus synergies and trade-offs, ones relating specifically to current policy developments in the EU policy framework of the European Green Deal. Each of these case studies represents a high-level policy area addressed by the European Green Deal, where applying a resource nexus approach can exemplify how synergies and trade-offs could be identified and the findings used to inform policy. The case studies are:

- the role of increased organic farming and reduced use of pesticides;
- sustainable bioenergy; and
- electric vehicles and batteries.

The EEA Briefing “Applying a ‘resource nexus’ lens to policy: opportunities for increasing coherence” communicates highlights from this background report as a means of awakening the interest of wider audiences in the topic, increase their understanding of it; and enhance its usability for practical policymaking aimed at spurring on the comprehensive transitions that the European Green Deal proposes. The report and briefing support the EEA in achieving its overall strategic objectives of mobilising knowledge for responding to sustainability challenges and supporting sustainability transitions. Development of both documents involved the input of a number of outside experts that helped refine the findings of the background research and its policy implications in order to validate the results and increase the findings’ overall relevance for decision making.

1.1 The European Green Deal and its ambitious sustainability goals

Announced by the European Commission in December 2019, the European Green Deal (EGD) is a set of EU policy initiatives aiming to make the EU climate neutral by 2050 and foster transformational change toward sustainability (European Commission, 2021c). The 2050 climate-neutrality target is enshrined in the EU Climate Law[1] and will require fundamental changes in the ways we work, live, move, eat and trade (EEA, 2021b). The policy framework includes specific quantitative targets, many of which are to be reached by 2030. Many of the societal transitions required to reach these targets will involve profound changes to production and consumption systems and significant shifts in resource use.

Sustainability transitions are complex, long-term changes of entire consumption and production systems. Transitions are generally non-linear, open-ended developments, requiring technological, social and organisational innovations. This calls for a policy response that recognises the multi-causality of sustainability challenges and aims toward integrated and systemic policy frameworks (EEA, 2019c, p. 7). The European Green Deal constitutes such a response, specified via a number of objectives and targets and guided by the overall aim "to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use" (European Commission, 2019b).

The European Green Deal aims to promote these transitions via a number of strategies, such as the "EU Energy System Integration Strategy" for energy[2], the "Farm to Fork Strategy" for the food system[3] and the "Smart and Sustainable Mobility Strategy" for mobility[4]. Ensuring a transition to sustainable resource use is another ambition that lies at the heart of the European Green Deal, as can be seen in the "Circular Economy Action Plan"[5]. The European Commission maintains a website providing an overview of the European Green Deal that includes updates on new policy developments (https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en).

Resource-intensive consumption patterns—in Europe and globally—have driven environmental pressures and impacts to unprecedented levels (EEA, 2020c). While a reconfiguration of production and consumption systems is necessary to ease environmental pressures, given their shared reliance on natural systems, addressing problems in one area can cause unintended harm elsewhere (EEA, 2019d). Some of these trade-offs are recognised in the public debate, such as the need for more critical raw materials when shifting transport from fossil-fuel combustion to battery-electric motors. However, the European Green Deal aims to accelerate multiple transitions simultaneously and in a coordinated fashion, heightening the need to understand how sustainability goals in different systems may impact each other. Only a systemic analysis of such mechanisms can shed light on potentially unintended outcomes, such as shifting the burden to other resources and geographic areas.

Three production-consumption systems - food, energy and mobility – are among the key drivers of environmental pressures and impacts (EEA, 2019c). All these systems feature prominently

[1] European Climate Law: https://ec.europa.eu/clima/eu-action/european-green-deal/european-climate-law_en
[2] EU Energy System Integration Strategy,
[3] Farm to Fork Strategy: https://ec.europa.eu/food/horizontal-topics/farm-fork-strategy_en
[4] Smart and Sustainable Mobility Strategy: https://ec.europa.eu/transport/themes/mobilitystrategy_en
[5] Circular Economy Action Plan: https://ec.europa.eu/environment/strategy/circular-economy-action-plan_en

in the policy framework of the European Green Deal, alongside other sectors and policy areas. Box 1 shows how these systems relate to concerns within the resource nexus.

Box 1. Impacts on natural resources stemming from three key production-consumption systems - food, energy and mobility

Food, energy and mobility represent the core production-consumption systems that meet essential human needs. From the perspective of resource use, waste and harmful emissions, they contribute the bulk of humanity's burden on the environment.

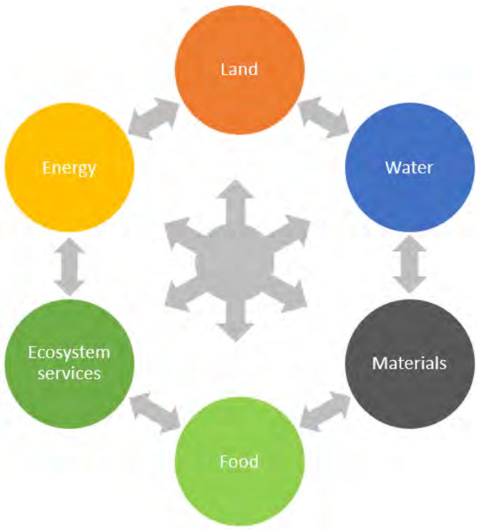
- **Food** - The food system has been called the "system with the biggest environmental impact" (Schmidt-Traub, 2021). It has massive effects on global freshwater use and land use, and is a main contributor to soil loss, biodiversity loss and climate change. Food is a key resource node within the Water-Energy-Food Nexus (WEF), which is the best analysed and most prominent nexus to date.
- **Energy** - Energy production, distribution, storage and consumption use resources for fuel, and for building and operating energy infrastructure. A key energy-related controversy revolves around the use of biofuels. Intended as a measure to reduce greenhouse gas emissions especially in the transport sector, biofuel production, if not carefully managed, can have negative impacts on food and feedstock prices and increase the pressure on a number of resources, including soil, land, water and biodiversity.
- **Mobility** - Mobility enables people to access spatially separated locations and goods to be shipped. Overcoming distance requires materials, land and energy resources, with the current transport system heavily dependent on the burning of fossil fuels. A major shift to the electrification of transport in the EU is underway and will accelerate in the coming years, with corresponding shifts in the types of resources required and their amounts, e.g. battery materials and expanded electricity generation.

1.2 The concept of the resource nexus

The FAO (2014) describes the resource nexus as a "conceptual approach to better understand and systematically analyse the interactions between the natural environment and human activities, and to work towards a more coordinated management and use of natural resources across sectors and scales".

The resource nexus gained prominence in 2011 via the conference "The Water, Energy and Food Security Nexus – Solutions for the Green Economy" (Hoff, 2011; UNEP, 2017). In the following decade, the resource nexus has seen further development, with over 1,000 peer-reviewed publications addressing the water-energy-food nexus alone (Hogeboom, 2021). Recent research carried out via the EU's Horizon 2020 programme examined the nexus between water, land, energy, food and climate, and generated specific policy-coherence recommendations for the European Green Deal (see SIM4NEXUS, 2020).

Figure 1. The resource nexus



Resource nexus assessments analyse the direct and indirect resource interconnections, as well as synergies and trade-offs that can be generated by policy interventions within and across policy domains, potentially increasing policy coherence. By shedding light on the aggregate effects of large-scale, systemic changes, resource nexus assessments can help inform sustainability transitions and prevent costly errors.

The EEA's State of the Environment Report 2020 includes a concise overview of the resource nexus and related issues (EEA, 2019d, pp. 371-375). The resource nexus can be employed as a descriptive analytical framework for understanding resource interconnections and as an integrated approach to policymaking (Hogeboom, 2021). In the context of this report, the latter approach was adopted.

There are methodological challenges in the undertaking resource nexus assessments because of the complexities associated with social-ecological systems, such as multiple scales, regional differences and non-linear dynamics. To overcome disciplinary silos in resource nexus assessments, Albrecht et al. (2018) call for the development of mixed methods and transdisciplinary approaches "that incorporate social and political dimensions (...); utilise multiple and interdisciplinary approaches; and engage stakeholders and decision-makers".

Applying the resource nexus concept to European Green Deal policy development and implementation may help to identify key synergies and trade-offs across resource nodes to ensure policy initiatives under the EGD are both coherent in achieving their intended effects, as well as coordinated regarding the timing of interacting transition pathways.

2 Qualitative and quantitative characterisations of node interactions

The following characterisations of resource node interactions are based on existing assessments, both qualitative and quantitative, and in some cases, a combination of both. The characterisations aim at generalising the findings in a European context, including externalisation of costs (or negative impacts) to other actors and geographies, while acknowledging and reflecting context- and scale-specificity, where relevant.

In addition to resource node considerations, climate and health considerations are included in the characterisations. Climate change is one of the defining environmental challenges of our times and the connection between human health and the environment has gained increased relevance to public policy considerations in light of the coronavirus pandemic.

The description of interactions emphasizes the identification of synergies and trade-offs between resource uses. Interactions are characterised by highlighting two-way interactions (e.g. energy-food; materials-energy), as well as higher-order interactions (i.e. accounting for three way or higher interactions across nodes, such as land-water-food).

2.1 Node interactions by policy area

The characterisations of node interactions in this section are grouped according to three core policy areas: 1) energy; 2) food; and 3) mobility. Energy, food and mobility involve a complex web of socio-economic, technological, institutional and cultural elements. In addition, very important links between the food, energy and mobility systems arise because of their shared reliance on natural systems, both as a source of resources and as a sink for wastes and emissions. As a result, addressing problems in one area may simply shift the burden to other systems. Naturally, particular nexuses can occur in more than one policy area—an unavoidable repetition that is actually at the heart of nexus approaches to synergistic and complementary policymaking. Burden shifting can also take place in a geographic sense, wherein resource-related challenges are pushed to non-EU countries rather than being comprehensively addressed.

The following sections provide overviews of important node interactions relevant to food policy, energy policy and mobility policy, respectively.

2.2 Node interactions related to food policy

The following box highlights the present scale of selected food-related interconnections between nexus nodes.

Snapshots: food and the resource nexus

- More than 1/4 of the energy used globally is needed for food production.[6]
- The agricultural sector is the largest user of the world's freshwater resources.[7]
- By 2050 global food production would need to increase by 60% to meet the food requirements of a growing global population. [8]
- About half of the world's habitable land is used for agriculture. 77% of the agricultural land is used for livestock, only 23% for crop production.[9]
- The conversion of natural ecosystems for crop production or pasture is the largest driver of terrestrial habitat loss.[10]

[6] Ritchie (2019a)
[7] FAO (2017, p. 2)
[8] https://www.water-energy-food.org/mission
[9] Ritchie (2019b)
[10] IPBES (2019)

2.2.1 Introduction and key challenges

The food system has been called the “system with the biggest environmental impact” (Schmidt-Traub, 2021). It has massive effects on global freshwater use and land use, and is a main contributor to soil loss, biodiversity loss and climate change. The Water-Energy-Food Nexus (WEF) is the best analysed and most prominent nexus. It came to the agenda over ten years ago (Varghese, 2009) and quickly became the centrepiece of some high-level political agendas.[11] Integrated water approaches have been advocated already in the early 1990s (Dombrowsky, 2011). Land has been analysed within the water-energy-land nexus, with food production understood as a key ecosystem service of all three resources (Cremades et al., 2019, p. 2). Soil, as one component of land, has been identified as the “forgotten piece” to the WEF-nexus (Hatfield et al., 2017). While food production is understood as an ecosystem service, ecosystem services have also been brought together with the WEF-nexus rather than only within an ecosystem-services - food nexus (Carmona-Moreno et al., 2019).

2.2.2 Node interactions

Water – energy – food nexus

The food sector – and thus food policy – is strongly interconnected with the water and energy sector (watergy). Globally, demand for food, water and energy is projected to rise, due to a growing world population, urbanization, economic growth and changing diets (UN Water, 2021). In Europe, cultivating, processing, packing and distributing food requires about 26% of the final energy consumption (Monforti-Ferrario et al., 2015; data for 2013). Agriculture is responsible for 59% of total water use, mainly from agriculture in Southern Europe (EEA, 2021e). In these semi-arid regions, energy needs for (pressurized) irrigation networks have reached 0.95-1.55kWh/m^3 annually (Soto-García et al., 2013, p. 1084). The optimisation of water and energy use in agriculture is a key issue in research and practice (Pardo Picazo et al., 2018, p.1f). In wetter, colder areas of Europe, energy use stems mainly from agriculture in greenhouses: the Netherlands has the highest share of energy consumption by agriculture in final energy consumption in the EU (Eurostat, 2021a).

Further interconnections in the WEF-nexus include:

- Freshwater is needed for extracting, refining and processing fossil fuels and for cooling power plants. In 2015, the energy sector in the EU required 74 billion m^3 for operation, 3.8 billion m^3 of freshwater was consumed (Medarac et al. 2018, pp. 8, 16). Withdrawal intensity is highest for nuclear power plants, followed by coal power plants. Consumption intensity is very high for fracking, coal mining, the growth of biotic resources and nuclear power plants (Union of Concerned Scientists, 2011; Magill, 2015).
- Energy is needed to pump, treat, desalinate and distribute water.
- Agriculture is the biggest polluter of European freshwater (via pesticides, fertilizers such as nitrogen and phosphorus, and other agrochemicals).
- 78% of global ocean and freshwater eutrophication (the pollution of waterways with nutrient-rich pollutants) is caused by agriculture (Poore and Nemecek, 2018).

Food – materials nexus

[11] E.g. the “Nexus-Conference” Bonn 2011: The Water, Energy and Food Security Nexus – Solutions for the Green Economy”

A food-materials nexus is not as widely researched as other nexus interactions related to food, but with the push to a circular economy, in which the functions provided by abiotic materials (e.g. plastics and concrete) should be increasingly replaced by biotic materials (e.g. bioplastics and wood) (Langsdorf and Duin, 2021, p. 8), competition with food production is likely to arise. The projected negative effects, such as additional eutrophication (Wijnen, 2015) from higher production of energy crops in Europe would apply and be acerbated by a further increase in the use of biotic resources for the bioeconomy. The production, distribution and retailing of food requires significant materials in the form of minerals for fertilisers (including significant imports from outside the EU), chemicals for pesticides and herbicides, as well as significant machinery, buildings, transport infrastructure and packaging.

Food – ecosystem services nexus

Ecosystem services naturally are strongly interlinked with water, energy and food security. Healthy ecosystems are a precondition for a productive food system and the most efficient way to improve water quality. The provision of food itself is considered an ecosystem service (Millenium Ecosystem Assessment, 2005, p. vi). Healthy ecosystems, including biodiversity, underpin food production by aiding crop pollination and soil formation (IRP, 2021, p. 6). Three out of four crops worldwide producing fruits or seeds depend, partly, on pollinators. At the same time intensive agriculture is a key threat to pollinators (FAO, 2018, p. 3, 12). Globally, one fifth of the land surface covered by vegetation showed declining trends in productivity (Carmona-Moreno et al., 2019, p. 13).[12] Safeguarding a functioning ecosystem helps maximizing yields long term (Schmidt-Traub, 2021). Land-use change, mostly related to food production, has had the largest relative negative impact on nature over the last 50 years (IPBES, 2019, p. 12).

Food – land nexus

In the EU, agriculture accounts for ~ 40% of land use (Eurostat, 2021f). The impact of agriculture on the land depends on the agricultural techniques used and the amount of food that is produced on an area. Environmental effects of food production include land degradation (erosion, soil compaction) and pollution with pesticides, herbicides and plastic waste. As worldwide demand for food is growing, so will demand for cropland (Laspidou et al., 2017, p. 110). Land-use change associated with expansion of agricultural activity or other human uses of bioproductive capacity causes reductions in land coverage of natural ecosystems (e.g. loss of forests due to deforestation) and these impacts can occur worldwide driven by the global trade in food products.

Trade- offs

Examples of trade-offs from these interlinkages in the current policy framework include the following:

- Intensification of agriculture generally leads to more water and energy use, as well as more water pollution.
- Water used for growing plants for biofuels or for consumption in power plants cannot be used in agriculture.

[12] Data for 1998 to 2013.

- Water needed for the cooling of power plants has negative impacts on the aquatic ecosystem of the water source used from the discharge of warm water. But, depending on the technology, can also impact the food system as hundreds of millions of fish and aquatic animals can die when they get sucked into the cooling systems of power plants (The Guardian, 2021; NRDC, 2014).

Synergies

Examples of synergies from these interlinkages in the current policy framework include the following:

- Increasing energy efficiency can reduce demand for the amount of land and water going to energy production.
- Switching to solar and wind energy will reduce water withdrawal and consumption in the European Union, as renewable energy technologies require significant less freshwater than nuclear power plants and coal power plants. This water can then be used in food production or left in natural ecosystems for environmental reasons.
- Switching to renewable energy technologies such as wind and solar reduces thermal pollution of water bodies, as renewable energy technologies - as opposed to all nuclear and fossil fuel power plants - require no cooling. Thermoelectric plants often use water from natural water bodies to cool. While dry cooling exists, it is less efficient and thus increases emissions and costs. Thermal water pollution reduces oxygen levels and affects the ecosystem of the water body (Clark, 2019).
- Policies to reduce food loss along the value chain and food waste at the point of consumption helps reduce water withdrawal and consumption as well as energy use.
- No-till agriculture reduces soil erosion and energy use from agriculture, improves the water balance and reduces horizontal transfer of nutrients and pesticides. However, in conventional farming it requires the use of total herbicides (Agrarheute, 2015). Organic farming can apply no-till agriculture if more complex agricultural techniques, involving green-manures, the right machinery and crop rotations are chosen (Ökolandbau, 2020; Ökologo, 2015). Governments can support farmers in finding the best solutions in their region by funding projects and compensating for crop losses in the research stage.
- The digitalisation of agriculture (“precision agriculture”) can help to intensify agricultural production while reducing environmental damage. Digitalisation can help process huge amounts of data to optimise and automate water and energy use in agriculture, as well as collecting and distributing data to improve agricultural practices, from tillage to harvesting methods and timing. This helps to reduce water and energy use as well as crop losses. Optimising agriculture on existing agricultural land protects biodiversity by preventing the rising demand for agricultural products from causing encroachment of farmland into natural ecosystems (WBGU, 2019, p. 210f). Digitalisation should also be used to monitor the effects of the intensification of agriculture, as in the past the intensification has had negative effects on biodiversity. Critics argue, however, that the digitalisation of agriculture also has a number of shortcomings, from the general flaw of optimising an agricultural system that is understood as malfunctioning by some critics as opposed to moving to agroecology. Other concrete concerns range from data security to the high costs and the associated financial dependencies of farmers (Friends of the Earth Europe, 2020).

2.2.3 Relevance to climate and health

Food production is a driver of climate change, as it currently accounts for roughly a quarter of global greenhouse gas emissions (Poore and Nemecek, 2018). At the same time climate change impacts food production. These impacts differ between regions: it is expected that warmer and dryer regions will suffer production losses while currently wetter, cooler regions may benefit from longer harvesting periods. However, extreme weather events like floods and droughts affect food production negatively in all regions (Laspidou et al. 2017, p. 54).

Naturally the interconnections between health and food are also very strong. While globally the decrease in hunger is a great success, there is still widespread micronutrient deficiency in many countries (Schmidt-Traub, 2021). At the same time overweight and obesity are a key driver for health problems. In 2019, over half of the European population were overweight (Eurostat, 2021g). Food quality and pesticide residues impact human health. Particulate matter emissions from agricultural production and distribution have negative health effects (Bundesforschung-sanstalt für Landwirtschaft, 2002).

For both the impact of food production on climate change as well as for the health impacts significant improvements could be achieved through changes in diets (reduction of animal food products and processed food products) (Westhoek et al., 2014) and – regarding climate impacts – by reducing food waste.

2.3 Node interactions related to energy policy

The following box highlights the present scale of selected energy-related interconnections between nexus nodes.

Snapshots: energy and the resource nexus

- Roughly 2,500 litres of water are required to produce 1 litre of liquid biofuel.[13]
- 43% of total freshwater withdrawals in Europe are for power plant cooling.[14]
- Increases in biofuel production may lead to indirect land-use changes that partially offset climate benefits by inducing conversion of carbon-rich non-agricultural land into relatively carbon-poor agricultural land.[15]
- In 2019, the global primary energy mix was made up of: oil 33.1%; coal 27.0%; natural gas 24.2%; hydroelectricity 6%; renewables 5.0%; and nuclear 4.3%.[16]
- The energy sector is responsible for 78% of total greenhouse gas emissions in the EU.[17]
- In 2018, long-term exposure to $PM_{2.5}$ was responsible for approximately 379 000 premature deaths in the EU-28.[18]

[13] WWAP (2017)
[14] WWAP (2014, p. 3)
[15] Laspidou et al. (2017, p. 119)
[16] BP (2020; p. 10)
[17] EEA (2020b, p. 86)
[18] EEA (2020a, p. 7)

2.3.1 Introduction and key challenges

Energy production, distribution, storage and consumption uses resources as fuels and also uses a wide variety of resources for building and operating energy infrastructure. Addressing the challenge of global climate change will require deep systemic reforms in the types and amounts of resources utilised for energy. A systems integration approach will be required to realize the potential of new technologies to work together to make the energy system into one that relies primarily on the efficient use of energy from renewable sources.

A key energy-related controversy revolving around the use of biofuels. Intended as a measure to reduce greenhouse gas emissions especially in the transport sector, the admixture of biofuels to fossil fuels has negative impacts on food and feedstock prices and increases the pressure on a number of resources, including soil, land, water and biodiversity.

A recent EEA study used life-cycle analysis to investigate how growth in renewable electricity generation across the EU since 2005 has affected key dimensions of concern, finding that the increase in renewable energy has likely decreased global pressures linked to climate change, acidification, eutrophication and particulate matter formation (EEA, 2020e, p. 2).

2.3.2 Key node interactions

Materials – energy nexus

The extraction, refinement, production recycling and disposal of materials as well as the manipulation of materials in manufacturing use significant energy resources. Industry accounts for approximately one quarter of energy consumption in the EU (Eurostat, 2021b), showing the strong connection between the energy node and materials node in the resource nexus.

The materials – energy nexus is central to the adoption of renewable-energy technologies and therefore of critical importance in the fight against climate change. Materials are needed to build electricity generating technologies such as windmills or solar panels as are the rare-earth materials needed for batteries and electric vehicle motors (IEA, 2021). The latter nexus has been a research focus in recent years. However, with technological advances including substitutions for rare materials in e.g. batteries, new recycling options being developed on the one hand, but also soaring demand on the other hand, insights on this energy-materials nexus remain a moving target.

As demand for certain materials increases, the energy required to recover materials from ores increases if the production process includes lower quality ores to meet demand.

Water –food – land – ecosystems – energy nexus

The admixture of biofuels to fossil fuels can increase food and feed prices when production of biofuel feedstock competes for crops and cropland. Biofuel production increases the pressure on a number of resources, including soil, land, water and biodiversity. Multiple and competing claims for bioeconomic production cannot be resolved in isolation nor should the bioeconomy be expanded in a way or to an extent that threatens ecosystems and biodiversity.

Energy is an input of central importance across the spectrum of agri-food activities, including production, distribution and storage.

Ecosystem – energy nexus

Energy production can negatively impact ecosystems and biodiversity. Such negative effects are associated most notably with fossil fuel production (in the event of spills). The decision on whether to place energy-production facilities in certain places is related to potential environmental and ecosystem risks, e.g. nuclear energy (radioactivity leaks), wind energy (effects on bird populations) and the siting of renewable energy production in marine environments (on the surface and underwater).

Land – energy nexus

Fossil fuel production requires land surface area, most notably surface coal mining, which strips away all surface vegetation over the entire area being mined and displaces animal populations. Underground mining for fossil fuels also has a significant above-ground footprint on the land. Effects on the land can occur over larger areas due to run-off and pollution from mining sites, including accidental spills. Due to the global trade in fossil energy, these effects can take place far from the location where the resulting energy is produced and consumed.

