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Background Paper: Key mitigation options to close the global 2030 ambition and action gap

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Background Paper: Key mitigation options to close the global 2030 ambition and action gap

Interim report

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Abstract: Background Paper: Key mitigation options to close the global 2030 ambition and action gap to achieve the Paris Agreement Long-term temperature objective

Achieving the Paris Agreement Long-term temperature goal (PA LTTG) requires closing the 2030 ambition and action gap between emissions levels consistent with the Paris Agreement and emissions levels projected with current targets and policies. G20 countries have a crucial role to play in realising increased climate policy ambition, given their economic power and prosperity, as well as their influence on investments, technology deployment and financial flows. This briefing paper provides an overview of mitigation options that have been analysed in recent literature and that can contribute to closing the emissions gap in 2030. This provides the basis to identify key policy areas and promising options for intergovernmental cooperation between the G20 nations, as well as possibly other relevant actors.

Kurzbeschreibung: Zentrale Minderungsoptionen, um die globale 2030-Ambitions- und Aktionslücke zu schließen und das Langfrist-Temperaturziel des Paris-Abkommens zu erreichen

Um das Langfrist-Temperaturziel des Paris-Abkommens zu erreichen, muss die Ambitions- und Aktionslücke geschlossen werden, die zwischen Paris-Abkommen konsistenten Emissionspfaden und den Emissionspfaden mit heute bestehenden Zielen und Maßnahmen für das Jahr 2030 besteht. G20-Staaten nehmen eine Schlüsselrolle ein, um diese notwendige Steigerung von Klimaschutzambition zu erreichen: Mit ihrer wirtschaftlichen Macht und kollektivem Wohlstand sowie ihrem Einfluss auf Investitionen, Technologieentwicklung und Finanzflüsse. Mit diesem Bericht wird ein Überblick über Minderungsoptionen vorgelegt, die in der aktuellen Literatur analysiert wurden und die dazu beitragen können, die Ambitionslücke zu schließen. Auf dieser Grundlage können zentrale Politikfelder und vielversprechende Optionen für zwischenstaatliche Zusammenarbeit zwischen G20-Staaten und möglicherweise weiteren Akteuren identifiziert werden.

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List of abbreviations

AR	Afforestation and Reforestation
ASEAN	Association of Southeast Asian Nations
BAT	Best Available Technology
BECCS	Bioenergy and carbon capture and storage
BREEAM	Building Research Establishment Environmental Assessment Method
CEO	Chief Executive Officer
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Use
CO_2	Carbon Dioxide
CO_2eq	Carbon Dioxide equivalent
CDR	Carbon Dioxide Removal
COP	Conference of the Parties
ETC	Energy Transitions Commission
EGR	Emissions Gap Report
ETS	European Trading System
EU	European Union
EV	Electric Vehicle
FTA	Free Trade Agreement
GDP	Gross Domestic Product
GHG	Greenhouse gas
Gt CO_2	Gigatonnes Carbon Dioxide
HVAC	Heating, Ventilation and Air Conditioning
IAM	Integrated Assessment Model
ICE	Internal Combustion Engine
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
LEED	Leadership in Energy and Environmental Design
LTS	Long-term strategy
NDC	Nationally Determined Contribution
OECD	Organisation for Economic Co-operation and Development
PA	Paris Agreement
p.a.	Per annum
PA LTTG	Paris Agreement Long-term temperature goal
PV	Photovoltaic
RE	Renewable Energy
RET	Renewable Energy Target
SPM	Summary for Policymakers
SR1.5	IPCC Special Report on 1.5
LTTG	Long-term temperature goal

AR	Afforestation and Reforestation
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNSG	United Nations Secretary General
VRE	Variable Renewable Energy
WTO	World Trade Organisation

Summary

Achieving the Paris Agreement Long-term temperature goal (PA LTTG) requires closing the 2030 ambition and action gap between emissions levels consistent with the Paris Agreement and emissions levels projected with current targets and policies.

G20 countries have a crucial role to play in realising increased climate policy ambition, given their economic power and prosperity, as well as their influence on investments, technology deployment and financial flows.

This briefing paper provides an overview of mitigation options that have been analysed in recent literature and that can contribute now to closing the emissions gap by 2030. It provides a basis to identify key policy areas and promising options for intergovernmental cooperation between the G20 nations, as well as possibly other relevant actors.

The key characteristics of Paris Agreement pathways highlight the urgent need for transformational change in all sectors to close the ambition gap and keep the PA LTTG within reach. Two key characteristics of mitigation pathways in line with the PA LTTG are relevant for the identification of effective policy areas and cooperation initiatives to close the gap:

- All sectoral transformations have to happen in parallel and in an integrated manner. There is no space for offsetting one against the other, given the urgency to achieve additional emission reductions to close the 2030 ambition and action gap.
- Energy and land use transformations need to be carefully planned and managed, taking into account both linkages between sectoral transformations (e.g. biomass use for energy and for achieving negative emissions), and policies selected in order to maximise synergies with sustainable development.

A large volume of literature including analyses at regional and national levels shows how the 2030 ambition and action gap can be closed with existing technologies and to a large extent with proven policies that can easily be replicated and adopted more broadly.

The energy sector transformation with large mitigation potential to close the 2030 ambition and action gap is critically dependent on three strongly linked elements:

- Fast decarbonisation of electricity generation, in particular through phasing out fossil fuels and shifting to renewable energy
- Reduction of total energy use and increase in energy efficiency across all end use sectors
- Decarbonisation of end use sectors through direct or indirect electrification (sector coupling).

In the area of land-use, two policy areas need to be highlighted to achieve the key benchmarks for closing the gap:

- Agriculture: Demand-side measures (especially on reducing food waste and inducing dietary changes) can provide mitigation potential additional to mitigation on the supply side but have not been covered broadly in policies yet.
- Forestry: The need to halt deforestation through protection of existing forests, restore degraded forests and increase afforestation is a key policy area.

Zusammenfassung

Um das Langfrist-Temperaturziel des Pariser Abkommens zu erreichen, müssen die Ambitions- und Aktionslücken geschlossen werden, die zwischen Paris-Abkommen konsistenten Emissionspfaden und den Emissionspfaden mit heute bestehenden Zielen und Maßnahmen für das Jahr 2030 bestehen.

Die G20-Staaten nehmen eine Schlüsselrolle ein, um diese notwendige Steigerung von Klimaschutzambition zu erreichen: Mit ihrer wirtschaftlichen Macht und kollektivem Wohlstand sowie ihrem Einfluss auf Investitionen, Technologieentwicklung und Finanzflüsse.

Mit diesem Bericht wird ein Überblick über Minderungsoptionen vorgelegt, die in der aktuellen Literatur analysiert wurden und die dazu beitragen können, die Ambitionslücke zu schließen. Auf dieser Grundlage können zentrale Politikfelder und vielversprechende Optionen für zwischenstaatliche Zusammenarbeit zwischen G20-Staaten und möglicherweise weiteren Akteuren identifiziert werden.

Die Untersuchung der Schlüsselelemente von Pfaden zur Erreichung des 1.5 Grad-Ziels des Pariser Abkommens zeigt, wie dringend eine Transformation in allen Sektoren ist, um die Ambitionslücke zu schließen und das Langfrist-Temperaturziel des Pariser Abkommens erreichen zu können. Zwei Erkenntnisse sind von besonderer Bedeutung für die Identifizierung von effektiven Politikfeldern und Kooperationsinitiativen, um die Lücke zu schließen:

- Alle sektoralen Transformationen müssen parallel und integriert umgesetzt werden. Das bedeutet angesichts der Dringlichkeit zusätzlicher Emissionsminderungen, um die Ambitions- und Aktions-Lücke zu schließen: Es gibt keinen Platz dafür, die eine Maßnahme gegen die andere zu verrechnen.

- Transformationen des Energiesystems und der Landnutzung müssen sorgfältig geplant und umgesetzt werden und Abhängigkeiten sowohl zwischen sektoralen Transformationen (zum Beispiel Biomassenutzung und das Erzielen negativer Emissionen) als auch Politiken zu berücksichtigen, um Synergien mit nachhaltiger Entwicklung nutzen zu können.

Die Auswertung der Literatur einschließlich von Analysen auf regionaler und nationaler Ebene zeigt, dass die Ambitions- und Aktionslücke für 2030 mit existierenden Technologien und weitestgehend auch mit bewährten Politiken, die breiter angewendet werden können, geschlossen werden kann.

Die Transformation der Energiesysteme mit großen Minderungspotenzialen zur Schließung der Ambitions- und Aktionslücke hängt insbesondre von drei eng verbundenen Schritten ab:

- Schnelle Dekarbonisierung der Stromerzeugung, insbesondere durch Ausstieg aus fossilen Energieträgern und Umstieg auf Erneuerbare Energien;

- Verringerung der absoluten Energienutzung und Erhöhung der Energieeffizienz in allen Nachfragesektoren;

- Dekarbonisierung der Nachfragesektoren durch direkte oder indirekte Elektrifizierung (Sektorkopplung).