Renewable-energy production requires surface area for wind parks and solar installations. In addition, the inherent variability of these renewable sources requires the support of additional electricity-distribution infrastructure (e.g. power lines, transformers and storage) to match real-time electricity supply and demand. These uses compete with other potential uses of the land and also have aesthetic impacts on the landscape as well as noise impacts that affect public acceptance of increased renewables generation.

Water – energy nexus

Water plays an important role in several types of energy production, including hydroelectric plants, growing plants for biofuels and cooling for fossil-fuel and nuclear plants. The warm water discharged from thermal plants can negatively impact aquatic ecosystems by raising the ambient water temperature. Hydroelectric dams disrupt riverine habitats and flood the landscape, which entails loss of ecological, cultural and historical value. Some energy extraction, transport and production activities can also cause pollution of ground and surface water.

Energy is required for pumping groundwater, treating and distributing water, wastewater treatment, and desalination of seawater.

Trade- offs

Examples of trade-offs from these interlinkages in the current policy framework include the following:

- The transition from fossil-fuel-based energy to renewables will increase demand for certain materials and potentially increase demand for land and water (e.g. for certain types of biofuels or biofuel production within certain areas).
- Any expansion of bioenergy entails trade-offs with competing uses—especially food production and ecosystem services—that would require the same resource inputs.

Synergies

Examples of synergies from these interlinkages in the current policy framework include the following:

- In areas with energy-intensive water production measures (e.g. desalination) saving water also saves energy (UNEP, 2017, p. 77).
- Integrated sustainable energy systems enable infrastructure and generation capacity to be used more efficiently. Systemic solutions may involve new and interlinked technologies such as smart grids that combine energy storage with solar and wind energy.

- Renewable-electricity generation reduces carbon emissions and can also reduce impacts such as eutrophication, ecotoxicity and particulate matter emissions (UNEP, 2017, p. 78).
- Circular economy measures, such as second-life use of EV-batteries and EV-battery recycling, can help address trade-offs between increased demand for some materials associated with renewable-energy transitions (Drabik and Rizos, 2018).

2.3.3 Relevance to climate and health

The use of fossil fuels for energy is the central driver of global climate change. More than 75% of the EU's greenhouse gas emissions are due to the production and use of energy, including for transport (Eurostat, 2021e). In addition, the combustion of fossil fuels in power plants, industry and transport are the main sources of several air pollutants that lead to adverse health impacts. The extraction and delivery of fossil fuels also results in emissions of methane—a potent greenhouse gas—that contribute to climate change.

Climate change and extreme weather events increasingly affect the energy system, with renewable energy sources being particularly affected. Climate resilience is thus an important dimension of the transition to clean energy (EEA, 2019a, p. 5).

2.4 Node interactions related to mobility policy

The following box highlights the present scale of selected mobility-related interconnections between nexus nodes.

Snapshots: mobility and the resource nexus

- Globally, Europe is the continent with the highest proportion of land used for settlement, production systems and infrastructure.[19]
- After water, concrete is the second most widely used material in the world. Per year, twice as much concrete is used in comparison to all other construction materials combined.[20]
- Most life-cycle analyses find that battery-electric vehicles (BEVs) have lower life-cycle greenhouse gas emissions than internal-combustion vehicles. Despite higher GHG emissions in the raw materials and production stages for BEVs, these emissions can be more than offset by lower per-kilometre emissions. The extent to which this occurs depends on how the electricity is generated.[21]
- In 2018, transport was responsible for 24.6% of EU greenhouse gas emissions, a higher proportion than its 14.8% share of greenhouse gas emissions in 1990.[22]

2.4.1 Introduction and key challenges

Mobility enables people to access spatially separated locations and also enables the shipment of goods domestically and internationally. Overcoming these distances uses materials, land and energy resources, with the current transport system heavily dependent on the burning of

[19] EEA (2020f)
[20] The Cement Sustainability Initiative (2009)
[21] EEA (2018, p. 57)
[22] Eurostat (2021c)

fossil fuels. A major shift to the electrification of transport in the EU is underway and will accelerate in the coming years, with corresponding shifts in the types of resources required and their amounts. The resource nexus approach allows joint consideration of these diverse implications. Mobility patterns are about more than vehicles; they are also shaped by density and distance. Redesigning cities in a denser and more polycentric way is widely deemed to have multiple co-benefits. Dense cities allow reducing individual motorized transport; denser housing also reduces material per capita requirements as well as energy for heating and cooling. So the energy-material nexus is affected positively by this rather systematic environmental strategy. However, very dense living almost eradicates the citizens' possibilities to self-supply any basic commodities, which has diverse effects: city dwellers are more vulnerable in case of catastrophes, dense living fosters the spread of diseases, and the enormous demand in cities for food is currently tied to a system of industrial agriculture that has negative impact on soils, land, and biodiversity.

2.4.2 Node interactions

Land – ecosystems – energy nexus

Land use (a use across physical space) and transport (an overcoming of spatial distance) are inextricably connected with one another. The development of human infrastructure competes with ecosystem services to varying degrees depending on the intensity and type of use and the potential ecosystem services foregone. Compact settlement patterns are one way of reducing pressure on natural systems and decreasing the amount of materials and energy needed for transport. Transport systems based around the use of private cars require large amounts of land for driving and parking while urban planning optimised for cars reduces the quality of life in cities.

Integrated transport planning combines considerations of transport, urban planning, economic development and the environment for the purposes of maintaining and enhancing people's access to what they seek and improving their quality of life. This multidimensional planning approach predates the more recent resource-nexus approach but is similar in the way it integrates multiple simultaneous considerations. Rather than considering only the supply of transport as its aim, a demand-led approach in the context of integrated transport planning can help uncover the underlying access needs that people wish to fulfil (Schwedes and Hoor, 2019, p. 1).

Materials – energy nexus

Significant resources are used over the lifecycle of transport systems, including materials extraction, infrastructure construction, vehicle manufacturing, fuel production, operation of infrastructure and vehicles as well as their maintenance (Chester et al., 2012, p. 6). Public transport and non-motorised mobility require fewer materials and less energy than private motorised transport.

Material efficiency in vehicle production can contribute to reduced demand for energy. These material-efficiency strategies include smaller trip-appropriate vehicles, material substitution, car-sharing, ride-sharing, increased end-of-life material recovery and increased vehicle lifetimes (IRP, 2020, p. 29).

Trade- offs

Examples of trade-offs from these interlinkages in the current policy framework include the following:

- The transition from fossil fuels to electric mobility will entail increased mining of rare-earth metals for electric motors and lithium, nickel and cobalt[23] for batteries, shifting global mining patterns and thereby the burdens and benefits of those activities.
- Replacing fossil fuels with biofuels increases demand for biomass production, which increases demand for land and water resources and can compete with the use of these resources for food production and preservation of ecosystem services.

Synergies

Examples of synergies from these interlinkages in the current policy framework include the following:

- Using compact settlements patterns reduces land take by built areas, reduces material needs for infrastructure, reduces distances travelled and enables the use of more environmentally friendly modes of transport such as walking, cycling, public transport and rail.
- Increased vehicle occupancy reduces the number of vehicles needed, thereby reducing demand for materials to manufacture vehicles and reducing the energy required to move them.
- According to a modelling study by IRP (2020), "material efficiency strategies could reduce GHG emissions from the material cycle of passenger cars in 2050 by 57%–70% in G7 countries" (p. 8).

Box 2. Beyond mobility – cities and resource nexus synergies

„Cities constitute systems of major importance through which all of the major resources flow. . . . [W]ell-designed cities — incorporating energy-efficient buildings, high-density, mixed-use settlements well-served by public transport, walking and cycling lanes, and green spaces — can have numerous complementary and mutually reinforcing benefits. For example, high-density, mixed-use settlements tend to have lower energy consumption per household. Their density also allows shared infrastructures for recycling and reuse of materials and water to be used more effectively and can dramatically reduce private vehicle transport demand due to ease of access to destinations and good public transport links. The reduction in private vehicle transport demand in turn reduces both car ownership and the need for car parking spaces. This favours more green spaces and reduces the land area that is covered by impermeable surfaces, thereby improving groundwater recharging."

Reproduced from UNEP (2017, p. 78)

2.4.3 Relevance to climate and health

Transport is a major source of greenhouse gas emissions in the EU and its relative share of emissions compared to other sectors has been growing. It has been one of the more difficult sectors to decarbonise due to the high energy-density advantage of fossil fuels and the still-remaining need for significant technological development and charging infrastructure investments to accelerate electric-vehicle adoption.

[23] More than 70% of the world's cobalt is from the Democratic Republic of the Congo (DRC) with documented human-rights abuses occurring in the country, especially in artisanal and small-scale mining operations (Council on Foreign Relations, 2020).

Health impacts associated with transport include air pollution, accidents, noise exposure and human-toxicity impacts. Some modes of transport, most notably private cars, contribute to sedentary lifestyles while others, such as walking and bicycling can provide healthful exercise. A transition to electric vehicles will reduce noise exposure at low traffic speeds, will shift the profile of air pollution impacts (from those associated with vehicle emissions to power-generation emissions) and will likely increase toxicity impacts due to metal mining for batteries and motors (EEA, 2018, pp. 58-9).[24]

[24] A detailed overview of the various health effects of vehicle electrification can be found in EEA (2018, pp. 58-9).

3 Characterisation of European Green Deal policies related to food, mobility and energy with high resource nexus relevance

The European Green Deal consists of a complementary set of high-level policies addressing multiple topic areas, including climate, energy, agriculture, industry, environment, oceans, transport, finance, regional development, as well as research and innovation (European Commission, 2021b).

This section identifies those high-level EGD policies in the areas of energy, food and mobility that are most relevant from a resource nexus perspective, summarising the main objectives, targets and transformation pathways in the relevant production and consumption systems. In addition, the key synergies and trade-offs across resource nexus nodes are identified, facilitating a comparison of the high-level policies regarding their nexus relevance.

The framework used for these characterisations is one of using the resource nexus perspective to examine current policies. In the case of the European Green Deal, this implies focusing more on production rather than consumption. The extent of the major system reconfigurations examined are the reconfigurations as described in the European Green Deal. Some reflections around consumption are nevertheless made. Future assessment work and policy development could more fully address consumption-side aspects from a resource nexus perspective.

3.1 Identifying relevant European Green Deal policies

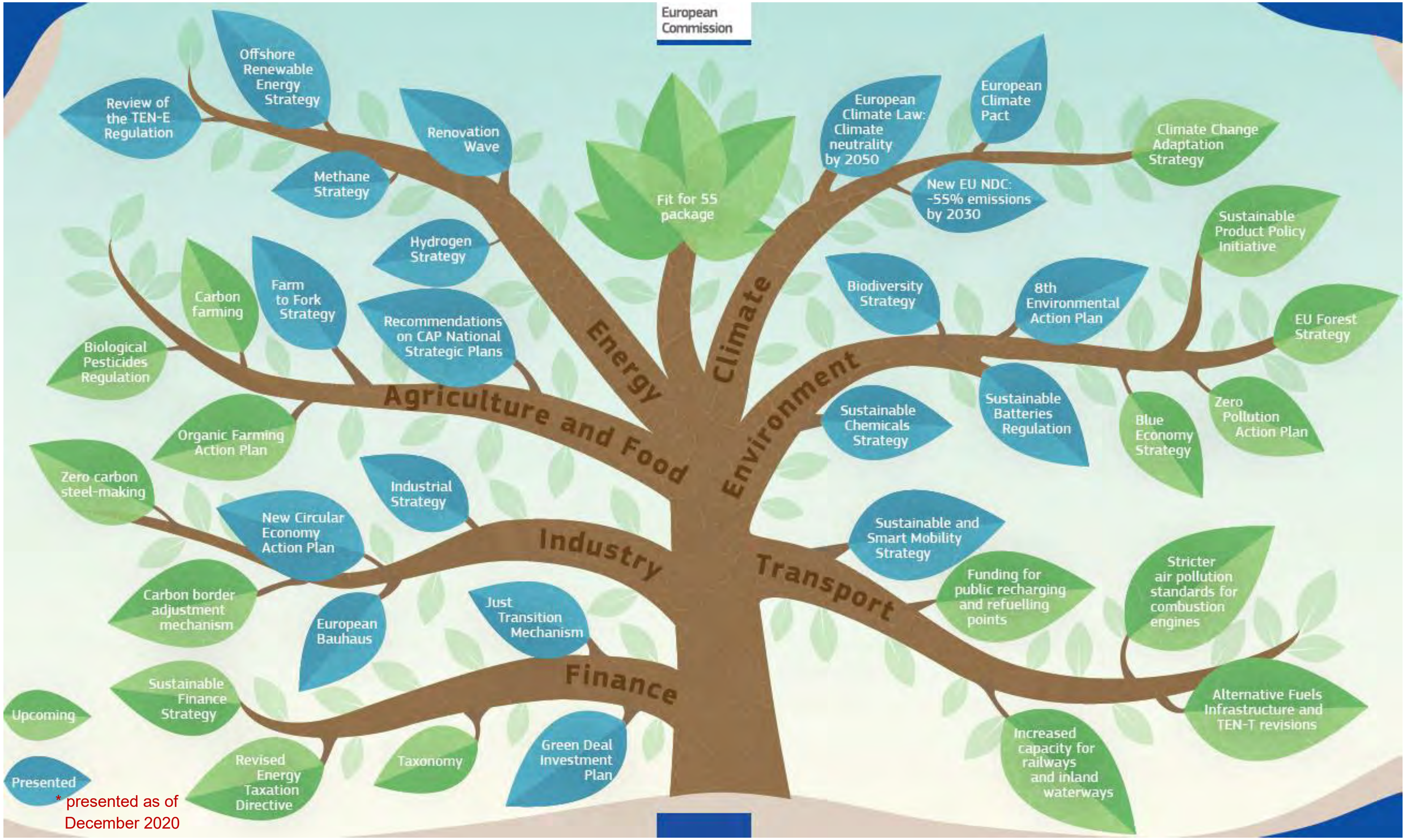
The following screening criteria were used to identify the EGD policies most relevant to include in this study, based on the predefined scope for this study:

1. **Resource nexus** - The key screening criterion for identifying relevant EGD policies is the extent to which multiple resource nodes are affected by EGD policy choices and a resource-nexus approach seems promising for identifying potential synergies and trade-offs.
2. **Transition pathways** –EGD policies are considered more relevant for this study if they require major sustainability transitions that involve multiple, related transitions in production and consumption systems.
3. **Policy topics** - The policy topics of interest according to the study scope are **energy**, **food** and **mobility**, three topics that account for a large share of overall resource consumption.
4. **Additional considerations** - In line with the predefined project scope, preference is given to EGD policies that are also relevant to the issues of **climate** and **health.**
5. **Specific targets** – In agreement with the EEA, an additional criterion was added after commencement of the project: EGD policies identifying specific **targets** are to be considered of higher relevance for the study, as such policies are further developed and lend themselves more easily to analysis in terms of transition pathways.

Other topic areas and considerations addressed by the European Green Deal not included in the list above are either not covered in this report or mentioned only incidentally. Such exclusions are based solely on considerations of the topical relevance for this study in regard to the above criteria; these exclusions do not constitute a comparative judgment regarding the fundamental importance of the policies.

Figure 2 provides a graphical overview of the topic areas and associated policies of the European Green Deal. Policies presented by the Commission by June 2021 were screened using the above screening criteria. For an overview of the screened policies, please see Table 1.

Figure 2. Tree graphic providing an overview of European Green Deal initiatives



Source: Reproduced from *https://ec.europa.eu/clima/sites/default/files/eu-climate-action/docs/green_deal_birthday_tree_en.pdf; Available at: https://ec.europa.eu/clima/policies/eu-climate-action_en. The graphic represents the status of presented and upcoming European Green Deal initiatives as of December 2020. A more recent graphic is not yet available from the European Commission.*

For each high-level EGD policy examined, the following information was compiled:

- **Name of the policy**
- **Overarching EGD objective supported by the policy**
- **Main objectives of the policy**
- **Specific targets of the policy** (the target and date to be reached)
- **Policy topic(s)** (one or more of energy, food, mobility)
- **Resource nexuses involved** (two or more of ecosystem services, energy, food, land, materials, water)

The compiled information was entered into an overview matrix.[25] As that matrix is quite large, this report text extracts key elements to highlight particular issues.

Table 1 provides an overview of the European Green Deal policies deemed by the project team to be the most relevant to major transitions and to clearly relate to more than one node in the resource nexus. The table groups policies by EGD objective and shows whether the high-level policies relate closely to the topics of energy, food and mobility. Policies not closely related to energy, food or mobility were removed from further consideration in the screening.

Table 1. Relation of European Green Deal policies to the topics of energy, food and mobility

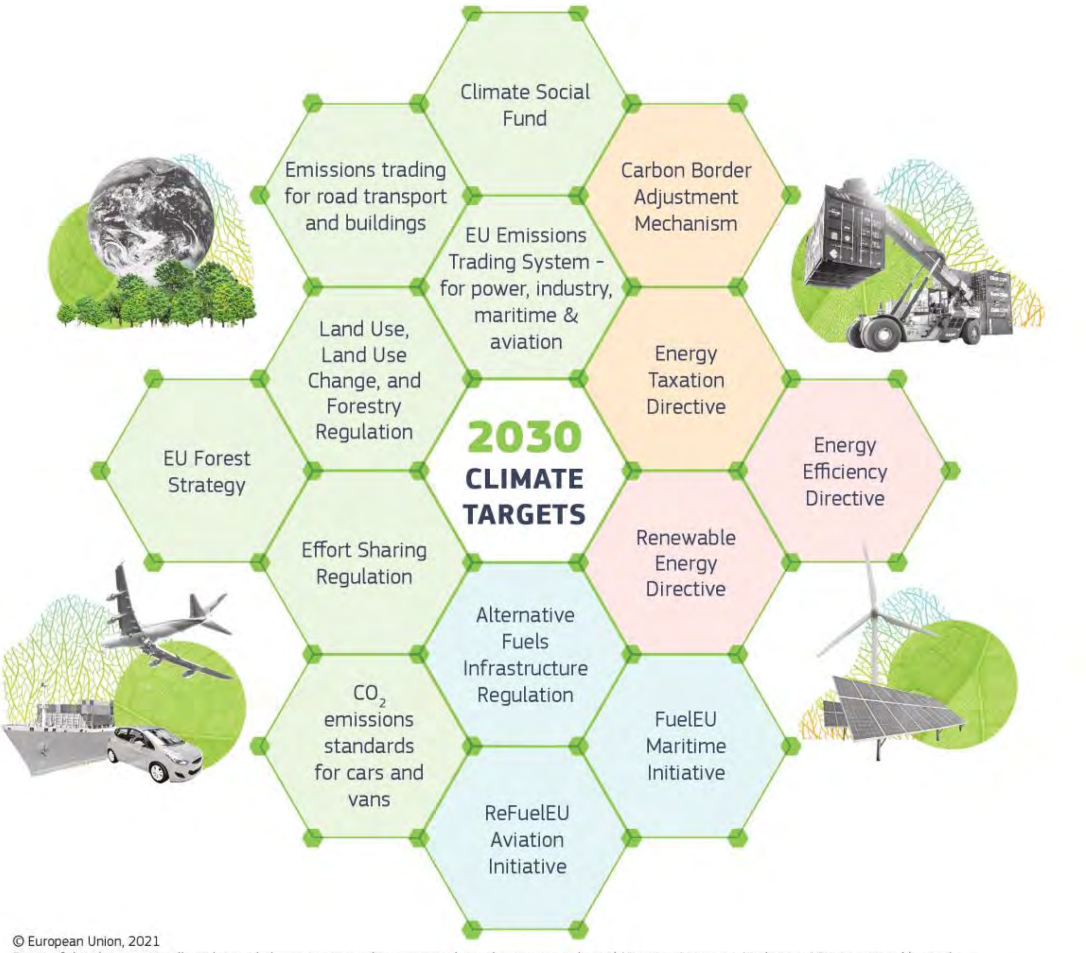
EGD high-level policies grouped by policy objective	Link to document	Energy	Food	Mobility
Objective: More ambitious EU climate protection targets for 2030 and 2050				
2030 Climate Target Plan	link	E	F	M
EU Strategy on Climate Adaptation	link	E	F	M
European Climate Law	link	E	F	M
European Climate Pact	link	E	F	M
Objective: Mobilizing industry for a clean and circular economy				
Circular economy action plan	link	E	F	M
EU Industrial Strategy	link	E		M
Sustainable Batteries Regulation	link	E		M
Objective: Supply of clean, affordable and secure energy				
A Hydrogen Strategy for a Climate Neutral Europe	link	E		
EU Energy System Integration Strategy	link	E		
EU Methane Strategy	link	E	F	

[25] Please note: the overview matrix is an interim work product, designed to reduce the complexity and increase the quality of the screening process in the project; it is not intended to serve as a publishable final document.

European Clean Hydrogen Alliance	link	E		
Offshore Renewable Energy Strategy	link	E		
Review of the TEN-E Regulation	link	E		M
Objective: A fair, healthy and environmentally friendly food system				
"Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system"	link		F	
Recommendations on CAP National Strategic Plans	link		F	
Objective: Preserving and restoring ecosystems and biodiversity				
Biodiversity Strategy for 2030 (includes EU Nature Restoration Plan)	link		F	
Objective: Accelerating the shift to sustainable and smart mobility				
Sustainable and Smart Mobility Strategy	link			M
Objective: Building and renovating in an energy and resource efficient way				
Renovation Wave Strategy	link	E		M
New European Bauhaus	link	E		M
Objective: Zero-pollution ambition for a toxic-free environment				
Chemicals strategy for sustainability	link		F	
Revising measures to address pollution from large industrial installations	link			
Zero pollution action plan	link		F	M

On 14 July 2021, the European Commission presented its "Fit for 55" package, which includes legislative proposals revising the EU's climate and energy policy framework in order to reach the more ambitious 2030 reduction target of a 55% reduction in emissions, compared to 1990 levels. The timing of the release of the Fit for 55 package was too late for inclusion of its legislative proposals in the screening exercise described in this report. Figure 3 provides an overview of the elements included in the Fit for 55 package and further information can be found at the European Commission's set of webpages on the topic, entitled Delivering the European Green Deal.

Figure 3. Overview of elements included in the Fit for 55 Package



Source: Reproduced from European Commission

3.2 Characterising European Green Deal policies according to nexus relevance

As a next step in the screening process, the EGD policies were grouped according to the relevant topics and policy areas they address, resulting in a long list of potential case studies.

In line with the project scope, the topic experts in the project team deliberated over the long list of case-study candidates, seeking to develop a short list of case-study candidates to send to the EEA by identifying three highly suitable policy areas for the topics of energy, food and mobility respectively, for a total of nine policy areas. The following policy areas show the result of these deliberations and constitute the short list for consideration as case studies:

- For the topic of **energy**
    - Policy area: **bioenergy**
    - Policy area: **grid infrastructure and renewables installation**
    - Policy area: **building renovation**

- For the topic of **food**
  - Policy area: **organic farming and pesticides**
  - Policy area: **fertilisers**
  - Policy area: **pollinators**
- For the topic of **mobility**
  - Policy area: **electric vehicle batteries**
  - Policy area: **sustainable and smart mobility**
  - Policy area: **hydrogen for transport**

These nine policy areas are considered particularly relevant based on the screening criteria described at the beginning of Section 3.1 and further details demonstrating their suitability as case-study candidates are shown in the overviews provided for each below, including their relevance to the policy issues of climate and health. These policy areas are all strongly related to transition pathways and a resource-nexus approach appears to be useful for enhancing the effectiveness of policy interventions due to the multiple resource nodes involved.