In der Landnutzung sind zwei Politikfelder entscheidend, um die Lücke zu schließen:

- Landwirtschaft: Maßnahmen auf der Nachfrageseite (insbesondere zur Verringerung von Lebensmittelabfällen und Unterstützung des Wandels von Ernährungsgewohnheiten)

können zusätzliche Minderungen zu Maßnahmen auf der Angebotsseite erzielen, wurden aber bisher noch nicht umfassend mit Politiken adressiert;

- Wald: Die Notwendigkeit, die Entwaldung durch den Schutz bestehender Wälder zu stoppen, degradierte Wälder wiederherzustellen und die Wiederbewaldung zu verstärken, ist ein zentraler Politikbereich.

1 Introduction

With the Paris Agreement (PA), the international community has adopted the objective of "[h]olding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognising that this would significantly reduce the risks and impacts of climate change".

The IPCC Special Report on 1.5°C (SR1.5), adopted and published in October 2018, highlights that we are already seeing the consequences of 1°C of global warming, and that a number of climate change impacts could be avoided by limiting global warming to 1.5°C compared to 2°C, or more (IPCC, 2018). Two subsequent IPCC Special Reports focusing on Land and on the Oceans, further highlight the urgency of limiting warming to the 1.5°C limit agreed with the PA (IPCC, 2019a, 2019b).

The Paris Outcome Decision (UNFCCC, 2016) requests parties to communicate by 2020, new and updated Nationally Determined Contributions (NDCs) with a timeframe up to 2030. This request was reiterated by Parties at the recent conference in Madrid in December 2019, re-emphasising "with serious concern the urgent need to address the significant gap between the aggregate effect of Parties' mitigation efforts in terms of global annual emissions of greenhouse gases" and emission pathways consistent with the PA long-term temperature goal (LTTG) (UNFCCC, 2020).

Achieving the PA LTTG requires transformative systemic change across all sectors of the economy and society, integrated with sustainable development (Climate Analytics, 2019c). A collective improvement in ambition that yields a 50% reduction from the 2030 emissions levels implied by current NDCs is necessary to be consistent with the PA LTTG (Climate Analytics, 2019b). The large mobilisation of civil society, particularly the youth, and the strong call by the United Nations Secretary General (UNSG) for ambition ahead of the September 2019 climate summit have created a strong political momentum, with a large and increasing number of countries committing to, or working towards, more ambitious targets for 2030 as well as carbon neutrality by 2050[1]. Yet it is a sobering fact that currently only three (Argentina[2] ,Mexico, South Africa) G20 countries have thus far committed to enhance their NDC by 2020[3]. The EU has recently committed to a greenhouse gas (GHG) neutrality goal by 2050[4] and is working towards updating its NDC which is not yet supported by all Member States.

G20 countries have a crucial role to play in realising increased climate policy ambition, given their economic power and prosperity, as well as their influence on investments, technology deployment and financial flows (Climate Action Tracker, 2019a; Climate Transparency, 2019f).

This briefing paper provides an overview of mitigation options that have been discussed in recent assessments and analyses and that can contribute to closing the emissions gap in 2030. The overview's aim is to identify key policy areas and promising options for intergovernmental cooperation between the G20 nations, as well as possibly other relevant actors.

[1] As of December 11th, 103 countries are responding to the urgent need to reduce emissions in the next decade by having communicated an enhanced NDC or signalling their intention to work towards enhancing the ambition of their NDCs by 2020. In addition, 11 countries have started internal processes in their national plans and policies to boost ambition by 2020. See https://s3-sa-east-1.amazonaws.com/cop25.cl/documents/eng/1312+Annex+Alliance+ENGLISH.pdf

[2] Argentina has already revised its NDC in 2016.

[3] See https://www.wri.org/blog/2019/11/which-countries-will-step-climate-commitments-2020-what-we-know-now

[4] council conclusions https://www.consilium.europa.eu/media/41768/12-euco-final-conclusions-en.pdf