The following characterisations of these policy areas were developed and shared with EEA as an interim work product for case-study selection. The purpose of these characterisations was to support this selection exercise (the purpose was not to build a thorough catalogue of resource-nexus interactions documented with evidence from the literature). Consistent with the project scope, the project team was tasked with identifying resource issues for which employing a resource-nexus approach seems especially promising for: 1) improving the effectiveness of specific policy interventions to the issues; and 2) acting as paradigmatic models[26] that can be emulated and enhanced outside the scope of this project. The selection of the most promising topics to characterise was based on expert judgment, including discussion among the staff experts on the project.[27]

The following characterisations depict key attributes of the policy areas in the short list of candidates to be examined in more detail as case studies within the project.

Overview of the policy areas strongly related to the resource nexus and also associated with significant transition pathways

Note: Resource-node interactions synergistic with the policy aim are indicated with a plus sign (+); Resource-node interactions involving trade-offs to consider in pursuing the policy aim are indicated with a minus sign (-); Mixed effects (+/-); Ambiguous effects that cannot be clarified without further research beyond the scope of this screening exercise are indicated with a question mark (?). Brief descriptions are also included regarding some resource-node interactions where the reasoning warrants further explanation. The resource-node interactions the project team considers most significant are in ***bold****.*

Topic: Energy

- **Policy area: *bioenergy***

[26] The case studies are intended to be both specific to the policy areas while developing a general approach that can be emulated or adapted by others seeking to apply resource-nexus approaches to policy deliberations on additional topics.

[27] In June 2021, the list of these nine policy areas was presented to EEA staff for discussion and was also reviewed by an external steering group in August 2021 for comment.

- **EGD supporting policies:** EU Strategy for Energy System Integration; Directive (EU)2015/1513, which is aimed to reduce indirect land use change for biofuels and bioliquids (see European Commission, 2019a); revised Renewable Energy Directive (RED II; see European Commission, 2018b)
- **Overarching EGD objective:** Supply of clean, affordable and secure energy
- **Targets**: Incentivise the use of agriculture residues to produce sustainable biogas and biofuels
- **Key nexus synergies and trade-offs**: **ecosystem services (-), energy (?), food (-), land (-),** materials (fossil fuels) (+), **water (-)** — The extent of resource-nexus impacts of increased bioenergy production vary significantly based on the type of feedstock used and whether feedstock competes with crop production and whether direct/indirect land-use change occurs as a result (e.g. converting pristine land).
- **Transition pathways:** The transition pathway to sustainable bioenergy entails a shift to advanced biofuels (those using non-food biomass) and careful monitoring of direct and indirect effects of bioenergy production to ensure truly sustainable practices. The European Commission's impact assessment of the European Green Deal proposal to modify the Renewable Energy Directive (RED II) states that "strengthened sustainability criteria for bioenergy will have positive impacts on biodiversity, the carbon sink and air quality" (European Commission, 2021e, p. 2).
- **Issues:** climate change (+/?)
- **EU external**: unsustainable bioenergy sources (e.g. palm oil) and land-use conversion
- **Useful links**: https://ec.europa.eu/energy/topics/renewable-energy/biofuels/sustainability-criteria_en?redir=1 ; https://www.energy-transitions.org/energy-transitions-commission-warns-demand-for-biomass-likely-to-exceed-sustainable-supply/

- **Policy area:** ***grid infrastructure and renewables installation***
  - **EGD supporting policies:** Review of the TEN-E Regulation; EU Energy System Integration Strategy; revised Renewable Energy Directive, Offshore Renewable Energy Strategy.
  - **Overarching EGD objective:** Supply of clean, affordable and secure energy
  - **Targets:** Interconnect energy systems and better link/integrate renewable energy sources to the grid (source: EGD Clean Energy factsheet). Doubling share of renewables in the EU energy mix to 40% by 2030 (source: proposed revised Renewable Energy Directive)
  - **Key nexus synergies and trade-offs:** ecosystem services (+/-), **energy (+),** land (+/-), materials (+/-), water (+) — Grid infrastructure requires land and materials, but if the land use or material use per kwh is reduced in total due to a reduced need to build up renewable energy technologies, the effect might be positive. Reduced demand for cooling water of thermal plants.
  - **Transition pathways:** The development and build-out of renewable energy and related infrastructure rapidly and at scale as a replacement for fossil-fuel based energy is associated with a massive transitional effort across many dimensions (e.g. technological, commercial, financial, societal).
  - **Issues:** climate change (+), health (+)
  - **EU external**: international grid interconnections (e.g. Norway, Morocco)

- **Useful links**: https://ec.europa.eu/info/news/commission-presents-renewable-energy-directive-revision-2021-jul-14_en

- **Policy area:** ***building renovation***
  - **EGD supporting policy:** Renovation Wave Strategy
  - **Overarching EGD objective:** Building and renovating in an energy and resource efficient way
  - **Targets:** By 2030, at least double the annual energy renovation rate of residential and non-residential buildings; foster deep energy renovations. Mobilising forces at all levels towards these goals will result in 35 million building units renovated by 2030. The increased rate and depth of renovation will have to be maintained also post-2030 in order to reach EU-wide climate neutrality by 2050.
  - **Key nexus synergies and trade-offs:** energy (**+**), materials (**-/+**), ecosystem services (**-**) – Energy renovations to buildings will require significant material resources but will also extend some renovated buildings' usable lifetimes, which saves material resources.
  - **Transition pathways:** The annex to the Renovation Wave Action Plan (link) identifies a large number of transformative shifts that will be spurred on by the policy, including reviewing material-recovery targets and supporting the market for secondary raw materials.
  - **Issues:** climate change (**+**), health (**+**)
  - **EU external**: wood imports
  - **Useful link**: https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en

Topic: Food

- **Policy area:** ***organic farming and pesticides***
  - **EGD supporting policies**: Farm to Fork Strategy; Biodiversity Strategy for 2030
  - **Overarching EGD objective:** A fair, healthy and environmentally friendly food system
  - **Targets**: <u>Organic farming</u> - By 2030, at least 25% of agricultural land is under organic farming management; the uptake of agro-ecological practices is significantly increased. <u>Pesticides</u> - By 2030, a 50% reduction in the use and risk of pesticides (source: Farm to Fork Strategy)
  - **Key nexus synergies and trade-offs**: ecosystem services (**+**) – energy (**?**) – food (security, health) (**+**) – land (**-**) – materials (**?**) – water (**+/-**). **—** Organic farming requires more land due to lower productivity. It may result in less water pollution but possibly more water use.
  - **Issues:** climate change (**?**), health (**+**)
  - **Transition pathways:** To scale up organic farming to the foreseen level, significant changes are required in production, processing, retailing and consumer demand. Suitable solutions are needed regarding the additional land area required for organic farming due to its lower per-hectare productivity.
  - **EU external**: international trade components of the Farm to Fork Strategy
  - **Useful links**: https://ec.europa.eu/food/horizontal-topics/farm-fork-strategy_en; https://www.cleanenergywire.org/factsheets/eus-farm-fork-strategy-impacts-climate-productivity-and-trade

- **Policy area:** ***fertilisers***
  - **EGD supporting policies:** Farm to Fork Strategy, Biodiversity Strategy for 2030
  - **Overarching EGD objective:** A fair, healthy and environmentally friendly food system
  - **Target:** By 2030, a 20% reduction in the use of fertilisers
  - **Key nexus synergies and trade-offs:** ecosystem services (**+**) – energy (**?**) – food (production) (**-**) – land (**-**) – materials (**+**) – water (**+**)
  - **Issues:** climate change (**+**), health (**+**)
  - **Transition pathways:** Mineral-based fertilisers are extensively used to optimise production[28]; the European Commission indicates that fertilisers accounted for approximately 60% of the registered yield increases in the last 50 years.[29] A transition away from fertilizers requires addressing the productivity implications for land use and food security in the EU.
  - **EU external**: phosphorus imports
  - **Useful links**: https://www.carbonbrief.org/nitrogen-fertiliser-use-could-threaten-global-climate-goals; https://www.europarl.europa.eu/RegData/etudes/BRIE/2016/582010/EPRS_BRI(2016)582010_EN.pdf

- **Policy area:** ***pollinators***
  - **EGD supporting policies:** Biodiversity Strategy for 2030; Farm to Fork Strategy; EU Pollinators Initiative
  - **Overarching EGD objectives:** A fair, healthy and environmentally friendly food system; Preserving and restoring ecosystems and biodiversity
  - **Targets:** The decline in pollinators is reversed by supporting the maintenance, creation and connection of healthy habitats for pollinators, reducing the impacts of pesticides on pollinators, and by tackling the spread of non-native species that carry harmful pathogens and diseases.
  - **Key nexus synergies and trade-offs**: ecosystem services (**+**) – energy (**?**) – food (production) (**+**) – land (**+/-**) – materials (**?**)
  - **Issues:** climate change (n.a.), health (n.a.)
  - **Transition pathways:** According to the EU Pollinators Initiative, better knowledge is needed regarding the extent of decline and effective countermeasures; the causes are systemic, involve a broad range of actors and are difficult to change (habitat loss, pesticides, invasive species, climate change, pollution and diseases), making this a complex and uncertain transition.
  - **EU external:** n.a.
  - **Useful links:** https://ec.europa.eu/environment/nature/conservation/species/pollinators/documents/EU_pollinators_initiative.pdf

Topic: Mobility

- **Policy area:** ***electric vehicle batteries***
  - **EGD supporting policies:** Sustainable and Smart Mobility Strategy; Sustainable Batteries Regulation

[28] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_mineral_fertiliser_consumption
[29] https://www.europarl.europa.eu/RegData/etudes/BRIE/2016/582010/EPRS_BRI(2016)582010_EN.pdf

  - **Targets:** By 2030, at least 30 million zero-emission vehicles will be in operation on European roads.
  - **Key nexus synergies and trade-offs:** energy (+/-) - land (+/-) - materials (+/-) — The shift from fossil fuels to batteries as an energy source will reduce use of some materials while increasing consumption of other materials; this will involve a shift in the geographic locations of material extraction and processing.
  - **Issues:** climate change (+), health (+)
  - **Transition pathways:** Significant transitions through many interconnected production and consumption systems within the EU and globally.
  - **EU external**: mining of lithium, cobalt, rare-earth minerals
  - **Useful links**. https://ec.europa.eu/transport/themes/mobilitystrategy_en; https://ec.europa.eu/environment/topics/waste-and-recycling/batteries-and-accumulators_en

- **Policy area:** ***sustainable and smart mobility***
  - **EGD supporting policies:** Sustainable and Smart Mobility Strategy
  - **Targets:** From Sustainable and Smart Mobility Strategy: By 2030: at least 30 million zero-emission vehicles will be in operation on European roads. By 2030: 100 European cities will be climate neutral. By 2030: high-speed rail traffic will double. By 2030: scheduled collective travel of under 500 km should be carbon neutral within the EU. By 2030: automated mobility will be deployed at large scale. By 2030: zero-emission vessels will become ready for market. By 2035: zero-emission large aircraft will become ready for market. By 2050: nearly all cars, vans, buses as well as new heavy-duty vehicles will be zero-emission. By 2050: rail freight traffic will double. By 2050: high-speed rail traffic will triple. By 2050: the multimodal Trans-European Transport Network (TEN-T) equipped for sustainable and smart transport with high-speed connectivity will be operational for the comprehensive network.
  - **Key nexus synergies and trade-offs:** energy (+) - land (+) - materials (++/-) — The policy aims to make mobility more energy and land efficient. A shift from internal combustion engines to electric vehicles and related infrastructure will reduce use of some materials (e.g. fossil fuels) while increasing consumption of other materials (e.g. metals, rare earths).
  - **Issues:** climate change (+), health (+)
  - **Transition pathways:** This is a large-scale, high technology (e.g. digitalisation) transitions involving complex, competing and interconnected mobility networks and complex production chains.
  - **EU external**: international trade in electronics, mining in non-EU countries (e.g. lithium).
  - **Useful links**: https://ec.europa.eu/transport/themes/mobilitystrategy_en

- **Policy area:** ***hydrogen for transport***
  - **EGD supporting policies:** Review of the TEN-E Regulation; Communication: A hydrogen strategy for a climate-neutral Europe, EU Strategy for Energy System Integration
  - **Targets:** today - 2024: installation of at least 6GW of renewable hydrogen electrolysers and the production of up to 1 million tonnes of renewable hydrogen. 2025 - 2030: at least 40GW of renewable hydrogen electrolysers and the production of up to 10 million tonnes of renewable hydrogen. 2030:

renewable hydrogen will be deployed at a large scale across all hard-to-de-carbonise sectors.
- **Key nexus synergies and trade-offs:** energy (**+**) – land (**-**) – materials (**?**). Net effects depend on any crowding out of non-hydrogen renewable invest-ments (and other factors).
- **Issues:** climate change (**+**), health (**+**)
- **Transition pathways:** Use of hydrogen in fuel-cell vehicles would require significant cost reductions to be competitive with battery-electric vehicles. Improving the environmental impacts of hydrogen production requires a shift in production methods and energy sources used. The EU Hydrogen Strat-egy foresees a phased approach over the years 2020 to 2050 (see Euro-pean Commission, 2020d)
- **EU external**: hydrogen imports
- **Useful links**: https://www.theguardian.com/environment/2020/oct/03/green-hydrogen-from-renewables-could-become-cheapest-transformative-fuel-within-a-decade vs. https://www.theguardian.com/commentisfree/2021/mar/16/hydrogen-nuclear-net-zero-carbon-renewables

3.3 Selecting high-level European Green Deal policies and related transition pathways for further analysis

Based on the characterisations in the preceding section and exchanges with EEA staff regarding the characterisations of nexus relevance above, the following three high-level policy areas are selected for more detailed examination as case studies:

- **Food:** Organic farming and pesticides
- **Energy:** Bioenergy
- **Mobility:** Electric-vehicle batteries

The main considerations justifying these selections are the following:

1. **Topic coverage** - All three policy areas should be represented, with one case study each for energy, food and mobility, respectively.
2. **Exclusions** - Sustainable and smart mobility was removed from consideration as being too diffuse and large-scale a topic for the scope of the present study.
3. **Resource-nexus interactions** - Of the topics remaining for consideration, the three topics selected involve relatively significant resource-nexus interactions (both synergies and trade-offs) compared to the other topics in their policy area.
4. **Transition pathways** - The three topics selected are all associated with significant transitions involving multiple and interrelated production and consumption systems with cross-dependencies of resource nodes to achieve scale.
5. **Case-study interactions** - By having ***bioenergy*** as well as **organic farming and pesticides**, the interactions of these two cases can also be considered given their reliance on land-based bioproduction. This is a useful test regarding to what extent resource-nexus approaches on related issues can be additive when combined, generating additional insights.

6. **A linchpin technology** – The **electric-vehicle battery** case addresses a linchpin technological component in the broader transition to sustainable and smart mobility with implications external to the EU due to the need for lithium, cobalt and rare-earth minerals, as well as connection to the circular economy via battery second-life applications and recycling.

4 Case studies: European Green Deal challenges and opportunities from a resource nexus lens

The remaining sections of this report consist of three case studies, each covering a high-level policy area addressed by the European Green Deal—organic farming and pesticides; bioenergy; and electric-vehicle batteries, respectively.

The overall objective of the case studies is to demonstrate what a resource nexus approach could bring to improving the level of knowledge regarding systemic challenges and sustainability transitions. The resource nexus approach was developed as a framework that could help bring complex interrelationships of resource use to light and make them a central focus of policy considerations, especially in the context of identifying synergies and trade-offs across resource uses. These case studies try to operationalise the resource nexus approach for application to the European Green Deal—an encompassing policy framework aimed at significant and long-term sustainability transitions.

Each case study has a similar structure. First, we characterise the emerging policy framework in the context of the European Green Deal and the specific targets and transitions the framework calls for. Following this, we characterise how the resource nodes in the nexus interrelated, specifically identifying ways that resource nodes are affected by the foreseen transitions. We explore the key challenges and opportunities from a resource nexus perspective, identifying potential synergies and trade-offs. Finally, we conclude each case with a brief assessment of specific ways the resource nexus could help inform policymaking in that policy area.

Two infographic approaches were developed for these case studies to support a better understanding of the interrelationships of resource nodes and their relation to transition pathways. Each case study employs the same graphics as a means of developing and testing consistent visual approaches that could make a contribution to increasing the accessibility of resource nexus concepts and supporting their use in active policymaking contexts.

5 Case study 1: How a resource-nexus approach can support an effective transition towards a

sustainable food system: the role of increased organic farming and reduced use of pesticides

5.1 Policy framework: vision, targets and transitions

Organic farming encompasses a number of different production techniques that aim to produce food by using natural substances and processes as well as implementing higher standards in animal husbandry. The key differences to industrial agriculture are the prohibition to use synthetic fertilisers, genetically modified organisms and ionising radiation. The use of antibiotics is severely restricted. The use of chemical pesticides in organic agriculture is restricted, so the target of reducing the use and risk of chemical and more hazardous pesticides by 50% by 2030 is strongly interconnected with the uptake of organic farming.

This case study presents how a resource nexus approach can support transition pathways to increase organic farming and reduce pesticide use.

The European Green Deal states that it requires a set of "deeply transformative policies" (European Commission, 2019b, p. 4) to deliver its goals. Regarding the transition of the food system the European Commission sees farmers and fishermen as key figures, whilst acknowledging that food policy should cover the whole food chain (European Commission, 2019b, p. 12). The overarching, long-term goals for the food system are spelled out in the Farm to Fork Strategy. The food system of the future requires:

> "ensuring that the food chain, covering food production, transport, distribution, marketing and consumption, has a neutral or positive environmental impact, preserving and restoring the land, freshwater and sea-based resources on which the food system depends; helping to mitigate climate change and adapting to its impacts; protecting land, soil, water, air, plant and animal health and welfare; and reversing the loss of biodiversity. Furthermore, the access to sufficient and nutritious food and the affordability of sustainable food are key goals."[30]

This rather visionary approach gives little insight on the pathways to reach the future system. However, the transition of a major system, such as the food system, requires changing several subsystems. Here, we identify the subsystems by sorting the key targets thematically. The overarching goal of a "sustainable food system" is translated into several targets in the European Green Deal and related policy documents:

[30] Farm to Fork Strategy: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52020DC0381&from=EN

Subsector	Target
Organic Farming/ Pesticide use	• 50% reduction of the use and risk of pesticides • Manage 25% of agricultural land under organic farming and promote the uptake of agro-ecological practices
Fertiliser use	• 20% reduction in the use of fertilisers
Antimicrobial use	• 50% reduction in sales of antimicrobials used for farmed animals
Ecosystems and biodiversity	• Turn at least 30% of EU's land and 30% of seas into effectively managed and coherent protected areas • Restore degraded ecosystems and stop any further damage to nature • Reverse the decline of pollinators • Establish biodiversity-rich landscape features on at least 10% of farmland • Restore at least 25,000 km of the EU's rivers to be free flowing • Plant over 3 billion diverse, biodiversity rich trees.
Emissions reductions	• Increase agriculture, fisheries and aquaculture GHG reduction target to over 50% (previously 40% target)

Organic farming and pesticide use reduction are two components of a broader transition to a sustainable food system. We will look at this subsystem and its possible transition pathways more closely.

5.2 Key documents that contain policy proposals for organic farming and pesticide use

The targets and actions to reach 50% reduction of pesticide use and get to 25% organic farming are spread over a number of policy documents, with the key documents being:

- The Farm to Fork Strategy (F2F), 2020
- The Action Plan for the Development of Organic Production (Organic Action Plan), 2021
- The Common Agricultural Policy (CAP).[31]

[31] The EU "Biodiversity Strategy for 2030. Bringing nature back into our lives", 2020, is intended by the European Commission to work "in tandem" with the Farm to Fork Strategy and the new CAP, especially as organic farming has positive effects on biodiversity. The second part of the target to increase organic farming to 25% by 2030 "*and promote the uptake of agro-ecological practices"* is quoted from the Biodiversity Strategy (p.14). The Farm to Fork strategy mentions the target of a 25% increase in organic farming and "a significant increase in organic aquaculture" (Farm to Fork Strategy, p. 11).

A number of key policies are still upcoming, especially the “Review of Sustainable Use of Pesticides Directive”[32] and the “Proposal for a legislative framework for sustainable food systems”.

The **European Green Deal** states the need to increase organic farming and mentions the possibility of EU Member States using lower VAT rates to boost organic farming.[33] The Annex of the European Green Deal, which lists actions planned, also announces measures (including legislative) to significantly reduce the use and risk of chemical pesticides, as well as the use of fertilizers and antibiotics. The European Commission wants to work with EU Member States to ensure that national strategic plans for agriculture reflect the ambitions of the European Green Deal and the Farm to Fork Strategy, and lead to the use of sustainable practices, including organic farming. The strategic plans should furthermore support the reduction of pesticides, fertilisers and antibiotics use.

The **Farm to Fork Strategy** presents the heart of the transition of the food system under the European Green Deal. It aims to integrate food production and consumption in one strategy. Whilst the strategy states that organic farming should be promoted, regarding actions, it refers mainly to other policies (namely the CAP and the Organic Action Plan). In the actions list of the strategy only the determination of modalities for criteria for sustainable food procurement (including organic products) in public institutions are listed. While the Farm to Fork Strategy describes a transition that targets the entire production and consumption system, the more concrete actions as listed in the strategy’s annex do not add up to a coherent transition pathway that covers the span of farm to fork. There is a strong focus on the production side, whilst the consumption side is hardly dealt with (see Figure 4 and Table 3).

The **Action Plan for the Development of Organic Production** (2021) is the key document for the increase of organic production. It is organised around three axes: 1) stimulate **demand** and consumer trust; 2) **production and processing** (stimulate conversion and reinforcing the value chain); and **environmental sustainability**.

To increase the **demand,** the European Commission

- proposes a number of actions to increase information on the benefits of organic food and use budget for the promotion of organic products;
- aims to stimulate the uptake of organics in public canteens and schools;
- wants to enhance trust in the EU organic logo and prevent fraud; improve traceability including by applying innovative technologies to creating digital product passports; and
- aims to obtain commitments from retailers, wholesalers and other distributers for the sale of organic products.

To support the **production and processing** of organic products, the European Commission:

- aims to stimulate the conversion of holdings to organic production with CAP support;

[32] Upcoming relevant initiatives include the ‘Carbon farming initiative’ (2021), the ‘Regulatory Certification Framework for removals’ (2023)
EU Soil Strategy – Summer 2021

[33] The European Green Deal still emphasized the need to ensure rapid adoption of the EC’s proposal on value added tax, so that member states could make use of a lower VAT rate on organic fruit and vegetables.

- develop a sector analysis;
- support the organization of the food chain; and
- reinforce local and small-volume processing.

To improve the contribution of organic farming to **sustainability** the European Commission intends to:

- increase research, innovation and knowledge exchange on how to increase yields;
- fund research on alternative approaches to contentious inputs (such as copper); and
- adopt a framework on plastic use.