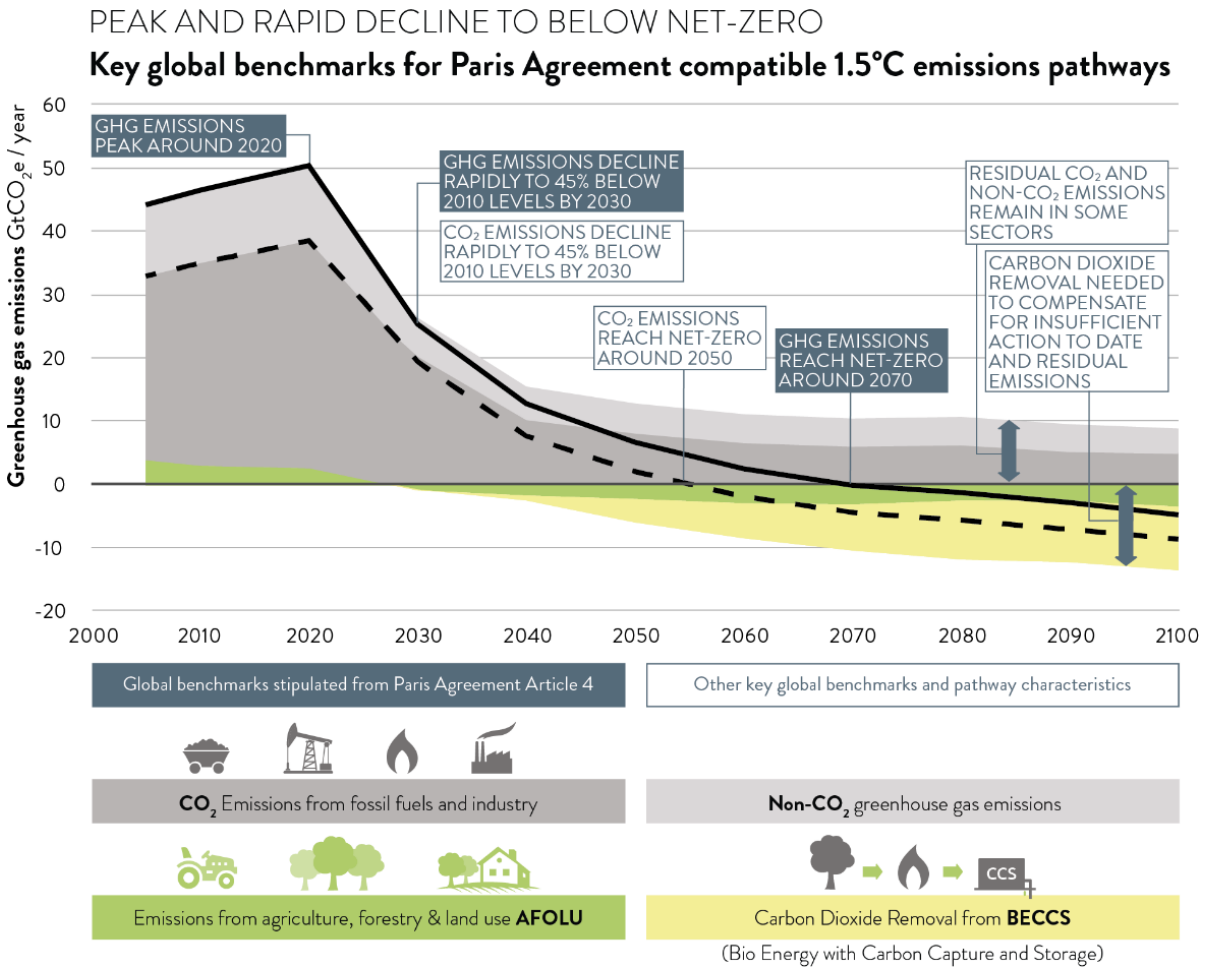
2 Mitigation pathways in line with the Paris Agreement

In its Special Report on the 1.5°C limit (IPCC SR1.5), the IPCC for the first time comprehensively analysed socio-economic mitigation paths that allow global warming to be limited to 1.5°C compared with pre-industrial levels using complex energy-economic/land-use models (Integrated Assessment Models, IAMs). In the Summary for Policymakers (SPM), the IPCC defines the group of mitigation pathways that are compatible with the PA LTTG as those that either keep warming below 1.5°C ("no overshoot"), or those that temporarily exceed the 1.5°C limit only minimally (below 0.1°C) and then return to a value below the limit before 2100 ("low overshoot"). Due to the high historical and thus cumulative emissions, and because some emissions cannot be completely reduced to zero (e.g. emissions from agriculture), a certain degree of carbon dioxide removal (CDR) from the atmosphere is required. This is reflected in the Integrated Assessment Model (IAM) pathways assessed by the IPCC through two main options: either as large-scale afforestation and reforestation (AR) or the use of bio-energy and carbon dioxide storage (BECCS).

The IPCC finds limits for a sustainable use of both CDR options globally by 2050 to be below 5 $GtCO_2$ p.a. for BECCS and below 3.6 Gt CO_2 p.a. for sequestration through AR while noting uncertainty in the assessment of sustainable use and economic and technical potential in the latter half of the century. A level of emissions within a range of 25-28 Gt $C0_2$eq needs to be achieved by 2030 (Climate Analytics, 2019c; UNEP, 2019) to limit dependence on CDR within this sustainable use limit. This range stands in stark contrast to the collective level of ambition implied by the current set of NDCs which would raise emissions to 52-58 GtCO2eq by 2030.