The **Common Agricultural Policy (CAP)** remains the main policy instrument of European agricultural policy. A reform of the CAP has been delayed and is now expected to come to effect January 2023. The European Commission wants to work with EU Member States to ensure that national strategic plans for agriculture reflect the ambitions of the European Green Deal and the Farm to Fork Strategy, leading to the use of sustainable practices such as precision agriculture, organic farming, agro-ecology, agro-forestry and stricter animal-welfare standards. While financial support to the agricultural sector still makes up more than one third of the entire EU budget (~58 billion in 2019), under 2% of the CAP budget is used for organic farming.[34]

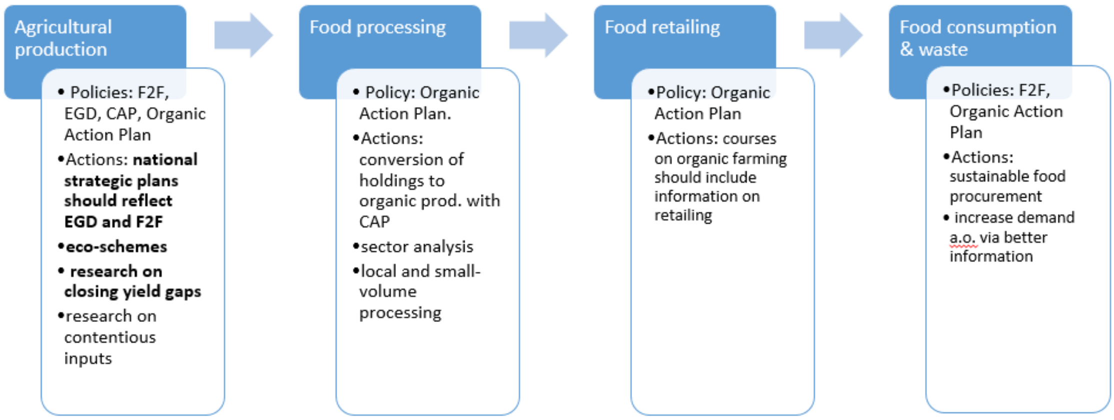
In the next CAP period, funds for organic farming shall be increased in order to reach the 25% target. Currently organic farming is subsidised via the second pillar of the CAP, which supports rural development. In the next CAP period one new instrument will be so-called eco-schemes under which a number of practices, including organic farming, shall be supported (European Commission, 2021d). EU Member States will have to set eco-schemes in their CAP strategic plans and the European Commission has to approve them. The schemes will entail a budget of €38 – 58 billion (period 2023 – 2027)[35] and make up at least 25% of the direct payments.[36] So while they are optional, not taking advantage of the schemes means a reduction of direct payments to farmers. Finally the EU agri-food promotion policy should support boosting demand.[37]

Currently, 8.5% of European agriculture is organic (European Commission, 2021i, p.1). The **transition pathway to reach the European target of 25% organic farming** woven from the policy instruments presented above focusses strongly on the production side (see Figure 4 and Table 1). While a certain focus on the production side is necessary, the other elements of the system—food processing, food retailing and consumption—are hardly targeted. The role of low food prices is hardly mentioned and the pricing power of large retailers, for example, is not addressed.[38] If current trends continue, it is expected that the food sector as a whole will be characterised by even higher competitiveness and export orientation in the future (EEA, 2019d, p. 354).

[34] https://ec.europa.eu/commission/presscorner/detail/en/IP_21_1275
[35] https://ec.europa.eu/commission/presscorner/detail/en/IP_21_1275
[36] https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/new-cap-2023-27_en
[37] https://ec.europa.eu/commission/presscorner/detail/en/QANDA_21_1277
[38] Albeit the investigation of the legal possibility of forming or joining specific organic producer organisations aim at strengthening farmers vis a vis unfair trading practices (see Organic Action Plan p. 14).

The Organic Action Plan aims to increase the *demand* for organic products, but the proposed instruments focus on soft measures such as increasing information on the benefits of organic farming and on labelling. The main policy instrument to achieve the objectives of the EGD, the F2F and the Organic Action Plan remains the CAP, its eco-schemes and national strategic plans.

Figure 4. Overview of key policy documents that aim to increase organic agriculture, grouped according to the food-system elements they target



Note: authors' depiction

However, even without the new CAP in effect the organic sector is growing with regard to area, producers and markets. Organic farmland increased by 5.9% in 2019[39] and is expected to reach 15-18% or total agricultural land by 2030[40] without any additional measures and possibly the targeted 25%, if the eco-schemes and other policy actions mentioned above lead to closing the remaining gap.[41]

If this is the case, is the problem solved? Unfortunately not – the transition pathway emerging from policy documents today may achieve 25% agricultural land under organic farming in 2030 but may also lead to a number of unintended environmentally harmful side effects for various resources. The resource-nexus approach shows why this could happen.

[39] https://www.fibl.org/en/info-centre/news/european-organic-market-grew-to-euro-45-billion-in-2019
[40] https://ec.europa.eu/commission/presscorner/detail/en/IP_21_1275
[41] With regard to the transition pathways in the member states it is important to note that there are significant differences between the share of organic farming in the countries, ranging from 0.5% to over 25%. While the 25% target for organic farming is an EU target these differences (will) have consequences on the effect of 25% organic farming in the EU: The benefits of organic farming will be unevenly distributed, which is especially problematic with regards to the effects on biodiversity – local biodiversity can only be saved locally. See: https://ec.europa.eu/commission/presscorner/detail/en/QANDA_21_1277.

5.3 A resource-nexus perspective on organic farming and pesticide use

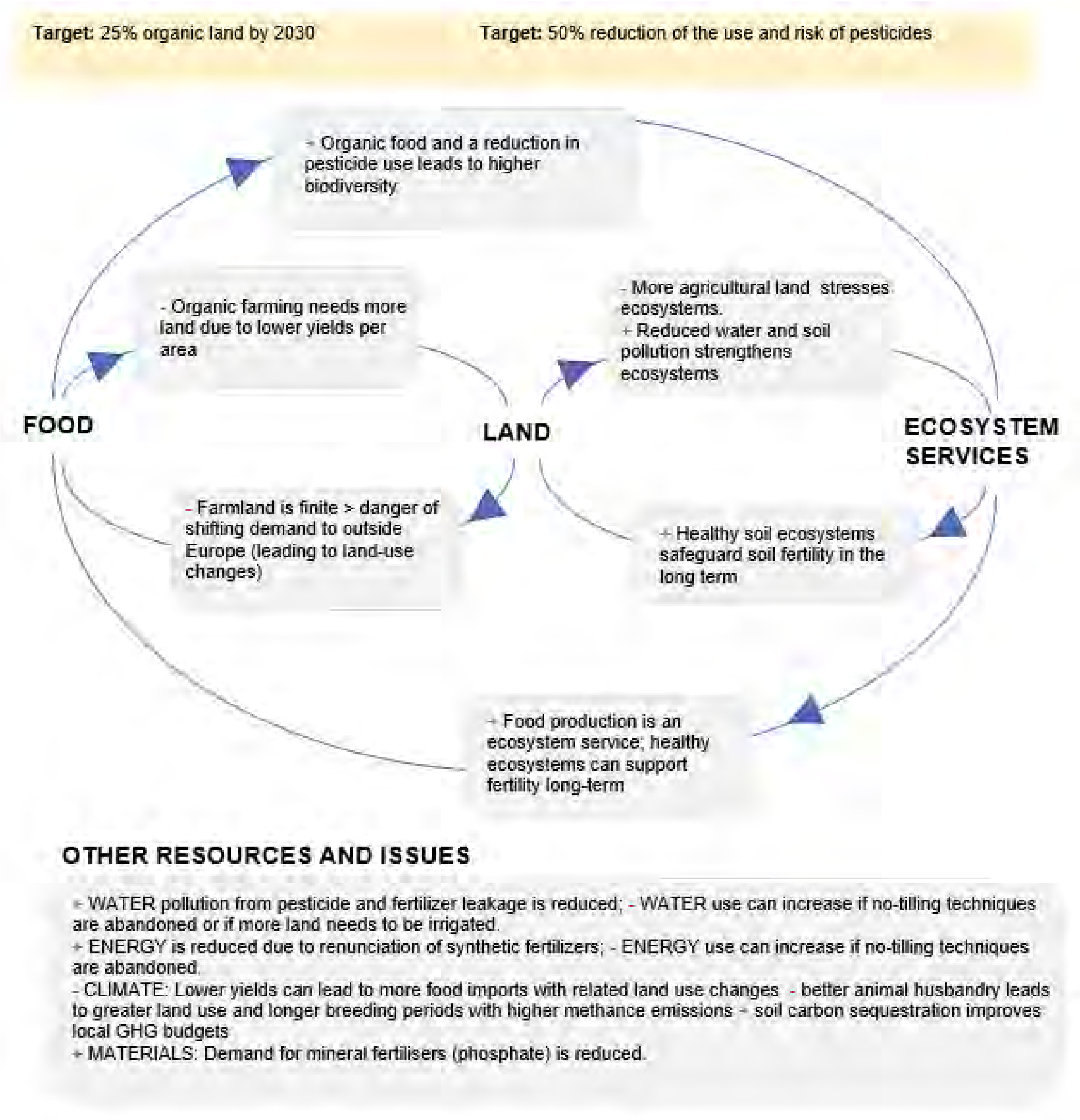
5.3.1 The value of the resource-nexus approach for navigating the transition pathway for organic farming and pesticide-use reductions

The European Green Deal acknowledges the interconnectedness of food production with other key systems: It recognizes the role of food production for climate change and biodiversity loss (p. 7), as well as air, water and soil pollution and the consumption of natural resources. The current production patterns and food waste are addressed, as are food-related health problems such as obesity and other diseases (p. 11).

While the European Green Deal, the Farm to Fork Strategy and the Biodiversity Strategy do, to some extent, recognize the interconnections between food production and other key resources, taking organic farming into focus and looking at the proposed transition, it becomes clear that a systematic nexus approach could help develop better policy.

The documents do not provide a transition pathway that covers the full value chain. The Organic Action Plan provides a more holistic approach, but the effects on other resources are considered only selectively. For example, the positive effects of organic farming on biodiversity are mentioned, but the lower yields of organic crops are debated only in the context of economic viability, not in the context of land use. **Figure 5** depicts the key interconnections of organic food production with several resource nodes: water, land and energy. Additionally, the interconnection climate change is presented. While a full presentation of all real-world connections is not possible, an overview of the most important interactions helps identify shortcomings of the current transition pathways and leads to considerations regarding how they might have to be improved in order to shift to more organic farming in a way that maximizes benefits on all key resources, while minimizing trade-offs.

Figure 5. Resource node interconnections of increasing organic farming



Note: figure design based on Pasqual, et al. (2018)

5.3.2 Increasing organic farming: synergies and trade-offs with selected resources

The following overviews describe the key synergies and trade-offs of increased organic farming with other resource nodes, including ecosystem services, water, land and energy. In addition, synergies and trade-offs with the topics of climate and health are described.

Ecosystem services:

+ The positive effects of organic agriculture and a decrease in the use of pesticides on ecosystem-services have been major arguments for promotion of these goals via public policy. Land farmed organically is around 30% richer in biodiversity (Organic Action Plan, p. 1) with advantages for above- and below-ground biodiversity (Tuck et al., 2014, p. 746, IPBES 2019, p. 59). [42]

+ The higher biodiversity naturally encompasses pollinators, thus the European target of reversing the decline of pollinators is also supported.

+ /- The target for 25% organic agriculture is a European target. Ecosystems in laggard countries will still be under pressure from conventional agriculture, even if the target is reached. The shift to organic agriculture will take place where nation states and the economy support it, not necessarily where it would be most beneficial for ecosystem services, such as biodiversity. While this is not a negative impact of organic agriculture on ecosystem services, it is a limit to the benefits of organic agriculture on ecosystem services.

- Bio-pesticides used in organic farming, such as copper, can harm soil and aquatic organisms, earthworms as well as small mammals and birds (Wilbois et al., 2009, p. 142). Especially the reduction of earthworms in turn reduces soil fertility in the long term.

Food

- Organic agriculture has a lower temporal stability per unit yield (-15%), as pests and diseases are more difficult to control. As the world population keeps growing and societies strive to improve diets at the same time, food demand is expected to rise for another 40 years. Lower yields and crop losses can increasingly endanger food security (Connor, 2014, 187-190). Finding solutions to increase temporal stability are therefore needed. (Knapp and van der Heijden, 2018, pp. 2, 4).

+ / - While food security will most likely not be a major problem in Europe due to the ability of most Europeans to pay higher food prices, food security may decrease for low-income countries, as more land outside Europe is used to grow organic food for Europeans. [43] Even if food security is ensured, price increases due to a shift to organic agriculture may put lower-income households at a disadvantage, worsening their diets. However, there is also scientific evidence that organic systems, characterised by diversified crops, have shown to be more resilient to extreme climatic events thus increasing food security for small scale farmers under more extreme climatic conditions (FAO, 2021, p. 6).

+ higher food quality (benefits to health)

- Some regions may not be able to increase organic farming under current conditions, if there is not enough livestock farming – and thus not sufficient manure (Hirschnitz-Garbers and Langsdorf, upcoming).

[42] https://ec.europa.eu/commission/presscorner/detail/en/IP_21_1275

[43] A study of the United States Department of Agriculture (2020) estimates that the reductions in the use of land, fertilizers, antimicrobials and pesticides will increase the number of food insecure people globally by 22 million. While the study refers to the Farm to Fork Strategy in general, the shift to more organic farming is a key tool to achieve the reductions of fertilizer, antimicrobial and pesticide use. Researchers have questioned the scenario assumptions and modelling of the study stating that it leads to overly pessimistic results. But they also acknowledge that reducing plant protection and fertilizer will reduce output and thus will lead to land use changes outside Europe (see Zimmer, 2020).

Water

+ Organic farming helps reduce water pollution as no chemical fertilizers are used and the use of pesticides and antimicrobials is reduced. Agriculture is the biggest polluter of European freshwater, via pesticides, fertilizers such as nitrogen and phosphorus, and other agrochemicals (WWAP, 2015). The run-off of excess nitrogen and phosphorous creates imbalances in aquatic ecosystems, leading to eutrophication and hypoxia. This in turn affects aquatic biodiversity (EEA 2020g, p. 31) and fishing yields. However, while the overall impact of organic farming on water sources is better than from conventional farming, scientific uncertainties remain, especially with regard to phosphorus leakage (Seufert and Ramankutty, 2017, p. 6f; FAO, 2017, 3ff,).

+ Organic soils have higher water-holding capacities, but scientific evidence is not clear on the water use per unit output (Seufert and Ramankutty, 2017, p. 8).

- Potential increase in water use as some farmers that currently use no- or low-till techniques in conventional agriculture may need to use the plough again in order to control weeds as they shift to organic farming, leading to increased water evaporation. No- or low-till agriculture techniques usually control weeds through use of total herbicides (glyphosate).

Land

- Organic farming leads to higher land use as reductions in chemical and pesticide input increase crop losses and make agriculture less intensive. The yield gap varies between regions (with higher gaps in northern Europe) and crop groups. For oilseeds, the gap is a low 1%, for legumes approximately 5% and higher for potatoes or cereals (EEA, 2020g, p. 67). Some experts estimate that average organic yields are 80% of conventional yields (de Ponti et al., 2012, p. 8), while others calculate the yield gap to be significantly higher. A research group that aimed to assess the effects of a shift to 100% organic food production in England and Wales using a life-cycle-assessment predict a drop in total food production (in metabolizable energy) of around 40% (Smith et al. 2019, p. 2; IPBES, 2019, p. 59).

+ Soil is a key component of land. Soil erosion seems to be lower under organic farming, due to a better soil structure. Soil health and fertility (measured by nutrient status or physical properties) are higher (Seufert and Ramankutty, 2017, p. 3), which might somewhat reduce the yield gap per unit of area land in the long term.

+ Water-retention capacities on organic farmland can be higher due to the soil conservation techniques often applied in organic farming, such as incorporating crop residues. This increases resilience against droughts (EEA, 2020g, p. 80), which will become increasingly important under a changing climate.

Energy

+ Energy use is reduced due to the renunciation of synthetic fertilizers. Synthetic nitrogen fertilizers need to be manufactured in a highly energy-intensive process. Ammonia, a key chemical, produced via the Haber-Bosch process, is the most energy-intensive commodity chemical, responsible for 1-2% of global energy consumption (Kyriakou et al. 2020, p. 142). Natural gas is required as a raw material and an energy source in the production of ammonia. As natural gas prices rise so will prices for synthetic nitrogen fertilizers. In 2021, producers of fertilizer have partly shut down their production due to rising gas prices, leading to a shortage of nitrogen fertilizer (Agrarheute 2021). Organic farmers are not allowed to use synthetic fertilizer and are thus not negatively affected by these developments.

- There is a potential increase in energy use as some farmers that shift from conventional to organic farming may give up no-till agriculture techniques, as these often require herbicide use, resulting in increased energy used for tilling.

- (?) While energy demand per unit of area is better under organic farming than under conventional farming, results are varied per unit of products, depending on crop, area and agricultural technique. (Smith et al. 2015, p. 280; Gomiero, Paoletti and Pimentel, 2008, p. 244f, 250), especially at the aggregate scale, as overall demand for land is likely to increase (see also ‘Land’).

Materials

- temporal stability of the produce is lower, leading to potential wastage and increased waste flows (see also ‘Food’)

+ fertilising with manure reduces demand for synthetic fertilizers and phosphate rock

Climate

-/+ GHG emissions can be lower under organic agriculture, but the net effect depends on a number of issues, including the yield gap. Skinner et al. (2014, p. 553) estimate that the gap must be under 17% for the net balance to be positive.

+ Organic farming has approximately 40% lower N_20 emissions compared to conventional farming (Skinner et al., 2014, p. 553). Through the management of nutrients, N_20 emissions from soils can be significantly reduced (Scialabba and Müller–Lindenlauf, 2010, p. 158).

+ Soil carbon storage may be another positive effect of organic farming, but to date it remains up for debate how this effect plays out in the long term (Seufert and Ramankutty, 2017, p. 5)

- Higher land-use and longer rearing times for livestock increase the greenhouse gas emissions per kg of meat produced. (Smith et al., 2019, p. 2f; Pieper et al., 2020)

- If the yield gap leads to a shift of agricultural production to outside of Europe this can have a negative climate impact due to land-use changes and emissions from transporting food to Europe (Smith et al., 2019, p. 1).

Health

+ While the health effects of organic food versus conventionally produced food are not yet fully quantifiable, there is evidence that organic foods are higher in antioxidant and omega-3 fatty acid concentrations in meat and dairy products. Organic crops also have lower cadmium and pesticides levels (Baranski et al. 2017, p. 1).

+ It has been estimated that 50%-80% of global antibiotics are used prophylactically in animal husbandry, contributing to the evolution of antibiotic-resistant bacteria. The use of antibiotics is strongly restricted in organic farming, EU regulations do not allow routine prophylactic medication (Mie et al. 2017, p. 11f).

+ Excess nitrates in drinking water can harm health as it affects the transport of oxygen by the blood to the tissues, leading to cyanosis (EEA, 2020f, p. 31). While nitrate run-off can occur on both conventional and organic farms there is some evidence that nitrate leaching is lower on organic farms (Benoit et al. 2014, p. 285).

Shifting burden outside the EU

- Land-grabbing i.e. large-scale transnational acquisitions of land, mostly in developing countries, which is often associated with evicting people or taking away access to land, water and other related resources for the rural poor (UNCCD, 2017), could be intensified if land demand associated to organic agriculture cannot be met in Europe. However, this could be substantially mitigated by change in consumption levels and patterns.

Table 2 presents an overview of the potential natural resource implications associated with this case study.

Table 2. Overview of potential synergies and trade-offs for increasing organic agriculture

Nexus nodes	Key insights: potential synergies (+) and trade-offs (-)
Ecosystem services	+ land farmed organically is around 30% richer in biodiversity, yet bio-pesticides used in organic farming can still harm soil and aquatic organisms
	- manure from livestock farming might become a bottleneck
Food	- food security may be reduced and become more import-dependent given limited availability of agricultural land
	- lower yields and crop losses can increasingly endanger food security for low-income households
	+ higher food quality (see 'Health')
Water	+ Organic farming helps reduce water pollution as no chemical fertilizers are used and the use of pesticides and antimicrobials is reduced.
	+ Water-retention capacities on organic farmland can be higher due to the soil conservation techniques, increasing resilience against droughts.
	- Water use might increase to control weeds, leading to increased water evaporation.
Land	- organic farming is often associated with higher land use, as reductions in chemical and pesticide input increase crop losses
	+ soil erosion is possibly reduced due to a better soil structure. Both soil health and fertility increase, reducing the yield gap and land demand.
Energy	+ energy use is reduced due to the renunciation of synthetic fertilizers (highly energy intensive)
	- increased energy demand if no-tilling techniques are abandoned and if cultivated land increases significantly
Materials	+ the demand for mineral fertilizers is reduced, as organic agriculture is based on recycling manure
	- Organic agriculture has a lower temporal stability per unit yield, so it can lead to higher wastage
Other aspects	
Climate	-/+ GHG emissions can be lower under organic agriculture, but the net effect depends on the yield gap and other issues

	+ Soil carbon storage may be another positive effect of organic farming, but its long-term effect remains unclear
	- Higher land-use and longer rearing times for livestock increase the greenhouse gas emissions per kg of meat produced.
Health	+ lower cadmium and pesticides residues
	+ the use of antibiotics is strongly restricted in organic farming
	+ nitrate leaching in drinking water is likely to be lower on organic farms
Shifting burden outside EU	- 'land-grabbing' i.e. largescale transnational acquisitions of land, mostly in developing countries, taking away access to land, water and other related resources for the rural poor could be intensified if land demand associated to organic agriculture cannot be met in Europe. This could be substantially mitigated by change in consumption levels and patterns.

Note: the direction and the intensity of the synergies (+) and trade-offs (-), are based on a review of literature and expert opinion.

5.4 Conclusion: How can the resource nexus approach help create a more sustainable transition pathway for organic farming and pesticides?

Organic farming and reduced pesticide use can have clear benefits for the environment, from carbon storage in the soil, to reducing pesticide leakage, to higher soil health and increasing biodiversity. At the same time, effects differ strongly from region to region and between production techniques chosen.

The relation of increased organic farming to climate-change issues illustrates the complex interactions: Organic farming can play a positive role in the fight against climate change as it can have lower CO_2 and N_2O emissions. Furthermore, the renunciation of synthetic fertilizers saves energy. However, methane emissions from organic farming (animal husbandry) are higher per kg meat produced due to higher land-use and longer rearing times. Other issues are still unclear: soil carbon sequestration may play a role in binding carbon, but long-term effects are not yet fully understood. So while organic farming *can* play a positive role in reducing GHG emissions, the specifics in the transition of the food system count. As of today, the yield gap between organic farming and conventional farming has not been closed. A yield gap increases land use. If the production of agricultural products shifts increasingly outside Europe due to the shift to organic farming, emissions to import foods to Europe increase as would emissions from land-use changes abroad. If farmers take up organic agriculture, energy and water saving no-tilling (or strip-seeding) techniques become highly challenging without total herbicides (glyphosate). Organic farming techniques[44], such as specific crop-rotations can allow no or low tilling; however, these are sophisticated techniques that require local research and may lead to massive crop losses in the experimentation phase. Most European farmers cannot afford long experimentation phases financially.

[44] Other approaches that may hold potential to counter some of the unintended side-effects or organic farming include agroforestry, silvopastoralism and permaculture. All these options should be further developed and be studied scientifically.

Research and support would be needed to support the introduction of these complex farming techniques.

How the knowledge from the resource nexus could help creating a more sustainable transition pathway – selected concrete suggestions:

The analysis of the transition pathway in current policy documents (see Section 5.2) has shown that there is a focus on the production side in the European Green Deal, the Farm to Fork Strategy and the CAP. The Organic Action Plan emphasises the demand side – but suggests mainly soft policy instruments. The resource nexus effects of production-side measures and consumption-side measures differ. To achieve the goals of the European Green Deal, it is important to develop transition pathways that allow for a transition of the consumption and production system, covering the entire value chain.

The resource interconnections have shown the benefits of organic farming especially for biodiversity and against water pollution, but also likely problematic effects regarding land use and possibly energy and water use, stemming mainly from the yield gap and the difficulty for no- or low-tilling techniques.