Taking into account no or low overshoot pathways that comply with these limits, key milestones for Paris Agreement consistent mitigation pathways can be identified (Climate Analytics, 2019c). One such crucial milestone is the need to peak total GHG and CO_2 emissions by 2020 and then reduce them rapidly by about 45% by 2030 compared to 2010. Total GHG emissions must reach net zero around 2070, while CO_2 emissions must reach net zero by 2050 and then become negative.

Figure 1: Milestones of reduction paths in accordance with the temperature target of the Paris Agreement, derived from IPCC SR1.5 reduction paths.



Source: [Climate Analytics (2019c)]

An important aspect of these pathways is the need to close the 2030 ambition and action gap. The UNEP Emissions Gap Report 2019 (UNEP, 2019) quantifies the gap between implementing the aggregate unconditional NDCs and the 1.5°C pathway to be about 32 Gt CO_2eq (range 29-35 Gt CO_2eq). The gap is even larger if current policies are considered, given many countries have not implemented sufficient policies to achieve their targets, leading on aggregate to an emissions level of 60 Gt CO_2eq and a 4 Gt CO_2eq larger gap according to the EGR 2019. The Climate Action Tracker (Climate Action Tracker, 2019a) assessed in its latest update in December 2019 that under current targets, the world will warm by 2.8°C (range 2.3 to 3.5°C) by the end of the century, close to twice the limit agreed in Paris, and even further in terms of their current policies, which would see the temperature rise by 3°C (range 2.3 to 4.1°C) by the end of the century.

The following key characteristics and global benchmarks for sectoral transformations can be derived based on the pathways summarised in the previous section (Climate Analytics, 2019c):

- Large reduction in energy demand across all end-use sectors by 2030,
- Fully decarbonised primary energy supply by mid-century,
- Fully decarbonised electricity generation by 2050,

- Electrification of end-use sectors and decarbonisation of final energy other than electricity
- Land use CO_2 emissions to reach net zero between 2025 and 2040 and negative emissions thereafter.
- Reduce non-CO_2 emissions from industry, agriculture, and waste.

All these sectoral transformations have to happen in parallel and in an integrated fashion. They cannot be offset one against the other in order to reach an emissions pathway that is consistent with the Paris Agreement 1.5°C limit.

The underlying pathways used to derive these benchmarks are based on a range of IAM scenarios covering a wide range of mitigation strategies, as illustrated by three of the four "illustrative model pathways" (P1, P2, and P3) referred to in the SPM of the IPCC SR15. In the pathways analysed here, BECCS has to be applied from about 2040 according to most scenarios to reach the required levels of negative emissions. The extent to which the pathways rely on CDR depends on assumptions of how fast energy demand can be reduced or consumption patterns can be changed, and how fast energy supply can be decarbonised or other emissions can be reduced.

IAMs are one line of evidence to evaluate technological and economic feasibility and provide least cost mitigation pathways in line with the PA LTTG, but come with their own limitations which generally lead to a more conservative approach to transformational change (Hare et al., 2018). Some recent IAM scenarios do explore assumptions and incorporate novel modelling of dramatically lowered energy demand and increased energy efficiency related to lifestyle choices and large-scale deployment of new technologies and behaviours beyond the energy sector, including information technology, urban development, sharing economies and healthier diets (Grubler et al., 2018; van Vuuren et al., 2018). These are also assessed in SR1.5 (such as the illustrative pathway P1) and typically lead to less reliance on CDR options (Hare et al., 2018).

While IAMs and other sectoral energy system models - such as those used by the International Energy Agency (IEA) - have had difficulties capturing the renewable energy (RE) revolution, they often include the continued use of fossil fuels for electricity generation, adding Carbon Capture and Storage (CCS) to reduce emissions. This is despite the fact that when this technology is deployed with fossil fuel power plants it is now widely seen as a relatively expensive mitigation option with an uncertain future, and furthermore, is not a zero emissions technology (Hare et al., 2018) and remaining emission need to be compensated with the use of BECCS. Some IAM pathways (for example the illustrative P1 scenario in IPCC SR15 SPM) (Grubler et al., 2018) and an increasing number of global or regional studies show how the energy system can be decarbonised without relying on CCS. The P1 scenario is a "Low Energy Demand" Scenario and assumes strong social and technological innovations leading to lower energy demand, as well as high and early net carbon uptake by the global land sector via afforestation.

All PA 1.5 pathways show a strong reduction in energy demand across all sectors by 2030, despite IAMs primarily focusing on supply side options and a reduction in fossil fuel use, particularly coal and oil, and very rapid increase in the use of renewable energy. Bioenergy is used in many PA 1.5 mitigation pathways, both with CCS (BECCS) and without, with large uncertainties regarding the limits of sustainable use.

Other sectoral analyses including an increasing number of 100% renewable energy scenarios (Creutzig et al., 2017; Jacobson et al., 2017; Löffler et al., 2017) show that fossil fuels can be phased out faster and completely, including through faster electrification of end use sectors (transport, buildings, industry) and replacing fossil fuels with biofuels or hydrogen for some

industrial processes like steel production. All these transformations require a substantial and rapid redirection of investment flows: According to the IPCC SR15 investment in low-emission technologies and energy efficiency must be doubled over the next 20 years and already overtake investment in fossil fuels in 2025, which must decline accordingly in the next 20 years.

PA 1.5 IAM pathways show electricity supply fully decarbonised before 2050, mainly by increasing the use of renewable energy sources (more than 50% by 2030 and more than three-quarters globally by 2050). The political, economic, social and technical feasibility of solar energy, wind energy, and electricity storage technologies has improved dramatically over the past few years, with costs dropping rapidly and corresponding growth trajectories much faster over the last years than expected (IRENA, 2019c), and typically reflected in energy system scenarios. Other zero or low carbon sources assumed in IAM scenarios are nuclear energy and fossil fuels with CCS and bioenergy with CCS (BECCS). These are unlikely to be able to compete with renewable energy in terms of costs, benefits, and other aspects of economic, social and political feasibility.

A number of global and regional bottom-up analyses of sectoral mitigation options also assessed by the IPCC in its SR1.5 show that residual CO_2 emissions from energy and industry (fossil fuel use) in the second half of the century can be mostly - if not completely - avoided by employing a wide range of mitigation options. These include phasing out fossil fuels and replacing them with 100% renewable energy; increased demand reduction and energy efficiency; faster decarbonisation of end use sectors through electrification and the transformation of industry processes or products. Implementation of this suite of options would thus reduce the need for CDR. These analyses will be evaluated in the following section to identify robust sectoral mitigation strategies.

In addition to decarbonising energy systems and achieving net-zero CO_2 emissions from land use, substantial reductions of emissions of non- CO_2 greenhouse gases such as methane and nitrous oxide from sectors like agriculture, industry and waste are needed, as well as a phase out of HFCs. Reductions in non- CO_2 greenhouse gases and air pollution components such as black carbon can result in significant co-benefits for air quality and human health. For example, phasing out fossil fuels means phasing out coal and gas extraction, which leads to reducing related fugitive emissions of methane. Black carbon emissions are also reduced when eliminating combustion of coal and oil. Addressing these emissions separately in an NDC or LTS would not lead to additional contributions to the Paris Agreement Long Term Temperature goal (Climate Analytics, 2019a; Rogelj et al., 2014).

3 Mitigation measures for key transformational strategies

3.1 Strategies for transformational change

The key characteristics of Paris Agreement compatible 1.5 pathways outlined in the previous section highlight the urgent need for transformational change in all sectors to close the ambition gap and keep the PA LTTG within reach. A large volume of literature which also include analyses at regional and national level (CAT, 2018) has demonstrated how this gap can be closed with existing technologies and to a large extent with proven policies that can easily be replicated and adopted more broadly (IPCC, 2018; UNEP, 2019, 2017). Effective implementation of some mitigation options analysed such as for the decarbonisation of industry processes or freight and transport (both passenger and freight), would require the development of new policies.

There are a range of key overarching best practice policies highlighted by IPCC SR15 and other assessments like UNEP EGR 2019. These include carbon pricing and reducing fossil fuel subsidies, as well as policies to support the required shift in investment, innovation policies to accelerate deployment of key renewable energy and storage technologies, and transition management, including at the regional level. The scale of the necessary transformation requires mid- and long-term planning to avoid locking in high emissions/high-carbon intensity, as well as good practice governance such as bringing stakeholders on board, and robust transparency frameworks.

The required transformational changes require a well-managed and planned transition of energy and land use, which could at the same time provide access to clean energy and many other co-benefits such as better air quality. The increased awareness of the climate-related crisis and risks to sustainable development have created a strengthened political momentum that governments can build on to support more ambition, while focusing increasingly on the need to ensure social cohesion and a just transition.

Another important aspect highlighted in (IPCC, 2018; UNEP, 2017, 2019) is how fast some of the key drivers have changed in the last years, improving feasibility of mitigation and therefore to close the gap, in particular through reduction in costs of renewable energy and storage technologies, as well as electric mobility. A change that has only quite recently been identified is technological progress with electrolysers, which in combination with low-cost renewable energy technologies can be a game changer in producing zero emissions fuels. Stopping deforestation requires addressing key drivers for land-use change and forest loss.