The transition pathway to increased organic farming thus requires changes on both the production and consumption sides:

1. **On the production side** -- More research on closing the yield gap and on organic farming techniques (such as crop rotations) is required. Supporting research and innovation on improving organic yields is already listed in the Organic Action Plan (p.19). In the budget negotiations for European research the European Commission needs to ensure that this research will be long term, sufficiently funded and carried out over a large variety of agricultural regions in Europe. It must furthermore be ensured that the knowledge gained is then distributed widely among European farmers and that their support is ensured. Research and innovation on organic farming techniques to reduce the environmental effects of organic farming (such as increased energy or water use due to tilling) is not yet addressed in the Organic Action Plan. This research should be included in the next funding period and results widely distributed (Schefer, 2020, p. 2).
2. **On the consumption side** - Greater changes need to happen on the consumption side. Organic food production requires more land, and farmland in the current consumption system is scarce. However, it need not be: today one fifth of food in the EU goes to waste while two-thirds of cereal production is used for animal feed. The trade-offs of organic farming could be balanced out, if consumption patterns changed.[45] Applying a resource nexus lens shows that there is no sustainable food system if diets don't change and if food waste is not tackled (UNEP, 2021; FAO 2019). While there is considerable effort on the latter[46], the consumption habits and diets do not feature in actual policy making. A shift to agroecology in Europe has been modelled and led to 40% reduction in GHG emissions from the agricultural sector, regaining biodiversity and a smaller global food footprint of Europe – despite a drop in production of 35% compared to 2010 (in Kcal) – if diets *and* agricultural technologies change (IDDRI, 2018, p. 3-6)

[45] https://www.wwf.eu/?4180941/Farm-to-Forks-targets-well-within-reach-confirms-JRC-study
[46] See here: https://ec.europa.eu/food/safety/food-waste/eu-actions-against-food-waste_en

Critics may argue that a need to avoid food waste and to change diets is hardly news. This is true. However, the value in applying the resource nexus is that it provides a neutral approach that brings together all relevant resource interconnections. In this concrete case study, it sheds light on a number of things:

1) The resource approach brings important information to all participants of the debate. For example, while the advantages and difficulties of no or low tilling techniques are obvious to all farmers, they are probably not well known outside the farming world – but worth understanding when pushing for more organic farming.

2) The key challenge for reducing the environmental burden of agriculture does not lie in achieving more organic farming; the key challenge lies in achieving more organic farming as part of an approach that also results in an overall conservation of resources and environmental protection. The current transition pathway does not yet cover the most important elements to achieve this. This may well be due to the emotional debate that revolves around eating habits. Equally, the communication between those in favour of organic practices and those in favour of conventional practices is often characterized by confrontation (Hirschnitz-Garbers and Langsdorf, forthcoming). A resource nexus approach can serve as a communication tool here, helping a constructive debate on the best policy solutions.

Table 3. Annex: Actions listed in the European Green Deal and related documents that relate to the increase in organic agriculture and reduction in pesticide use, sorted by production and consumption side (main target).

Policy/action	**Document**	**Time**	**Effect (direct/indirect)**	**Binding (yes/no/? [unclear])**	**Impact (high /medium /low)**
Actions targeting the production and consumption side					
Stakeholders to identify and remedy incoherent legislation that reduces the effectiveness in delivering the European Green Deal	EGD Annex		indirect	no	low
Proposal for a legislative framework for sustainable food systems	**F2F (Annex)**	**2023**	**indirect**	**yes (if legislation comes to effect)**	**high (if legislative)**
Actions targeting the production side					
Adopt recommendations to MS on implementing the future Common Agricultural Policy (CAP), before submission of draft Strategic Plans (2020)	F2F		indirect	no	med.
Examination of the draft national strategic plans, with reference to the ambitions of the European Green Deal and the Farm to Fork Strategy	EGD Annex	2020-2021	indirect	?	med.

Measures, including legislative, to significantly reduce the use and risk of chemical pesticides, as well as the use of fertilizers and antibiotics	**EGD Annex**		**Direct (if legislation comes to effect)**	**yes (if legislation comes to effect)**	**high (if legislative)**
Proposal for a revision of the Sustainable Use of Pesticides Directive to significantly reduce use and risk and dependency on pesticides and enhance Integrated Pest Management	F2F (Annex)	Q1 2022	direct	yes (once proposal is adopted)	high (depending on ambition)
Revision of the relevant implementing Regulations under the Plant Protection Products framework to facilitate placing on the market of plant protection products containing biological active substances	F2F (Annex)	Q4 2021			
Proposal for a revision of the pesticides statistics Regulation to overcome data gaps and reinforce evidence-based policy making	F2F (Annex)	2023	indirect	yes (once proposal is adopted)	low
Evaluation and revision of the existing animal welfare legislation, including on animal transport and slaughter of animals	F2F (Annex)	Q4 2023			
Proposal for a revision of the feed additives Regulation to reduce the environmental impact of livestock farming	F2F (Annex)	Q4 2021			
Proposal for a revision of the Farm Accountancy Data Network Regulation to transform it into a Farm Sustainability Data Network with a view to contribute to a wide uptake of sustainable farming practices	F2F (Annex)	Q2 2022			
Clarification of the scope of competition rules in the TFEU with regard to sustainability in collective actions.	F2F (Annex)	Q3 2022			
Proposal for a revision of EU marketing standards for agricultural, fishery and aquaculture products to ensure the uptake and supply of sustainable products	F2F (Annex)	2021-2022			

Actions targeting the consumption side						
Determine the best modalities for setting minimum mandatory criteria for sustainable food procurement to promote healthy and sustainable diets, including organic products, in schools and public institutions	F2F (Annex)	Q3 2021				

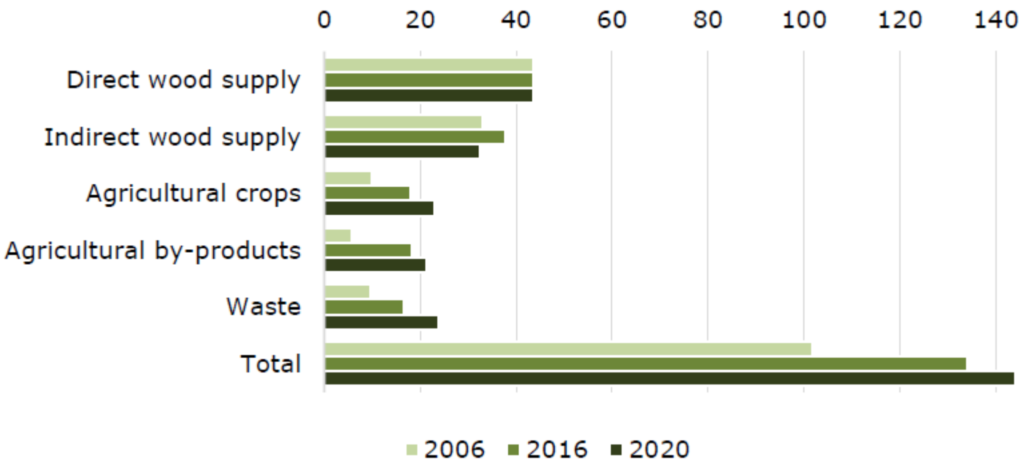
* Presumed high impact actions in **bold**.

6 Case study 2: a resource nexus lens on current EU plans to increase the production of bioenergy

Biomass can be converted into energy via combustion of solid biomass or after being refined into biofuel (a liquid) or biogas (a gas).[47] Biomass accounts for approximately 60% of renewable energy (and 10% of total energy) consumed in the EU. About 75% of bioenergy consumed goes to heating and cooling, with the remainder going to bioelectricity (13%) and transport biofuels (12%). Data on imports shows only 4% of biomass for energy is imported but this only includes direct trade of biomass for energy and does not include indirect trade (e.g. crops for food and feed that are partly used for bioenergy). Ninety-three percent of biomass is converted into energy in the same Member State from which the biomass is sourced. More than 60% of EU biomass used for energy comes from forestry, about 27% comes from agriculture and about 12% comes from waste (all figures from Scarlat, et al., 2019, pp. 1-3).[48]

Figure 6 provides an overview of the domestic EU primary energy supply of biomass for energy, showing supply for 2006 and 2016 alongside projected figures for 2020.

Figure 6. Domestic EU primary energy supply (Mtoe)



Note: Figure reproduced from Scarlat, et al. (2019, p. 2). Figures for 2020 are projected. Indirect supply of woody biomass includes: residues from sawmilling, woodworking, furniture industry (bark, sawdust), by-products of the pulp and paper industry (black liquor, tall oil) or processed fuelwood, post-consumer recycled wood (recycled wood for energy generation, household waste wood).

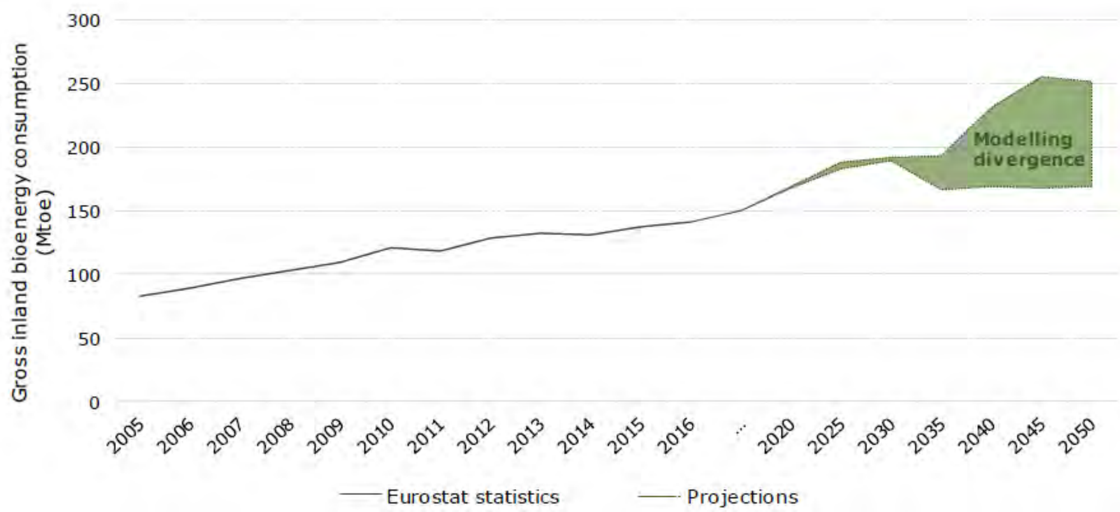
[47] The EU Energy System Integration Strategy defines **biofuels** as “liquid fuels produced from biomass, through a variety of processes and using a variety of feedstock, such as biodiesel, bioethanol and Hydrotreated Vegetable Oils (HVO)”, and **biogas** as “a gaseous mixture (primarily methane and carbon dioxide) produced from biomass, through the decomposition of organic matter in the absence of oxygen (anaerobically). Biogas can be used directly as a fuel, or be purified or ‘upgraded’ into biomethane, which can thus be used for the same applications as natural gas and injected into the gas grid.” (European Commission, 2020a, EU Energy System Integration Strategy, p. 11).

[48] Please note: statistics are for the year 2016 and pertain to the EU-28, including the UK.

Use of bioenergy in the EU has been growing and is projected to continue to grow. From 2005-2016, EU bioenergy consumption increased by more than 60%. The fastest growing subsector during this period was bioelectricity, which experienced growth of 160%, albeit growing from a very low initial level (Scarlat, et al., 2019, p. 4). The UK, which is included in the above statistics, was the fifth largest consumer of bioenergy in 2016 among EU Member States; its departure from the EU is not reflected in the above numbers.

Biofuels, biogas and biomethane—all based largely on food and feed crops--currently account for 3.5% of all gas and fuel consumption in the EU (European Commission, 2020c, p. 11).

Figure 7. Gross inland bioenergy consumption 2005-2016 and projections until 2050 (Mtoe) – EU-28 (includes UK)



Note: Figure reproduced from Scarlat et al. (2019, p. 6). Projections until 2050 are based on European Commission mitigation scenarios (for further details and links to the scenarios, please see Scarlat et al. (2019, p. 6).

Camia, et al. (2021) characterise the sustainability challenges related to biomass production as follows:

> “The demand for biomass is increasing worldwide yet climate change, increasing pressures on the environment and large-scale loss of animal and plant species are threatening biomass availability. The challenge we face is thus to reconcile this increased demand for biomass, aware of all its advantages in replacing fossil-based materials and fuels, with the sustainable management, including protection and restoration of the forest ecosystems that are producing it. The success with which we will be able to meet the ambitions of the European Green Deal, to take the path of a green recovery towards making Europe the first climate neutral continent and to restore biodiversity, will depend to a large extent on the ways in which we use our natural resources from the land and the sea to produce food, materials and energy.” (p.16).

Production of bioenergy is a resource-intensive activity that relates to all six nodes of the resource nexus—land, ecosystem services, food, water, energy and materials. Past expansion of bioenergy production—largely motivated by concerns about climate change—has caused unintended negative environmental effects such as indirect land-use change and diversion of food crops to energy production. EU policies have been revised to counter such effects, making the bioenergy policy framework a forerunner among multi-resource and systemic approaches to resource management. Despite this progress, ensuring sustainable use of bioenergy remains what Camia et al. (2021) refer to as a “wicked problem” that sits at the crossroads of the two greatest environmental challenges of the 21st century—biodiversity loss and climate change—and is “characterised by uncertainty about consequences, diverse and multiple engaged interests, conflicting knowledge claims and high stakes” (p. 6).

This case study presents how a resource-nexus approach could support increased awareness of these complex interconnections and help develop effective transition pathways to increased production of sustainable bioenergy, with a particular focus on advanced biofuels for transport. For readers seeking further background information on bioenergy, the recommended reading shown in Box 3 covers both biomass and biofuels in the EU context.

Box 3. Recommended reading: recent in-depth examinations of EU bioenergy issues

Advanced biofuels – Panoutsou, et al. (2021). Advanced biofuels to de-carbonise European transport by 2030: Markets, challenges, and policies that impact their successful market uptake (link); European Commission (2020e). Renewable energy: biofuels (link)

Biomass – Scarlat, et al. (2019). Brief on biomass for energy in the European Union (link); European Commission (2020f). Renewable energy: biomass (link)

Woody biomass – Camia et al. (2021). The use of woody biomass for energy purposes in the EU (link)

Note: Full citations can be found in the reference section.

6.1 Policy framework: vision, targets and transitions

Aiming to address climate change rapidly with ambition, the European Green Deal sets an objective of climate neutrality by 2050 for the EU. As a mid-term milestone in this transition, the European Parliament and European Council agreed a 2030 target of achieving a 55% reduction in greenhouse gas emissions (European Commission, 2021c). More than 75% of EU greenhouse gas emissions stem from the production and use of energy (Eurostat, 2021e)[49], which makes a profound shift to renewable energy an essential component of the European Green Deal. Alongside this, issues of energy affordability and energy security remain central concerns of the EU and Member States.

The European Green Deal proposes new targets relevant to bioenergy production that raise the level of ambition regarding renewables. Table 1 provides an overview of existing 2030 targets in the current policy framework as well as proposed targets in the context of the European Green Deal.

[49] About seventy-eight percent of total EU greenhouse gas emissions stemmed from energy use in 2018, with energy producing industries accounting for 28.0 % of total greenhouse gas emissions, fuel combustion by users for 25.5 % and the transport sector for 24.6 % (Eurostat, 2021e).

Table 4. Existing and proposed targets most relevant to bioenergy

Subsector	Target
Existing targets for 2020	• Reduction of the greenhouse gas intensity of transport fuels In EU Member States by at least 6% by 2020 compared to 2010, with Member States obliged to ensure that suppliers respect the target of 6% after 2020 (set in the Fuel Quality Directive).
Existing targets for 2030	• At least 40% cuts in greenhouse gas emissions, compared to 1990 levels[50] • At least 32% share for renewable energy (set in the Renewable Energy Directive (REDII)) • At least 32.5% improvement in energy efficiency relative to a business-as-usual scenario • Annual average increase of 1.3% in share of renewable energy for the heating and cooling sector in each Member State • After December 2023, “the share of high indirect land-use change biofuels, bioliquids and biomass fuels produced from food or feed crops for which a significant expansion of the production area into land with high carbon stock is observed” must be reduced to zero by 2030 (set in the Renewable Energy Directive (REDII)).
European Green Deal targets for 2030 (as proposed by the European Commission in its Fit for 55 package)	• At least 55% cuts in greenhouse gas emissions, compared to 1990 levels • At least 40% share for renewable energy (2030 Climate Target Plan) • At least 36-39% improvement in energy efficiency • At least 2.2% share for advanced biofuels and biogas in transport[51,52]

Sources: European Commission (2021a), European Commission (2021e) and European Commission (2021h)

Describing the European Commission’s foreseen transition pathway for bioenergy under the European Green Deal, the EU Strategy for Energy System Integration states that:

[50] The European Commission states that „The 40% greenhouse gas target is implemented by the EU Emissions Trading System, the Effort Sharing Regulation with Member States' emissions reduction targets and the Land use, land use change and forestry Regulation. In this way, all sectors will contribute to the achievement of the 40% target by both reducing emissions and increasing removals“ (European Commission, 2021a).

[51] Without multipliers in all transport modes, including international aviation and international marine bunkers (European Commission, 2021e).

[52] The EU Strategy for Energy System Integration states that „the use of “advanced” biofuels and biogas (gained from certain residues and by-products from agriculture and forestry activities, industrial and municipal waste in full respect of the waste hierarchy, and other ligno-cellulosic material) is encouraged under the Directive 2018/2001. Biofuels and biogas need to meet sustainability requirements to be statistically accounted as renewable under that Directive” (European Commission 2020c, p. 12). Annex IX of RED II defines what qualifies as an “advanced biofuel”.

> "[b]iofuels will have an important role to play, notably in hard-to-decarbonise transport modes, such as aviation or maritime – including through hybridisation projects linking biofuels and renewable hydrogen production. The Commission will in particular explore how to support to [sic] the quick development of innovative low-carbon fuels such as advanced biofuels, alongside synthetic fuels, across the whole value chain of the industry in Europe, leading to better coordination of the market actors and rapid increase of production capacity. Biomethane can contribute to the decarbonisation of the gas supply. However, the deployment of biofuels and biogases has so far been hampered by regulatory uncertainty. The revised Renewable Energy Directive has taken a first step to address these issues by introducing a target of 3.5% for the consumption of advanced biofuels and biogas in transport. The 6% greenhouse gas emission target of the Fuel Quality Directive also supports the deployment of biofuels. In addition, the Communication 'The role of Waste to Energy in the circular economy' clarifies which waste-to-energy approaches are more sustainable, including for the production of biomethane, while the Biodiversity Strategy underlines that the use of whole trees and food and feed crops for energy production should be minimised" (European Commission, 2020c, pp. 11-12).

Box 4 reproduces the European Commission's Q&A information regarding sustainable bioenergy that was provided 14 July 2021 in the context of describing the "Fit for 55" package for delivering the European Green Deal. As can be seen from the text, resource-nexus implications of bioenergy production are a central theme when discussing its sustainability, specifically its interrelations with the resource nodes energy, ecosystem services, land and food.

Box 4. European Commission Q&A regarding sustainable bioenergy

How will the Commission ensure that bioenergy is sustainable?

Bioenergy is a key part of the EU energy system, representing 12% of the overall energy mix and 60% of renewable energy consumption. Sustainable use of bioenergy contributes to the decarbonisation of the EU economy.

Climate neutrality will require increasing amounts of renewables and sustainable bioenergy will continue to play an important role. This is particularly important for hard-to-abate sectors in the context of an integrated energy system (e.g. heavy-duty transport and in industry). For several Member States, bioenergy is also indispensable as they transition away from fossil fuels towards cleaner energy sources.

The EU sustainability criteria for bioenergy were already significantly reinforced in the 2018 Renewable Energy Directive in order to reduce the risk of unsustainable bioenergy production and make sure that its use is efficient and results in high greenhouse gas savings. Its provisions cover biomass and biogas in heat and power, in addition to biofuels for transport. The directive also includes specific biodiversity and climate safeguards for forest biomass, which contributes around 60% of EU's bioenergy.

With today's proposals, the EU bioenergy sustainability criteria are further strengthened in line with the increased climate and biodiversity ambition of the European Green Deal:

- In order to further protect biodiversity-rich forests, the proposals prohibit the sourcing of woody biomass for energy production from primary forests, peatlands and wetlands, and only allows it from highly biodiverse forests when there's no interfere with nature protection purposes;

- It further specifies the sustainability criteria on harvesting and the maintenance of soil quality and biodiversity;
- To minimise the use of quality roundwood for energy production, undue distortive effects on the biomass raw material market and harmful impacts on biodiversity, the proposal promotes using biomass according to its highest economic and environmental added value (so-called cascading use). It prohibits national financial incentives which support the use of saw logs, veneer logs (high quality wood), and stumps and roots (that are important for the soil) for energy generation, and, under certain conditions, the production of electricity from forest biomass in electricity-only-installations;
- A future Delegated Act will set out which practices are considered to be in line with the cascading principle for minimising the use of quality roundwood for energy production, with due regard to national specificities. Further limitations regarding support schemes to forest biomass may be considered in the future, on the basis of a report on their impact on biodiversity and market distortions;
- To promote higher greenhouse gas savings, the directive will require all biomass-based heat and power installations to comply with minimum greenhouse gas saving thresholds. Currently this only applies to new installations;
- The EU sustainability criteria for biomass should in the future apply to smaller heat and power installations (equal or above 5MW) rather than the 20 MW threshold under the current directive.

These new measures will further ensure the sustainability of forest biomass used for energy production in the EU. They will also promote more resource-efficient use of biomass, minimising the risk of diversion of high quality roundwood away from high value uses such as construction or furniture making.

Underlining the importance of trees for the climate, and the environmental and economic benefits they provide, today's package also includes the new EU Forest Strategy aimed to increase EU forest area.

Source: Reproduced from European Commission, 2021, Questions and Answers - Making our energy system fit for our climate targets https://ec.europa.eu/commission/presscorner/detail/en/QANDA_21_3544

6.2 Key documents: existing framework and European Green Deal policy proposals for bioenergy

Existing framework - Directives

The directives relevant to bioenergy in the EU include:

- **RED II** – **Renewable Energy Directive (EU) 2018/2001** – Directive (EU) 2018/2001) of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources – (link)[53]
- **ILUC Directive** – **Directive to reduce indirect land use change for biofuels and bioliquids (EU) 2015/1513** — Directive (EU) 2015/1513 of the European Parliament and of the Council of 9 September 2015 amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources – (link)
- **FQD** – **Fuel Quality Directive 2009/30/EC** - Directive 2009/30/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 98/70/EC as regards the specification of petrol, diesel and gas-oil and introducing a mechanism to monitor and reduce greenhouse gas emissions and amending Council Directive 1999/32/EC as regards the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EEC – (link)
- **RED** – **Renewable Energy Directive 2009/28/EC** – Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC – (link)
- **Biofuels Directive 2003/30/EC** – Directive 2003/30/EC of the European Parliament and of the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport – *no longer in force after 31/12/2011 (repealed by Renewable Energy Directive 2009/28/EC)* – (link)

Key policy proposals in the context of the European Green Deal

The EU Strategy for Energy System Integration, part of the European Green Deal, identifies the revision of the Renewable Energy Directive along with proposed regulations regarding sustainable aviation and maritime fuels as opportunities to accelerate the development of the market for biofuels and biogases (European Commission, 2020c, pp. 11-12).

The following bullet points summarise bioenergy-relevant aspects of the three proposals:

- **Amendment to the Renewable Energy Directive to implement the ambition of the new 2030 climate target –** Regarding bioenergy, the proposed amendment strengthens sustainability criteria for the use of biomass for energy, stating that “the current REDII sustainability criteria for bioenergy need to be reinforced in a targeted way in light of the increased climate and biodiversity ambition of the EU Green Deal”

[53] RED II is the main EU policy promoting energy from renewable sources (see European Commission, 2018b). RED II “establishes a cap to first generation biofuels and limitations to high Indirect Land Use Change (ILUC) risk food and feedstocks, while reinforcing and extending sustainability criteria” (European Commission, 2020c, p. 11).

(European Commission, 2021e, p. 11). Box 5 illustrates how the proposal bases its revised sustainability criteria for bioenergy production on the interactions of nodes in the resource nexus.