Finally, recent reports (IPCC, 2018; UNEP, 2017, 2019) also support the strong link with sustainable development and co-benefits and the synergies with economic growth, which is an important agenda for the G20 (New Climate Economy, 2018; OECD, 2017).

While we largely focus on sectoral mitigation options in the following section, it is important to keep in mind interactions between sectors and strategies that take synergies but also potential trade-offs into account. It is of critical importance to consider these interlinkages, through development of integrated strategies covering all sectors as well as overarching policies and interlinkages.

3.2 Decarbonising energy systems: Sectoral and cross-sectoral mitigation options

3.2.1 Electrification and sector coupling

A key strategy for decarbonising the energy system is electrifying end-use sectors (transport, buildings, industrial processes) while also decarbonising end-use energy through the use of

biomass (within the framework of sustainable limits), green hydrogen, or other energy carriers/fuels generated with renewable electricity. This is true in particular for air and sea transport, and some industrial processes for which direct electrification is not the preferred option or not deemed possible. Both direct and indirect electrification can also support the integration of variable renewable energy providing options to enhance flexibility and reliability. They are sometimes also referred to as "sector coupling"[5]. Technological advances in this field are very dynamic, with recent studies moving forward the estimated timing of cost competitiveness of green hydrogen solutions and pointing to the importance of scaling up the supply chain (for transport for example) as well as manufacturing and end use equipment to drive costs down (Hydrogen Council, 2020).

Importantly Hydrogen Council (2020) finds that a hydrogen production and distribution system at scale will unlock hydrogen's competitiveness in many applications sooner than previously anticipated, and specifically by 2030. It identified 22 hydrogen applications comprising roughly 15 % of global energy consumption with large potential, and a need for initial funding in order to close the existing cost gap. Specifically, green – renewable energy based – hydrogen is expected to become competitive by 2030 once a critical scale of electrolysis capacity has been reached. Commercial vehicles, trains, and renewable hydrogen solutions are expected to become competitive with conventional options by 2030 for example for heavy-duty trucks, coaches with long range requirements, and forklifts.

This is similar to other successful transformations in the past that have seen an accelerated scaling up supported through concerted policies (e.g. feed-in tariffs for renewable energy technologies) (Climate Action Tracker, 2019e).

The potential of direct and indirect electrification highlights the crucial role of decarbonising power generation leading to increase in electricity demand to electrify end use sectors, directly or indirectly. This increase in demand needs to be factored into planning for renewable energy expansion.

3.2.2 Power generation: benchmarks for renewable energy uptake and fossil fuel phase out

The following benchmarks based on the PA 1.5 mitigation pathways summarised in the previous section can be identified:

- Decarbonised electricity generation reaches a median share of 73 % in 2030 and 93 % in 2050 in PA 1.5 mitigation pathways. This would largely need to be achieved with renewable energy and storage technologies given CCS and nuclear are likely not able to compete with renewable energy and storage despite their role in many scenarios. Costs of nuclear power have even increased over time in some developed countries, while costs of CCS have not been coming down over the last decade. Due to the high marginal cost of electricity production, CCS plants would be pushed out of operation first (Brouwer, 2015), making high capacity factors as assumed in many scenarios unlikely (Climate Analytics, 2019c).
- Coal use for power generation needs to peak by 2020 and to be reduced quickly afterwards in all regions, and to be reduced to 80 % below 2010 levels by 2030 and phased out before 2040, with many regions phasing out coal already by 2031 (Parra et al., 2019). Most

[5] https://www.irena.org/energytransition/Power-Sector-Transformation/Sector-Coupling

reductions of coal in the power sector need to happen before 2030, when the share of coal in electricity generation should not exceed 13 % anywhere and be around 6 % globally.

- Continued use of natural gas would only be consistent with the Paris Agreement if used with CCS. Even then it would play only a small role in electricity generation by 2050 at around 8 % of global electricity generation. Due to incomplete CO_2 capture rates, the use of gas with CCS would have to be balanced out with additional CDR.

- Natural gas without CCS peaks before 2030 and declines thereafter, to be halved by 2040 compared to 2010. It is phased out by 2050 in PA 1.5 mitigation pathways (CAT, 2019). This is in stark contrast with current developments and ramping up of gas production and infrastructure, highlighting the high risk of stranded assets. It also contradicts assertions that gas can continue to play a role as "bridging technology"[6].