Box 5. Resource nexus considerations and strengthened sustainability criteria in the proposed revision to the Renewable Energy Directive

There is a growing recognition of the need for alignment of bioenergy policies with the cascading principle of biomass use, with a view to ensuring fair access to the biomass raw material market for the development of innovative, high value-added bio-based solutions and a sustainable circular bioeconomy. When developing support schemes for bioenergy, Member States should therefore take into consideration the available sustainable supply of biomass for energy and non-energy uses and the maintenance of the national forest carbon sinks and ecosystems as well as the principles of the circular economy and the biomass cascading use, and the waste hierarchy established in Directive 2008/98/EC of the European Parliament and of the Council. For this, they should grant no support to the production of energy from saw logs, veener logs, stumps and roots and avoid promoting the use of quality roundwood for energy except in well-defined circumstances. In line with the cascading principle, woody biomass should be used according to its highest economic and environmental added value in the following order of priorities: 1) wood-based products, 2) extending their service life, 3) re-use, 4) recycling, 5) bio-energy and 6) disposal. Where no other use for woody biomass is economically viable or environmentally appropriate, energy recovery helps to reduce energy generation from non-renewable sources. Member States' support schemes for bioenergy should therefore be directed to such feedstocks for which little market competition exists with the material sectors, and whose sourcing is considered positive for both climate and biodiversity, in order to avoid negative incentives for unsustainable bioenergy pathways, as identified in the JRC report 'The use of woody biomass for energy production in the EU'.

Source: Reproduced from European Commission (2021e, p. 16)

- **ReFuelEU Aviation – sustainable aviation fuels** – The proposed regulation would require the gradual adoption of sustainable aviation fuels (advanced biofuels and synthetic fuels made from renewable energy (e-fuels). Feed and food crop-based biofuels are ineligible to be counted as sustainable aviation fuel due to competition with these uses as well as the potential for indirect land-use change, which "can lead to the extension of agricultural land into areas with high-carbon stock, such as forests, wetlands and peatland, causing additional greenhouse gas emissions and loss of biodiversity concerns" (European Commission, 2021f, p.16). Vegetable oils and waste lipids will be eligible as a means of speeding the early phase of the transition. To determine eligibility, RED II sustainability criteria will be used. Proposed fuel-share targets: 5% from 2030, with a minimum of 0.7% e-kerosene; 20% from 2035, with a minimum of 5% e-kerosene; 32% from 2040, with a minimum of 8% e-kerosene; 38% by 2045; with a minimum of 11% e-kerosene; and 63% by 2050, with a minimum of 28% e-kerosene" (European Commission, 2021f, Annex I).
- **FuelEU Maritime – green European maritime space –** The proposed regulation would set limits on the yearly average greenhouse gas intensity of the energy used on-board by a ship, requiring the following reductions compared to the reference year of 2020: -2% from 1 January 2025; -6% from 1 January 2030; -13% from 1 January 2035; -26% from 1 January 2040; -59% from 1 January 2045; -75% from 1 January

2050 (European Commission, 2021g, p. 23). The proposal excludes feed and food crop-based biofuels. To determine eligibility, RED II sustainability criteria will be used.

6.3 A resource-nexus perspective on bioenergy: biogas and biofuels

6.3.1 The value of the resource nexus for navigating transition pathways for biogas and biofuels

The scientific and policy debate around bioenergy precedes the formalized resource-nexus approach. Bioenergy has been a flagship issue that underlines the urgency of anticipating the unintended consequences and system dynamics of well-intentioned resource policies. For biofuels specifically, resource considerations are the main motivation behind phase-out requirement for first-generation biofuels within the current EU policy framework. Resource concerns are also behind the European Green Deal's proposals specifying that only advanced biofuels should be promoted as a transitional near-term bridge for the difficult-to-decarbonise sector of transport.

A transition pathway involving biofuels requires a shift to advanced biofuels (those using non-food biomass) and careful monitoring of direct and indirect effects to ensure practices are truly sustainable. The European Green Deal proposals a transition pathway that begins modestly in quantitative terms, with overall target percentages for "sustainable aviation fuel" and "reduction in GHG intensity" for maritime ships climbing significantly (see Table 6 and Table 7 below for the Commission's detailed scenario estimates for 2030 and 2050).

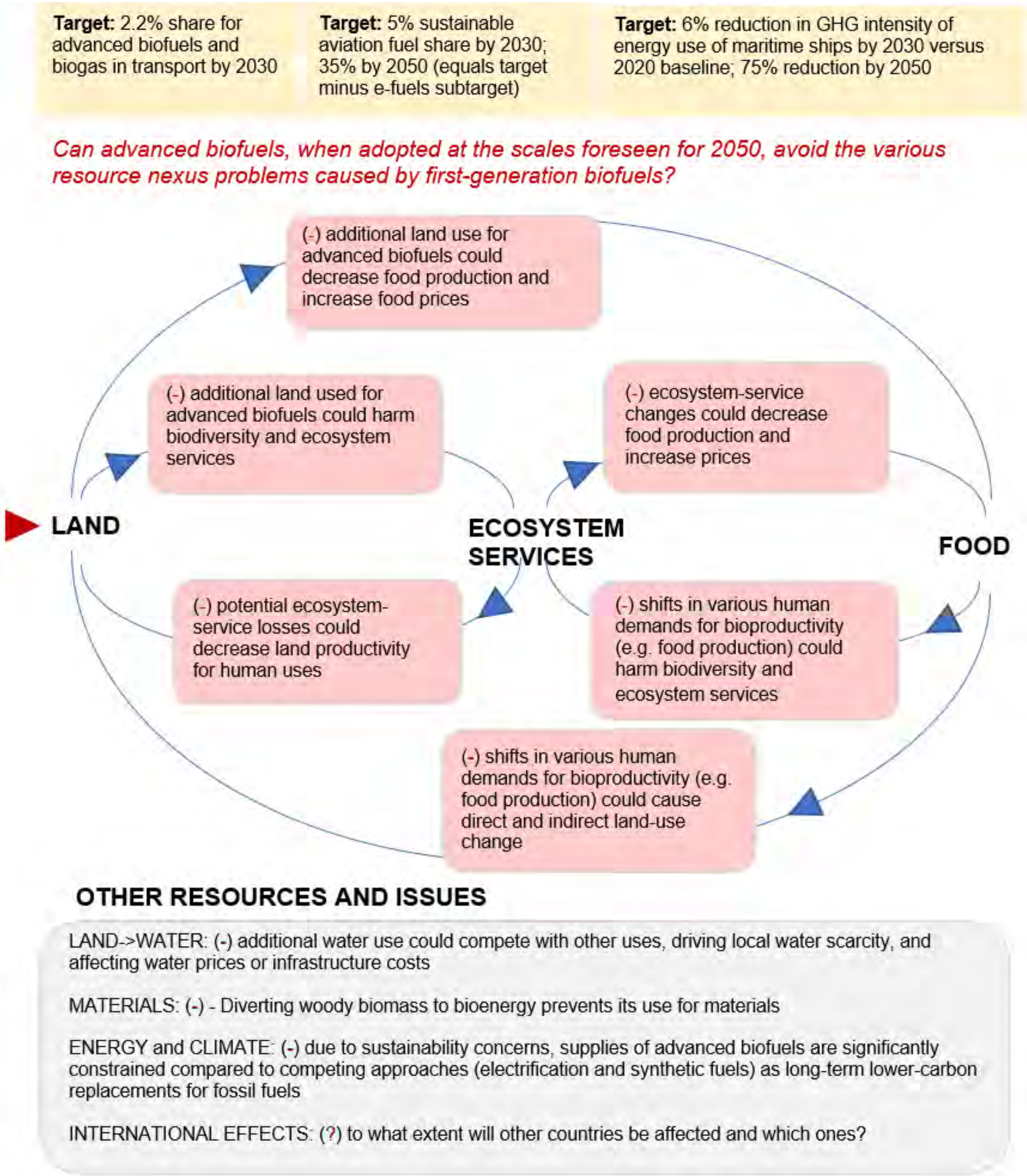
The Commission's plans to dramatically increase reliance on biofuels for transport through 2050. However, these plans are not founded on a widespread scientific consensus like the consensus that underpins climate-change science. It remains unclear whether advanced biofuels are sustainable at these scales. For example, Ripa et al. (2021) state that "[d]espite the vast literature, the assessment of the sustainability of biofuels, whether crop-based or advanced, has remained controversial and the uncertainty in relation to their possible benefits and risks has only been growing. Indeed, biofuels represent a 'wicked issue', i.e. an issue characterized by a diversity of conflicting values at stake, associated with high uncertainties and about which it is impossible to achieve an uncontested problem structuring" (p. 1).

Against this backdrop, Figure 8 presents an overview in resource nexus terms. The figure shows the European Green Deal targets most relevant to biofuels for transport followed by a graphical depiction of the resource nexus interactions. These are the interactions that will need to be monitored to ensure sustainable use of biofuels consistent with the EU's environmental and social policy objectives.

In identifying resource nexus interactions as positive (synergies), negative (trade-offs) or unknown, Figure 8 raises important questions regarding whether advanced biofuels produced at the scales foreseen in 2050 can avoid the negative consequences seen with first-generation biofuels, which lead to increased food prices as well as indirect land-use changes with negative environmental and climate impacts.

Of course, compared to first-generation biofuels, advanced biofuels have lower negative impacts on other resources. Indeed, lowering these negative impacts of biofuel production is their primary aim. If first-generation biofuels were the baseline for comparing synergies and trade-offs in Figure 8, then advanced biofuels would appear to be largely synergistic across the resource aims of the EU. But using first-generation biofuels as a baseline is only valid for comparisons where second-generation biofuels are replacing first-generation biofuels. At the scales foreseen for 2050, however, advanced biofuels are not acting as replacements for first generation biofuels. Instead, they compete with other approaches such as electrification and synthetic fuels.

Figure 8. Resource node interconnections of increasing production of advanced biofuels for transport



Note: The red arrow indicates the primary mechanism by which advanced biofuels influence the resource nexus (i.e. use of productive land). Figure design based on Pasqual, et al. (2018)

6.3.2 Increased production of advanced biofuels: potential synergies and trade-offs with selected resources

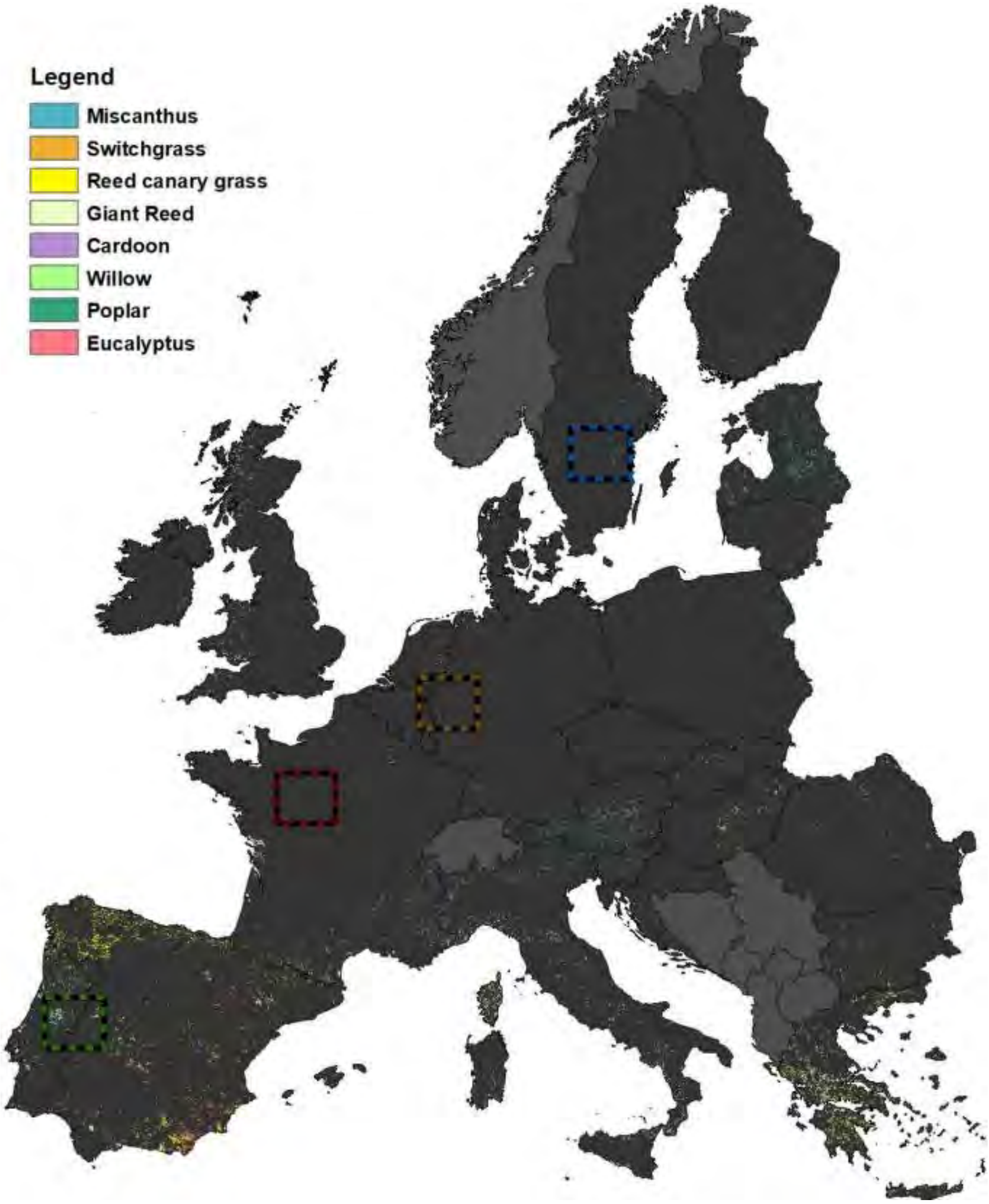
The following overviews describe potential synergies and trade-offs of increased production of advanced biofuels with other resource nodes, including land, ecosystem services, food, water and energy. In addition, synergies and trade-offs with the topics of climate and health are described.

Land

- Land quality: Panoutsou et al. (2021) describe land use as “the first planning step if the biomass feedstock . . . derives from dedicated crops”, stating that “decision making must consider challenges for improving soil quality, maintaining, and increasing soil carbon, rehabilitating degraded land, and avoiding land use change that may displace other existing land-based activities” (p. 5).

- Land quantity: Vera et al. (2017) conducted spatial analyses of land availability in the EU for lignocellulosic energy crop production based on land marginality and the RED II sustainability criteria for biofuels. Crop-specific biomass potentials were also calculated and mapped. They found that there would be 210,000 km^2 of marginal land available in 2050 for lignocellulosic energy crops that fits the RED II sustainability criteria. They also determined that only 75,000 km^2 of that land (equivalent to 1.7% of the surface area of the EU-28) is suitable for lignocellulosic energy crop production (p. 4). Figure 9 shows the areas in the EU-27 and UK where energy crops can feasibly be used for crop production in line with RED II sustainability criteria. A major concern highlighted in ETC (2021) is that demand for biomass could easily exceed sustainable levels of supply, requiring that clear priorities be set regarding where to selectively use biomass (namely for materials, aviation and specific niche energy applications).

Figure 9. Crops composition of the yield efficient biomass potential in Europe for 2050



Source: reproduced from Vera et al. (2017, p. 30). The “yield efficient biomass potential” means that for each location, the crop with the highest potential biomass yield is selected.

-/+ Landscape effects: Lignocellulosic crops may have a negative or positive aesthetic effect which will depend on the crop, context and peoples’ differing aesthetic preferences. Figure 10 provides a photo of giant miscanthus by way of example.

Figure 10. Giant Miscanthus

Source: eXtension Farm Energy (photo: John Caveny)[54]

Vera et al. (2017) find that „the potential production of lignocellulosic energy crops on marginal lands can cover to some extent future bioenergy demand. However, the deployment of such production should be done with care. Despite [its ability to] contribute towards EU GHG emissions reduction targets it can also generate considerable impacts in other areas. The implementation of lignocellulosic energy crops production in marginal land will require demanding location specific measures that promote an efficient use of water and include support practices targeted to reduce soil loss. In addition, considerable support from the government would be required to support farmers and implement location specific measures to reduce potential environmental impacts“ (pp. 52-3).

Ecosystem services:

- energy crop plantations have a detrimental impact on biodiversity due to mono-crop landscapes (ETC, 2021, p. 31)

+ some land-use models for biofuels could improve biodiversity, e.g. the use of degraded land for agroforesty that relies on diverse species (ETC, 2021, p. 19). However, other options like returning the same land to nature could generate higher environmental benefits (ETC, 2021, p. 31).

Food

- Advanced biofuels arose as an alternative to the first-generation biofuels that compete directly with food crops. Despite this progress, potential competition of transport biofuels with food production still looms as an ever-present threat. The following back-of-the-envelope comparison puts the energy appetite (and potential agricultural land appetite) of transport in stark relief.

- **Energy in EU food consumption** - Based on the average caloric intake per person in the EU of approximately 3,400 calories (WHO, 2019), the total European population of 447.7 million (Eurostat, 2020) has an estimated annual caloric intake from food of 1.5 trillion calories (kcal). Converting the energy units, this can be expressed as 150,000 Mtoe (million tonnes of oil equivalent).

[54] https://farm-energy.extension.org/miscanthus-miscanthus-x-giganteus-for-biofuel-production/

- **EU land for food production** - In 2016, farms in the EU-28 used 173 million hectares of land for agricultural production, equivalent to 39% of total EU land area (Eurostat, 2021c).
- **Energy for transport** - In 2019, the EU transport sector consumed 289 million Mtoe (Eurostat data series: nrg_bal_c).
- **EU land for advanced biofuels** - As described above, lands that are RED II compliant and can be productively used for bioenergy cover less than 2% of total EU land area (Vera et al., 2017).

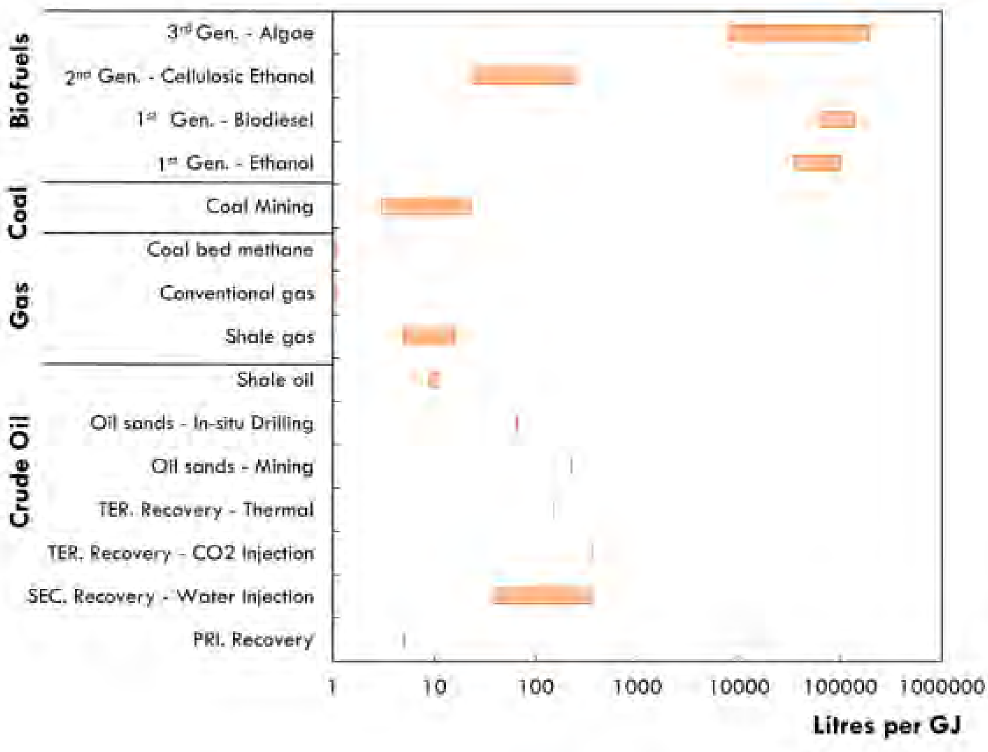
In a nutshell, this means that EU transport consumes approximately 1,900 times more energy than the amount of energy in European food consumption. At the same time, RED II-compliant land area for advance lignocellulosic biofuels is only 1/20th of the area used for agriculture today. This potentially enormous energy appetite lies behind the well-known food-vs-fuel debate regarding first generation biofuels and requires effective regulation and safeguards around any scaling of advanced biofuels.

Water

\+ In a study conducted by D'Odorico et al. (2018), they compared the water footprint of various fuels, including first generation, second generation (i.e. advanced) and third generation (algae) biofuels. Figure 11 shows the comparative water footprints of fossil fuel and biofuel production. Advanced biofuels have a significantly lower water footprint than the other biofuel types.

\- The water footprint of biofuel alternatives (electrification and synthetic fuels) is also of relevance. Synthetic fuel requires an estimated 40 litres per gigajoule (German Environment Agency, 2016). This is less than the average estimate for second generation biofuels shown in Figure 11.

Figure 11. Water footprint of fossil fuel and biofuel production



Source: Reproduced from D'Odorico et al. (2018, p. 482)

Energy

- Road transport: For road transport, advanced biofuels are not expected to be cost-competitive with battery-electric vehicles and hydrogen fuel cell vehicles in the future. In addition, zero-emission road transport can be achieved by 2050 without biofuels. Significant investment in biofuels infrastructure for road fuels therefore risks creating stranded assets as well as a strong lobby group invested in maintaining government support (ETC, 2021, pp. 70-2).

- Shipping: ETC (2021) finds that other sustainable energy options will outperform biofuels in the future and warrant accelerated development. These preferred options include electrification for short distances, and e-fuel alternatives such as green ammonia, green methanol and green hydrogen for long-distance shipping. At most, biofuels are a transition technology (p. 74).

+ Aviation: ETC (2021) finds long-haul aviation to be the only priority sector for increased use of biofuels due to the absence of feasible alternative energy supplies to replace fossil fuels. By 2050, biofuels, synfuels and carbon capture could all be playing important roles in decarbonising air transport (p. 79).

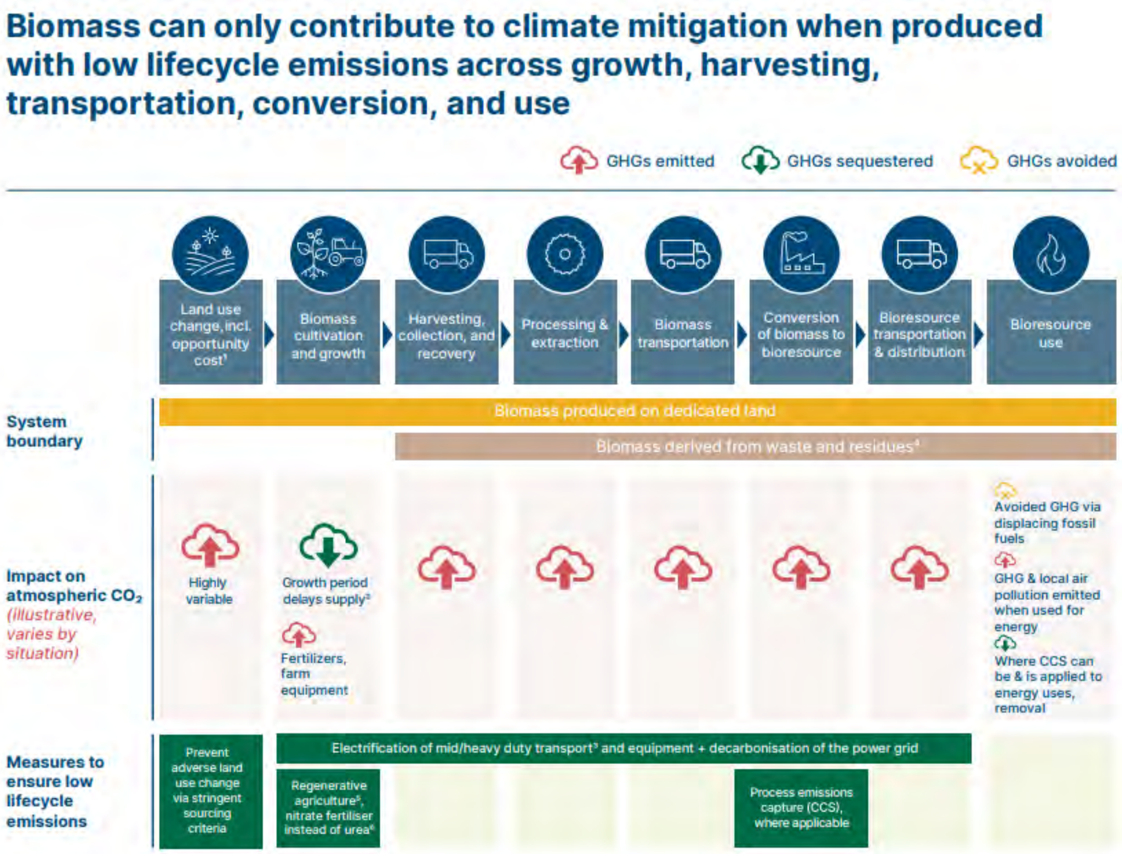
Materials

- Diverting woody biomass to bioenergy prevents its use for materials. ETC (2021) states that "Biomaterials such as solid wood and pulp and paper products are among the highest-value applications of biomass, utilising the intrinsic characteristics of bioresources: versatility, lightness, recyclability, and robustness" (p. 66) The EU Strategy for Energy System Integration calls for bioenergy use to be the second-lowest priority (above only disposal) in the cascade of economic and environmental added value. The highest priority in the cascade is creating wood-based products, followed by extending products' service life, their re-use, and recycling (European Commission, 2021e, p. 16). The top priorities in the cascade all relate to wood as a source of materials and methods to extend the useful life of these materials in a circular economy context.

Climate

(+/-) Converting biomass to biofuels entails several production steps, some of which emit GHGs, offsetting the GHGs sequestered by plants and soils. As shown in Figure 12, emissions of GHGs due to land-use changes vary significantly by the type of biomass and adherence to sustainability criteria meant to prevent adverse land-use change (ETC, 2021, p. 18). When comparing advanced biofuels to alternative energy options, analyses should consider the climate impacts over the full lifecycle of production and consumption for each option to ensure a valid comparison.

Figure 12. Factors affecting climate mitigation contributions of biomass production



Source: reproduced from ETC (2021, p. 18)

Health

+/- Road transport: Air Quality Expert Group (2011) reviewed air quality impacts of biofuels, concluding that consumption of biofuels as blends up to 15% has little effect on air quality. They found no benefits to air quality in countries with high levels of bioethanol consumption (p. 26)

- Shipping: Shipping produces significant air pollution in urban ports. This can be curbed via electrification and the use of on-shore power supply, rather than ships generating their on-board power supply via fuel combustion (European Commission, 2021h).

Shifting burden outside the EU

- Lignocellulose sourced from outside the EU may not be subject to the same sustainability criteria as EU-sourced material, requiring explicit EU policies and an ongoing monitoring framework to ensure that burdens are not shifted elsewhere

- Land considered marginal (and thus a candidate for advanced biofuels) may actually be relied on by low-income populations for their subsistence (livelihood, food and fuel) (Mohr, 2013, pp. 116-7)

Table 5, Overview of potential synergies and trade-offs for increasing production of advanced biofuels

Nexus nodes	Key insights: potential synergies (+) and trade-offs (-)
Land	- Only a small percentage of EU land area qualifies as marginal land area meeting RED II sustainability criteria for biofuels (on the order of 2% according to Vera et al. (2017)). Expansion of biofuel production beyond this amount would trigger land-use changes (direct or indirect) with negative environmental consequences. +/- Aesthetic effects on the landscape could be positive or negative, depending on a number of factors
Ecosystem services	- Energy crop plantations have a detrimental impact on biodiversity due to mono-crop landscapes +/- Some land-use models for biofuels could improve biodiversity, e.g. the use of degraded land for agroforesty that relies on diverse species, though reverting such lands to nature could achieve more for biodiversity
Food	- Despite progress beyond first-generation biofuels' "food-vs-fuel" issues, vigilance on the issue is warranted given the sheer scale of energy demand for transport combined with the extremely limited land area that is both suitable for growing feedstocks for biofuels while not suitable for food crops
Water	+ Advanced biofuels have a significantly lower average water footprint than first generation biofuels - Advanced biofuels have a higher water footprint than synthetic fuels (e-fuels)
Materials	- Diverting woody biomass to bioenergy prevents its use for materials. Under the European Green Deal, the use of wood for materials is to be prioritised over its use for energy.
Energy	- Road transport: advanced biofuels are not expected to be cost-competitive with battery-electric vehicles and hydrogen fuel cell vehicles in the future - Shipping: other sustainable energy options will outperform biofuels in the future and warrant accelerated development (electrification for short distances, and e-fuel alternatives for long-distance shipping) + Aviation: long-haul aviation is the transport sector to prioritise for increased use of biofuels due to the absence of feasible alternative energy supplies, though synfuels and carbon capture can play roles in the longer term
Other aspects	
Climate	+/- Emissions of GHGs due to land-use changes vary significantly by the type of biomass and adherence to sustainability criteria +/- Analyses comparing advanced biofuels to alternative energy options should consider the climate impacts over the full lifecycles of production and consumption for each option
Health	+/- Road transport: little effect on air pollution at low blend levels - Shipping: electrification and on-shore power supply reduce air pollution in ports stemming from ships' on-board power generators
Shifting burden outside EU	- lignocellulose sourced from outside the EU may not be subject to the same sustainability criteria as EU-sourced material - land considered marginal (and thus a candidate for advanced biofuels) may actually be relied on by low-income populations for their subsistence (livelihood, food and fuel)

Note: the direction and the intensity of the synergies (+ or ++) and trade-offs (- or --), are based on a review of literature and expert opinion.

6.3.3 Increasing production of biofuels: addressing potential synergies and trade-offs with selected resources

The issue of resource trade-offs related to first-generation biofuels are already covered extensively in the scientific and policy literature. Existing EU policies as well as some proposed policies under the European Green Deal aim to address these trade-offs by specifying that advanced biofuels must be used and putting in safeguards to counter indirect land-use change effects.

The European Commission's impact assessment for the FuelEU Maritime proposal states that "[m]odel projections show that EU has sufficient biomass available domestically to produce biofuels and bio-LNG for [the] EU international maritime sector" (European Commission, 2021g, p. 58). However, it is unclear from the analysis to what extent this conclusion is based on a consideration of the joint ambitions of all EU policies related to biofuel. The impact assessment merely states that "[t]he remaining feedstock is consumed in other transport sectors such as road transport and aviation" (European Commission (2021g, p. 58). Moreover, there is no definition of what "domestic potential" means nor how utilising the EU's entire domestic potential for biomass would relate to impacts on other dimensions of the resource nexus (e.g. land use change; ecosystem services, food production and water use).

Table 6. Used potential for the EU maritime sector as % of domestic potential in EU27

Used potential (% of domestic potential in the EU27)	POA		POB		POC	
	2030	2050	2030	2050	2030	2050
Part A						
Perennial crops	0.2%	10.9%	0.2%	13.3%	0.2%	11.8%
Annual crops	0.2%	10.6%	0.2%	12.8%	0.2%	11.4%
Forestry products	2.8%	15.4%	2.9%	19.7%	2.9%	16.9%
Forestry residues	2.3%	15.9%	2.4%	20.0%	2.3%	17.4%
Wood waste	1.7%	6.4%	1.8%	7.7%	1.8%	6.9%
Agricultural residues	1.4%	16.1%	1.5%	19.4%	1.5%	17.5%
Manure	2.4%	5.3%	2.4%	6.4%	2.4%	5.8%
Part B						
Non-agricultural oils	20.6%	27.4%	21.3%	34.4%	21.1%	29.9%

Source: PRIMES Biomass model, E3Modelling

Note: The table compares modelling results for three policy options for the periods 2030 and 2050, respectively (labelled here POA, POB and POC, though this appears to be a mislabelling as all other tables refer to PO1, PO2 and PO3). Source: Table reproduced from European Commission (2021g, p. 58)

Furthermore, despite the exclusion of feed- and food-crop biofuels from counting toward GHG-reduction targets, the impact assessment for the FuelEU Maritime proposal expects over 40% of feedstock (by weight) will come from crops while an additional 16% will come from forest products (see Table 7). There is no explicit explanation of the land-related dimension of this reliance on crops and its effects on indirect land-use changes, nor an explanation of how diversions of crop biomass this extensive may impact other aspects of the resource nexus as this biomass no longer flows to whatever its previous uses were.

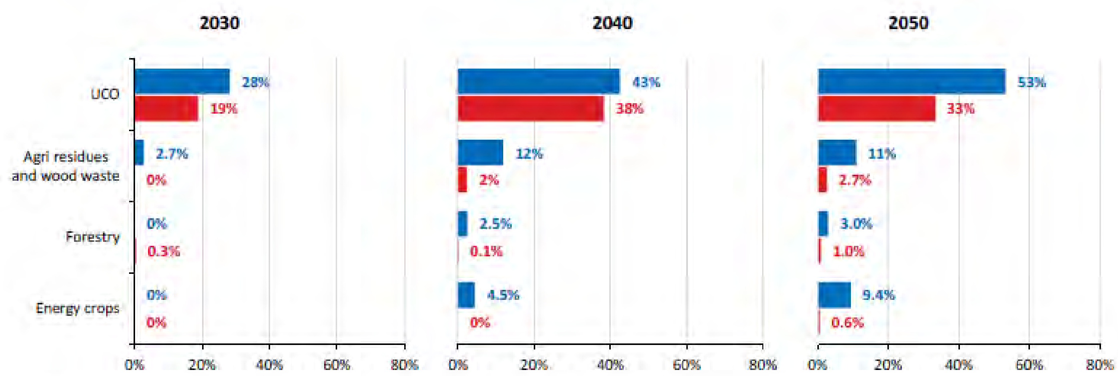
Table 7. Biomass feedstock consumption by type (in Mtonnes)

Feedstock consumption	PO1		PO2		PO3	
Mtonnes	2030	2050	2030	2050	2030	2050
Part A						
Perennial crops	0.0	6.3	0.0	7.7	0.0	6.9
Annual crops	0.3	33.6	0.3	40.8	0.3	36.4
Forestry products	3.1	14.4	3.2	18.4	3.1	15.9
Forestry residues	1.4	11.7	1.5	14.7	1.5	12.8
Wood waste	1.8	6.7	1.8	8.0	1.8	7.2
Agricultural residues	1.5	15.4	1.5	18.6	1.5	16.8
Manure	1.2	2.8	1.2	3.3	1.2	3.0
Part B						
Non-agricultural oils	0.80	1.4	0.83	1.8	0.82	1.6

Note: The table compares modelling results for three policy options (PO1, PO2 and PO3) for the periods 2030 and 2050, respectively. Source: Table reproduced from European Commission (2021g, pp. 57-58). PO1: "Prescriptive approach on the choice of technologies"; PO2: "Goal-based approach on technologies; PO3: "Goal-based approach on technology and reward mechanisms for overachievers" (for descriptions of the policy options, see European Commission, 2021g, pp. 37-40).

The FuelEU Maritime impact assessment forecasts that approximately 30% of the available feedstock of non-agricultural oils (mostly used cooking oil) would go to producing marine fuels while the ReFuelEU Aviation impact assessment expects that between 33% and 53% of used cooking oil would go toward producing aviation fuel in 2050. Much like the FuelEU Maritime impact assessment, which offers no definition of "domestic potential" or its implications, the ReFuelEU Aviation impact assessment does not define "available feedstock", whether this feedstock is strictly EU domestic, nor describe the implications of what large-scale diversions of this feedstock would mean for prior uses nor the various nodes of the resource nexus. As both impact assessments are based on modelling work done by the same consultant, using the PRIMES-Biomass model, it is not clear why this diversity of terms is employed. The publicly available manual of the PRIMES-Biomass model does not refer to any modelling of impacts across the resource nexus, such as impacts on land use or ecosystem services.[55]

Figure 13. Share of the available feedstock in the EU used for sustainable-aviation-fuel production



Source: Ricardo at al. Impact assessment support study; PRIMES-TREMOVE, E3Modelling
Note: UCO stands for used cooking oil. Solid biomass refers to feedstock included in Annex IX Part A.

[55] See https://e3modelling.com/modelling-tools/

Source: European Commission (2021f, p. 41). Note: blue bars represent all policy options except policy option B2; red bars represent policy option B2.

Table 8. Biomass feedstock consumption by type (in Mtonnes)

Mtonnes	2030		2050	
	UCO	Solid biomass	UCO	Solid biomass
Baseline	0.05	0.02	0.69	0.43
Policy Option A1	1.10	5.52	2.8	62.5
Policy Option A2	1.14	5.72	3.1	69.8
Policy Option B1	1.10	5.52	2.8	62.4
Policy Option B2	0.59	0.00	1.4	7.6
Policy Option C1	1.10	5.53	2.8	62.5
Policy Option C2	1.14	5.72	3.1	69.8

Source: Ricardo at al. Impact assessment support study; PRIMES-TREMOVE, E3Modelling.
Note: UCO stands for used cooking oil. Solid biomass refers to feedstock included in Annex IX Part A

Source: European Commission (2021f, p. 41): Policy options are: A1 “Obligation on the supply side (volume-based approach)”; A2: “Obligation on the supply side (CO_2 intensity reduction approach)”; B1: “Obligation on the demand side (intra and extra-EU scope)”; B2: “Obligation on the demand side (intra-EU scope)”; C1: “Obligation on supply and uplift (volume-based approach)”; C2: “Obligation on supply and uplift (CO2 intensity reduction approach)” (for descriptions of the policy options, see European Commission, 2021f, pp. 29-33).

6.4 Conclusion: How does a resource nexus lens help us evaluate transition pathways for bioenergy?

The food-vs-fuel debate around bioenergy has been an important catalyst for thinking about resource-nexus issues. As the EEA states in its State of the Environment Report 2020, “[t]he policy areas in which cross-sectoral thinking is most advanced are the agricultural and water sectors, because of agriculture’s key role as a source of pressures on aquatic environments. Nexus thinking does not emerge prominently in policies regulating the energy sector, except in relation to the impact of biofuels and bioliquids on biodiversity, water resources, water quality and soil quality” (EEA, 2019d, p. 373, citing Venghaus and Hake, 2018).

The European Green Deal proposals regarding bioenergy for transport call for rapid expansions of using biomass for transport fuels as a means to reduce climate impacts. To help prevent other environmental harms, these proposals rely on the existing framework of the revised Renewable Energy Directive (RED II) as a means of excluding categories of biomass associated with particularly negative impacts on other resource nodes.

However, the analyses behind the legislative framework seem to assume these categorical definitions will solve the problem for the long term despite the dramatic scale-up expected through 2050 in terms of the share of the EU’s biomass potential that would go toward energy for transport. The impact assessments behind the aviation and marine fuel proposals use inconsistent terms that are not defined, making the implications unclear to the policymakers, stakeholders and citizens interested in the resource impacts of low-carbon transport options.

A more thorough resource-nexus approach would consider the joint implications of having multiple transport modes pursuing ambitious de-carbonisation strategies simultaneously and consider the specific implications of such large-scale expansion for land use, ecosystem services, food production and the other nodes of the resource nexus.

7 Case study 3: How a resource-nexus approach can support an effective transition to sustainable mobility: the role of electric vehicles and batteries

7.1 Policy framework: vision, targets and transitions

Transport accounts for a quarter (European Commission, 2019b, p.10) to one third (Heinrich Böll Stiftung, 2021, p. 6) of CO_2 emissions in the European Union. Whereas industry, agriculture and the residential/commercial sector have achieved GHG emission reductions in the past three decades, transport emissions are still rising for road transport, aviation and shipping (EEA, 2019b). The European Green Deal (EGD) addresses transport under the headline "Accelerating the shift to sustainable and smart mobility":

> "The key target for the transport sector is a 90% reduction in transport emissions by 2050 (European Commission, 2019b, p. 10).[56] The European Green Deal aims to achieve this by boosting multimodal transport, more automated and connected mobility, increasing sustainable transport fuels and supporting those, among other measures, by having transport prices reflect the environmental and health costs. Furthermore, the European Commission proposes to boost production and deployment of 'sustainable alternative transport fuels'" (European Commission, 2019b, p. 11).

The following table presents the key goals and targets of the European Green Deal and its key transport policy, the "Sustainable and Smart Mobility Strategy" and sorts them into priority areas. These priority areas identify key pieces of the transition of the transport system in the European Green Deal. The two targets in **bold** relate to electric vehicles and batteries and are used as the basis for the specific transitions examined in this case study.

[56] The website of DG transport states the objective of a 60% cut in transport-related GHG emissions in 2050 (base: 1990). See: https://ec.europa.eu/info/topics/transport_en

Table 9. Key goals and targets of the European Green Deal, its "Sustainable and Smart Mobility Strategy", and the "Fit for 55 package"

Priority areas	Goals and targets
Automated and connected multi-modal mobility	• Develop smart systems for traffic management and 'Mobility as a Service' solutions • Substantial part of inland freight carried today by road should shift onto rail and inland waterways • High-speed rail traffic will double by 2030 and triple by 2050* • Automated mobility will be deployed at large scale* • Rail freight traffic will double; the multimodal Trans-European Transport Network equipped for sustainable and smart transport with high-speed connectivity will be operational for the comprehensive network by 2050*
Pricing	• Ending fossil-fuel subsidies • Extend emissions trading to maritime sector and reduce Emissions Trading System allowances allocated for free to airlines • Effective road pricing
Zero-emission mobility / alternative transport fuels Air pollution and overarching CO_2 emission legislation	• Commission will support deployment of public recharging and refuelling points where persistent gaps exist • Assessment of legislative options to boost the production and supply of sustainable alternative fuels for the different transport modes • Review Alternative Fuels Infrastructure Directive and TEN-T Regulation to accelerate deployment of zero- and low-emission vehicles • Require Member States to expand charging capacity in line with zero-emission car sales. Install charging and fuelling points at regular intervals on major highways: every 60 km for e-charging and every 150 km for hydrogen refuelling⁺ • **At least 30 million zero-emission vehicles will be in operation on European roads by 2030*** • **Average emissions of new cars come down by 55% from 2030 and 100% from 2035 compared to 2021 levels. All new cars registered as of 2035 will be zero-emission⁺** • **Nearly all cars, vans, buses as well as new heavy-duty vehicles will be zero-emission by 2050*** • Zero-emission vessels will become ready for market by 2030* • Set a maximum limit on GHG content of energy used by ships calling at European ports⁺ • Scheduled collective travel of under 500 km should be carbon neutral within the EU by 2030* • Zero-emission large aircraft will become ready for market by 2035* • Oblige fuel suppliers to blend increasing levels of sustainable aviation fuels in jet fuel⁺ • Proposal for more stringent air pollutant emissions standards for combustion-engine vehicles • Revise legislation on CO_2 emission performance • Consider extending emissions trading to road transport

* The goals and targets marked with * are from the "Sustainable and Smart Mobility Strategy", with ⁺ from the Fit for 55 package, all others from the European Green Deal.

The European Green Deal and the Sustainable and Smart Mobility Strategy present a number of zero-emission solutions, from e-vehicles and hydrogen fuel-cell vehicles to cargo-bikes and drones to decarbonise freight transport. A definition or list of zero-emission vehicle types is not provided in the strategy,[57] the European Commission has traditionally been careful to remain technology neutral.[58] Currently, there are three major alternative-drive technologies available: electric vehicles; hydrogen and fuel-cell vehicles; and synthetic fuels (produced using renewable energy).[59] Cycling and walking are the two classic zero-emission transport modes. In recent years, a number of electricity-powered options for shorter distances have been added to the picture, such as e-bikes and e-scooters. The Sustainable and Smart Mobility Strategy does not address policy opportunities to reduce and avoid transport, for example via better city planning or via digital solutions replacing travel requirements.

Despite the technology-neutral approach, electricity-powered vehicles appear likely to make up the bulk of reduced-emission vehicles in the future. This is mainly due to the higher efficiency of e-vehicles, compared to solutions that rely on producing a green fuel from renewable-energy sources first and then burning it. Electricity demand for hydrogen production is estimated to be three times higher and for synthetic fuel production over seven times higher than direct electricity use in an electric engine (BMU, 2021, p. 19).

This case study presents the transition of the transport system as foreseen in the European Green Deal and related policies with a focus on the issue of zero-emission mobility, specifically the transition to battery-electric vehicles. The transition from fossil-fuel powered vehicles to battery-electric vehicles raises multiple resource-related challenges for which a resource-nexus approach could prove helpful.

7.2 Key documents that contain policy proposals for the electrification of transport and for batteries

The key document of the European Green Deal to shape the transition of the transport sector and foster zero-emission mobility is the Sustainable and Smart Mobility Strategy. As the key component of an electric vehicle, batteries have the greatest environmental impact and also account for over a third of the overall cost of an electric vehicle (Statista, 2021). Today, batteries are mainly regulated[60] in the Batteries Directive (European Union, 2006). However, the increase in e-mobility—a minor issue in the 2006 directive currently in force—has increased the demand for new action and regulation. In 2017, the European Commission launched a cooperation platform called the “European Battery Alliance”. In 2018, a Strategic Action Plan for Batteries was put forward. The Communication focusses on batteries for sustainable mobility and aims to “make Europe a global leader in sustainable battery production and use” (European Commission, 2018a, p. 2). The Communication was developed prior to the European Green Deal and before the von der Leyen Commission took office in December 2019.

[57] The “Clean Vehicle Directive” (European Union, 2019, Article 4) defines a “zero-emission heavy duty vehicle” as a heavy-duty vehicle without internal combustion engine, or with an internal combustion engine that emits less than 1 g CO2/kWh or less than 1 g CO2/km in accordance with other regulations.

[58] The technology neutrality postulate has in practice complicated implications which cannot be discussed in more detail here. For further information see Agora Verkehrswende (2020).

[59] “Alternative fuels” include according to the “Alternative Fuels Directive” (European Union, 2014, Article 2) electricity, hydrogen, biofuels, synthetic and paraffinic fuels, natural gas and liquefied petroleum gas.

[60] Other regulations that touch battery production, use and disposal, e.g. the REACH Regulation (REGULATION (EC) No 1907/2006).

However, the European Green Deal announced an intention to keep implementing the Strategic Action Plan on Batteries and support the Battery Alliance. A new legislative proposal for a regulation on batteries and waste batteries was put forward in December 2020.

The **European Green Deal** itself mentions batteries in the context of possible legal requirements to boost the market for secondary raw materials with mandatory recycled content (p. 8). Furthermore, it announces a funding call to support the deployment of public recharging and refuelling points for alternative fuels; the assessment of legislative options to boost production and supply of sustainable alternative fuels; and a review of the Alternative Fuels Infrastructure Directive.

The **Sustainable and Smart Mobility Strategy** from 2020 (European Commission, 2020b) mentions that the new battery regulation will ensure that batteries are sustainable and notes that battery-electric vehicles are supported under the partnerships on batteries as part of Horizon Europe, and under the EU energy system integration (European Commission, 2020a). The future recharging infrastructure is expected to provide storage capacity and flexibility to the electricity system, which needs to be supported by revisions of the Alternative Fuels Directive, the Renewable Energy Directive, the Energy Performance of Buildings Directive (regarding charging infrastructure) and the Trans-European Transport Network Regulation. Furthermore, the Commission plans to support the battery value chain with regulatory and financial instruments. The above measures are mentioned in the strategy. However, in the annex to the strategy, which lists concrete actions in the next years, e-mobility and batteries are not specifically mentioned, other than a planned revision to the Buildings Directive to enhance provision on charging infrastructure.

The **Strategic Action Plan for Batteries (2018)** is organised around the battery value chain, aiming to support:

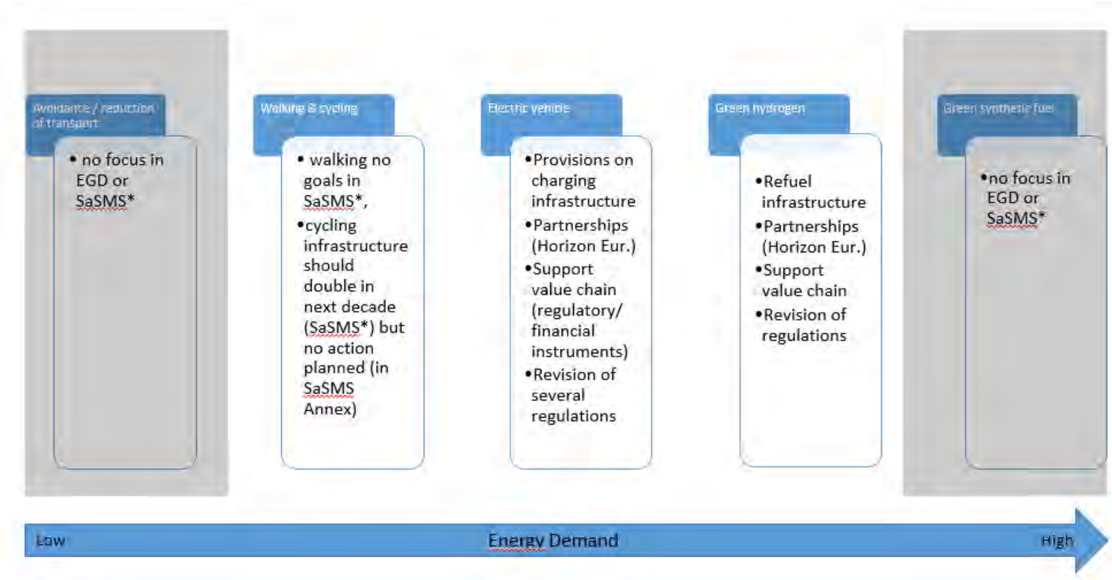
- the access to raw materials (e.g. sourcing in Europe; use all trade policy instruments);
- battery cells manufacturing at scale and a full competitive value chain in Europe (e.g. facilitate large-scale projects; dialogue between Member States to support manufacturing projects; make public funding or financing for projects available to reduce risk for the private sector);
- industrial leadership through stepped-up EU research and innovation (e.g. increase and use European research funding for batteries and pilot projects; large-scale long-term flagship research initiative [(~ EUR 1 billion]; use European Innovation Council for breakthrough innovations; Horizon 2020 smart grid and storage projects)
- a highly skilled workforce (e.g. skill mapping; create links between educational network and pilot line network; help universities etc. to build new degree courses)
- the sustainability of EU battery-cell manufacturing industry with the lowest environmental footprint possible (assess recycling targets; determine factors for the production of safe and sustainable batteries) and ensure consistency with the broader enabling and regulatory framework (e.g. tackle unfair practices in third countries such as subsidies; monitor and tackle market-access distortions; ensure consistency between rules of origin for electric vehicles and battery cells).

If the **new proposal for a regulation on batteries and waste batteries** comes into effect January 1, 2022 with the key proposals as of now still intact, it would increase transparency and traceability via an electronic information system and new requirements for a battery passport. From 2030 on, batteries would have to contain a certain amount of recycled cobalt (12%), lead (85%), lithium (4%) and nickel (4%). This amount would be required to increase from 2035 onwards. Furthermore, the CO_2 footprint of the batteries would have to be declared by manufacturers.

The overall **transition pathway to a** 90% reduction in transport emissions by 2050 as presented in the European Green Deal and the Sustainable and Smart Mobility Strategy focusses heavily on the shift to zero-emission drives. While the language is technology neutral, the zero-emission mobility in focus are e-mobility and hydrogen mobility. Taking a life-cycle perspective, there is naturally no such thing as “zero-emission mobility” and numerous environmental impacts add to the mere greenhouse gas emissions. From that standpoint, it is striking that “zero-emission mobility” options that have no or very little life-cycle emission such as avoidance of transport and increasing walking and cycling play no or only a minor role in the policy documents. Sharing options, be it classic public transport or new vehicle sharing options also play relatively minor roles.

So, while a 90% reduction of emissions does sound like it requires a transformative change, it can be argued that the EGD and the Sustainable and Smart Mobility Strategy do not present a change of the transport system, but rather a technology change (see Figure 4).

Figure 14. Overview of low- and zero-emission transportation modes and how they are targeted by the EGD and the Sustainable and Smart Mobility Strategy



Note: authors’ depiction. *Sustainable and Smart Mobility Strategy

Focussing in on e-vehicles shows a broad approach of the European Commission that includes the entire value chain. While the (planned) actions are numerous, and ambitions are great, the concrete targets and timeframe in the upcoming regulation (see Table 9) appear as if they could be quickly outpaced by real-world developments.

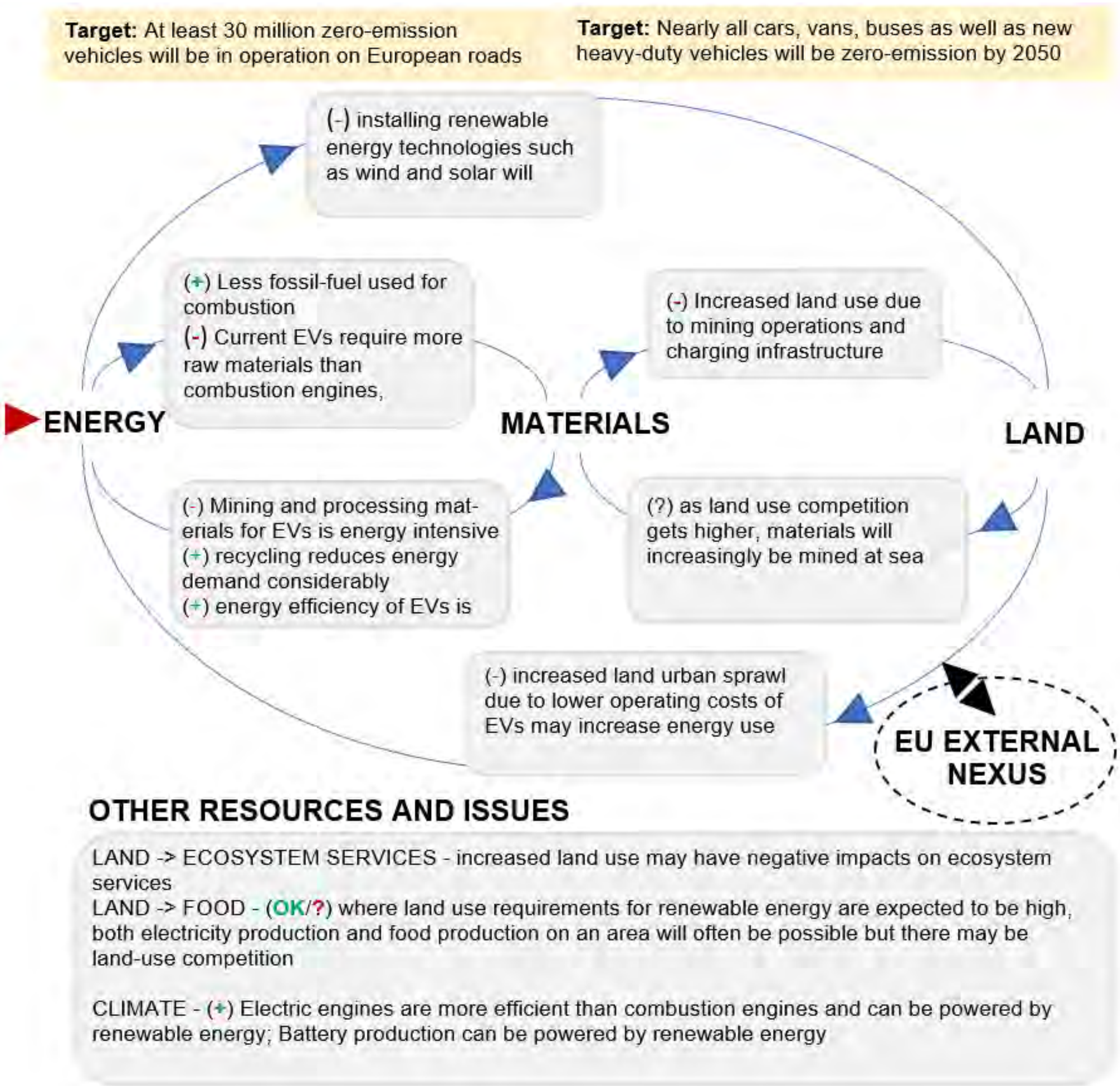
Taking a resource nexus approach helps understanding why including all zero-emission mobility options and a more ambitious approach to battery production and recycling would help the European Union to achieve its EGD goals.

7.3 A resource-nexus perspective on the electrification of transport and batteries

7.3.1 The value of the resource-nexus approach for navigating the transition pathway for the electrification of transport and batteries

The transition from fossil-fuel vehicles to electric vehicles requires a major shift in resource use for transport, most obviously in the shift from mining petroleum products for one-time combustion to mining the metals needed for long-term use in batteries. Figure 5 depicts key interactions among the nodes of the resource nexus regarding the electrification of transport and batteries.

Figure 15. Resource node interconnections of the electrification of transport and batteries



Note: figure design based on Pasqual, et al. (2018)

7.3.2 Increasing electric vehicles: synergies and trade-offs with selected resources

The following overviews describe the key synergies and trade-offs of increased use of battery-electric vehicles with other resource nodes, including ecosystem services, water, land, materials, food and energy. In addition, synergies and trade-offs with the topics of climate and health are described. Box 6 provides an overview of key raw materials needed for electric-vehicle batteries and related challenges.

Box 6. Key raw materials in electric-vehicle batteries

The principal raw materials in EV batteries are graphite, aluminium, and nickel. The key critical raw materials are cobalt and lithium. ***Cobalt*** is used in most lithium-ion batteries. Demand for cobalt has been increasing at 3-4% annually since 2010 and it is one of the most expensive raw materials in the production of batteries. However, due to the high and increasing cost and also human-rights violations occurring at some mines in the Democratic Republic of Congo, battery developers have been working on reducing the cobalt content. Newer batteries require as little as 5% cobalt and work to eliminate cobalt from lithium-ion batteries in the next two to three years (Observer, 2021). ***Lithium*** is the key element in current battery technology, global demand is expected to reach 240 000 tonnes by 2030 and over a million tonnes in 2050. Today about two thirds of global lithium is extracted in hardrock mining in Australia, salt lake brines in South America are the next biggest source. The latter received big media attention due to the intense water use in extraction, which increases water scarcity in an already arid region. The environmental impact of hardrock mining includes the dangers from tailings storage, such as water contamination or ruptures (Dolega et al., 2020, p. 18) Lithium mining in Europe includes low impact extraction from thermal water, which is still in a pilot phase. In the long term, lithium may be substituted by sodium in sodium- ion-batteries (DW, 2020). **Graphite** can be mined as natural graphite or produced synthetically. The synthetic production is very energy intensive, nevertheless GHG emissions from natural extraction are estimated to be similarly high, due to ecologically critical processing steps (Dolega et al., 2020, p. 8). **Nickel** is needed in highest quantity in lithium-ion batteries with the share still increasing due to the shift in battery technology (Drabik and Rizos, 2018, p. 9). Aluminium is also required in relatively high quantities for battery packs. **Aluminium** production is very energy intensive, but producing secondary aluminium is significantly less energy intensive.

Recommended reading:

- **EV battery recycling in the context of the circular economy** - Drabik and Rizos (2018). Prospects for electric vehicle batteries in a circular economy. CIRCULAR IMPACTS project. – (link) – The study examines four materials frequently used in EV batteries--cobalt, nickel, aluminium oxides and lithium—and discusses circular-economy approaches to their use, re-use and recycling.
- **Questions and answers about the battery value chain** - Thielmann et al. (2020). Batteries for electric cars: Fact check and need for action. Fraunhofer ISI, Karlsruhe – (link) – The briefing provides a concise overview of key challenges surrounding scaling the use of batteries in electric vehicles, including obtaining raw materials, reducing environmental impacts, as well as re-use and recycling.
- **A short but comprehensive view on the impacts of electric vehicles** - BMU - Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (2021). How eco-friendly are electric cars? A holistic view, Berlin – (link) – The briefing looks at the impact of electric vehicles with regards to noise, health, resources and climate. Also, other alternative drive technologies are compared with electric vehicles.
- **Analysis of electric vehicles from a systems perspective** - EEA (2018) - Electric vehicles from life cycle and circular economy perspectives - TERM 2018 — European Environment Agency – (link) – The report analyses anticipated environmental impacts of BEVs from a systems perspective, including life cycle assessment (LCA) and a broader 'circular economy' approach.

Ecosystem services

+ Anthropogenic noise pollution has major negative effects on animals. A meta-analysis on noise pollution has shown that all taxonomic groups (birds, mammals, fish, molluscs, amphibians, arthropods) are affected. Noise can impair the communication, foraging, homeostasis and distribution of organisms (Kunc and Schmidt, 2019, p. 1, 3f). Reduced noise pollution due to the electrification of transport will benefit terrestrial and aquatic animals. Electrification of transport implies expand existing capacity i.e. more cables (air or ground). This might have implications on ecosystems and their services.

Water

- Lithium mining increases water scarcity in already arid regions of South America Mining of lithium from solid rock is energy intensive and creates mining tailings, which need to be stored and pose a threat to local water reserves and biodiversity. (Dolega et al., 2020, p. 13f)

Land

- The increased demand for clean electricity and the associated need to install renewable energy technologies such as wind and solar will lead to increased land use in Europe. One study estimates that the EU has to devote 5,000 km^2 to photovoltaic panels and 56,000 km^2 to wind turbines to run just 40% of its vehicles with electricity (Orsi, 2021, p. 4)

- Only around 40% of Europeans would have access to a private charging point. Some forecasters have therefore warned that the increase in charging points will mean a greater land use of EVs in comparison to combustion vehicles (McKinsey, 2018) – at least as long as battery charging remains significantly slower than refuelling.

- Some experts have voiced the concern that the low operating costs of EVs may lead to increased urban sprawl. These experts assume that more people would leave the expensive living areas in city centres if transport costs are lower and if they could commute to work at low cost (Orsi, 2021, p.4).

- The international environmental impacts of mining activity depend on effective regulatory frameworks in non-EU countries and where those are not in place, perhaps on corporate social responsibility frameworks that ensure that raw materials in products imported into the EU have adequate social and environmental protections in place. Similar issues are relevant for the resource nodes water, materials and ecosystem services.

- Building up infrastructure for low emission mobility in parallel to the existing infrastructure increases overall land demand. This will be reduced in the long term when infrastructure for fossil fueled transportation is dismantled.

Energy

+ Electric engines work more efficiently than combustion engines, the cumulative energy demand for EVs is therefore lower (BMU, 2021, p. 15)

+/- Electricity demand will increase due to the electrification of transport. The increase depends on a number of factors, such as the overall transition of the transport system and how big the share of individualised transport will be or the electricity demand of the average vehicle. According to one scenario, the electric vehicle energy demand would make up ~ 10% of total electricity demand in the EU-28 in 2050, assuming an 80% share of e-vehicles. While this increase requires investments in distribution networks, these are expected to be manageable (Kasten et al., 2016, p. 47). However, the estimates vary considerably: while for example in the former scenario the share of electricity for e-vehicles in Germany is about the European average, another scenario forecasts that electricity demand would increase by about 20% in Germany[61] (Thielmann et al. 2020, p.20).

Materials

- Current EVs require more raw materials than combustion vehicles and they require a greater number of sometimes critical raw materials, including lithium, cobalt, graphite, nickel and copper (BMU, 2021, p. 16). For example, while a conventional car requires just over 30 kg of copper and manganese, a comparable electric car requires over 200 kg of copper, lithium, nickel, manganese, cobalt, graphite, zinc and rare earth minerals (IEA, 2021, p. 6).

+ The great demand for batteries has led to a surge in research and development, especially with regard to increasing efficiency and longevity, as well as on substituting the problematic raw materials required in current lithium-ion batteries. Cobalt use in batteries has declined, which compensates part of the steeply rising demand. A cobalt-free battery is under development. Lithium may, in the long term, be substituted with widely available and cheap natrium (Dolega et al., 2020, p. 18).

- The waste stream from batteries is expected to grow 600% by 2030. While the resources used in batteries can theoretically be recycled, Europe lacks large-scale recycling capacities to cope with the expected growth of waste materials (EEA, 2021c).

Food

- The increase in the demand for renewable electricity may increase land use competition to food production. However, while the land use requirements for renewable energy technologies are expected to be high, often both electricity production and food production on an area will be possible. While agricultural land is reduced due to the foundations of wind turbines, harvesting energy in addition to food production improves farmers' incomes. Potential fisheries impacts were not analysed as they are outside the scope of the case study.

Climate

+ Whether EVs are better for the climate than vehicles with combustion engines depends on the electricity mix. In 2020, renewable energy technologies (wind, solar, hydropower, biomass) supplied 38% of the EU`s electricity (Agora Energiewende and Ember, 2021, p. 4). A life-cycle assessment of petrol, diesel and electricity powered compact cars shows that the greenhouse gas emissions of EVs are ~ 30 % lower than those of a petrol vehicle and 23% lower than a diesel vehicle.[62] This balance can be expected to shift even more in favour of EVs once the electricity mix gets greener and if more batteries are produced with renewable electricity (BMU, 2021, p. 6f)

[61] While the latter case refers to a 100% share of e-vehicles, the estimate is still considerably higher, even if the e-vehicle share is adjusted.

[62] The life-cycle assessment was undertaken with the German electricity mix, which had a slightly higher renewables share (42%).

- There is a risk that the additional electricity required for the electrification of transport is produced from biomass – especially wood pellets - instead of wind and solar energy. The "Fit for 55 package" initiated an amendment of the Renewable Energy Directive to implement the ambition of the new 2030 climate target. The amendment proposes tighter rules for wood-burging to be classified as renewable. However, many experts and stakeholders demand that biomass should be removed from the list of renewable sources as burning biomass exacerbates climate change (Oxfam, 2021; European Commission, 2021e, p. 3).

Health

+ / - EVs do not produce exhaust pipe emissions providing strong health benefits especially in densely populated cities that frequently exceed air quality limit values. EVs have no local direct exhaust emissions of nitrogen oxides and particulate matter. However, air pollutants over the life cycle of EVs may be higher than for combustion vehicles, among other because the battery production is associated with high particulate matter emissions. (BMU, 2021, p 12ff)

+ EVs are quieter than conventional vehicles, which is expected to significantly reduce traffic noise in the future. Noise increases cardiovascular diseases, affects sleep negatively and puts psychological stress on humans, as it is perceived as annoying. The World Health Organisation recommends reducing noise levels from road traffic to below 53 dB during daytime and 45 dB during night time to reduce health effects (WHO, 2018, p. 30). It is estimated that 113 million people in Europe are exposed to traffic noise of at least 55dB (day-evening-night) (EEA, 2020d, p. 7) How much the noise will be reduced is a matter of speculation, as EVs will have to produce some sound for traffic security reasons, especially for children and the visually impaired. While at high speeds tyre noise and aerodynamic noise become more important than engine noise, the positive effects are biggest in living areas, where traffic speed is usually lower.

-/+ Mining of raw materials for EVs, for example Cobalt mining in artisanal mines in Congo is often associated with hazardous working conditions, child labour and negative impacts on miners' health (Mancini et al. 2020). However, overall the greater demand for Cobalt has created thousands of jobs in artisanal mining which help especially poor families to improve their living conditions (Ndagano, 2020).

+/- Like vehicles with combustion engines EV generate non-exhaust particle emissions due to the wear and tear on brakes, clutches, tyres, road surfaces as well as the suspension of road dust. EV's braking systems may generate lower particle emissions but other non-exhaust particle emissions may be higher, especially due to the higher weight of EVs (OECD, 2020, p. 8ff)

Table 10 presents an overview of the potential natural resource implications associated with this case study.

Table 10. Overview of potential synergies and trade-offs: electrification of transport and batteries.

Nexus nodes	Key insights: potential synergies (+) and trade-offs (-)
	- infrastructure developments and mining operations are likely to have severe negative effects on ecosystems and related services

Ecosystem services	+ reduced noise pollution due to the electrification of transport will benefit terrestrial and aquatic animals.
Food	- continued urban sprawl and infrastructure development might compete with agricultural land
Water	- mining operations are likely to entail a certain level of chemical pollution, and it could exacerbate water scarcity
Land	- the increased demand for electricity and the associated need to install renewable energy technologies such as wind and solar is expected to lead to increased land use in Europe
Energy	-/+ demand for electricity is likely to increase, as well as the need for batteries and infrastructures, while demand for fossil fuels is reduced
	+ cumulative energy demand for EVs could be lower than ICEs across their life cycles
Materials	- EVs require more raw materials than combustion vehicles and a greater number of critical raw materials, including lithium, cobalt, graphite, nickel and copper. Batteries and infrastructure development are the two key contributors.
Other aspects	
Climate	+ EVs are currently better for the climate than vehicles with combustion engines, depending on the electricity mix. That might vary significantly across Europe.
Health	+/- EVs do not produce direct exhaust pipe emissions (NOx and PM) providing strong health benefits. Yet, air pollutants over the life cycle of EVs may be higher than for combustion vehicles because of high PM emission stemming from battery production.
	+ EVs are quieter than conventional vehicles, which is expected to significantly reduce traffic noise in the future. Yet, at high speeds, the noise reduction effect is limited as the noise from tires dominates.
Shifting burden outside EU	- The potential shift of burden outside the EU is significant, given high material demand associated to EVs and related infrastructures. Raw materials products imported into the EU might not have adequate social and environmental protections in place, with potential detrimental effects on water, land, and ecosystems.

Note: the direction and the intensity of the synergies (+) and trade-offs (-), are based on a review of literature and expert opinion.

7.4 Conclusion: How can the resource nexus approach help create a more sustainable transition pathway to EVs and the associated battery use?

The decarbonisation of transport lags behind other sectors and transport's CO_2 emissions have continued to climb in the EU. To reverse this trend and meet the EU's climate goals, an ambitious shift toward zero-emission vehicles is required, with battery-electric vehicles making a decisive contribution in a transition away from fossil fuels. The resource implications are complex and global; the transition pathway involves high levels of technological innovation, the rapid diffusion of these technologies and the reconfiguration of whole industries, supply chains and transmission grids.

However, while the ambitions and challenge are great, the “transition” of the transport sector is mainly a transition of engine technologies. A technological transition – as opposed to a systems transition – will keep the shortcomings of the previous system and is likely to lead to unintended impacts and side-effects. An example is the trend to bigger and heavier cars, which is observable for cars with combustion engine and for e-vehicles alike, and in effect minimising the better environmental balance of e-vehicles.

Furthermore, the technological shift will lead to unintended consequences, many of which have been discussed above. The resource-nexus approach can help policymakers maintain an overview of the synergies with the electrification shift in other sectors as well as the trade-offs inherent in new demands on land for infrastructure and mined materials. The approach helps policymakers to identify these impacts and implement practices to mitigate negative effects. Practices to mitigate unintended consequences can make a big difference. For example, the ways that raw materials are sourced could reduce the greenhouse gas emissions in the process substantially (EEA, 2021a; EEA, 2021b).

But in a way, these highly advanced technological and policy solutions make it only more obvious that a system change is required to achieve a sustainable transport system. Zero-emissions transport will not come about only through effectively managing the shift in resources behind what powers private-vehicles. Reducing the CO_2 emissions of transport will also require avoiding and reducing trips where possible, offering attractive public-transport alternatives, and carrying out integrated land-use planning that fosters cities and towns where liveability is not overly dependent on mobility.

8 References

Please note: this list does not include all the European Green Deal policy documents mentioned in the report. Compiled lists of European Green Deal documents can be found in Table 1 of this report as well as the European Commission's set of webpages on the Fit for 55 package, entitled Delivering the European Green Deal.

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