A rapid uptake of wind and solar PV, enabling the phasing out of both coal and gas-fired power, has the greatest potential to close the emission gap to 2030 (UNEP, 2017) with large benefits for sustainable development. Renewable energy technologies are already competitive with fossil fuels (IRENA, 2019c) and costs are projected to continue to fall, with new wind and solar PV projected to be cheaper than 96% of all existing coal power in 2030 (Carbon Tracker Initiative, 2018). With RE already cheaper than constructing new natural gas power plants in the world's two largest emitting countries, the US and China (Dyson et al., 2019; Wood Mackenzie, 2019), new investments in gas-fired power plants are increasingly at risk of becoming stranded assets in both developed and developing countries.

Most countries have renewable energy targets (RETs) for timeframes to 2025 or 2030 and have been increasing their level of ambition (REN21, 2019), and many include them in their NDC. Those with RETs in their NDCs is currently limited almost exclusively to smaller and developing countries, with India, Canada, and Brazil being notable exceptions (IRENA, 2019b). Many countries' RETs, however, are not consistent with the Paris Agreement (this has been analysed, for example, for the EU, Argentina, Indonesia, and Turkey) (CAT, 2018; Climate Action Tracker, 2019d, 2019c, 2019b), and specific plans for new capacity are often not stringent enough in imposing an emission constraint necessary to meet LTTG. They also generally do not take into account the increased future demand that comes with electrification of end use sectors.

An increasing number of countries have implemented or are working on phasing out coal for power generation, but not always in the timeframe consistent with the Paris Agreement. However, many countries are planning or supporting a switch from coal to gas, including targets for increasing gas use (e.g. China, India) instead of or alongside switching to renewable energy (Argus Media, 2019; Singh & Sundria, 2018) Increasing gas use contrasts with the need for gas use to decreasing share in Paris Agreement consistent pathways.

The integration of variable renewable energies (VRE) into energy networks, however, requires stable backup power, increasingly possible with large-scale battery installations or pumped hydropower, as well as the use of smart devices and information technologies to precisely manage localised demand and distributed supply (IRENA, 2019a). Sector coupling like power to hydrogen will also help to manage VRE integration, and in doing so, will reduce emissions from sectors that are currently difficult to decarbonise (IRENA, 2018). Few countries have systematically adopted targets including sector coupling, but some countries and regions are far advanced in high uptake of VRE (Denmark, South Australia) (IEA, 2019b).

[6] See e.g. https://www.greentechmedia.com/articles/read/natural-gas-bridge-nearing-end

RE targets, fossil fuel phaseout targets and legislation, RE feed-in tariffs and auctioning, policies and investments in grid and market regulation to enable uptake of VRE, robust carbon pricing, and the phasing out of fossil fuel subsidies are some of the key proven and broadly applied policies identified to expedite the electrification of non-power sectors and the transition to 100% RE. Focusing on nationally appropriate "just transitions" for fossil fuel-dependent regions, however, is critical to ensure the political viability of rapid fossil fuel phaseouts (UNEP, 2019).

3.2.3 Fossil Fuel Production: Closing the production gap

Global planned fossil fuel production by 2030 is projected to lead to emissions of 39 $GtCO_2$, which is 21 $GtCO_2$ higher than levels compatible with limiting warming to 1.5°C (SEI et al., 2019).

While this "production gap" is largest for coal, oil and gas production plans are also not consistent with the 1.5 limit. Production plans are also not consistent with NDC targets, leading to the production gap being larger than the emissions gap (SEI et al., 2019).

There is minimal policy attention to addressing this production gap. To the contrary, key fossil fuel producing countries' governments are actively supporting their production in many ways, including through subsidies and public finance. The UNEP Production Gap report 2019 highlights this for seven top fossil fuel producers, all G20 members (China, US, Russia, India, Australia, Indonesia, Canada). Some Countries outside of the G20 (Belize, Costa Rica, Denmark, New Zealand) as well as France are partially or totally banning oil and gas exploration and extraction and some countries are in the process of phasing out coal extraction but partly based on economic considerations (Germany, Spain).

Exploration, production, and export bans or quotas, prohibition of key infrastructure or technologies, and ensuring comprehensive emissions assessments for new supply projects, are the key regulatory approaches to limit fossil fuel production that have been suggested but have largely not yet been implemented (Lazarus & van Asselt, 2018; SEI et al., 2019). These can be combined with fiscal approaches such as removing fossil fuel producer subsidies, and increasing royalties or introducing fees on production or export of fossil fuels.

In addition to closing this production gap, there are technical mitigation options to reduce fugitive emissions from continued fossil fuel production, for example from oil and gas extraction. Despite the commercial availability of such abatement options, global fugitive and vented methane emissions from oil and gas production was estimated at 2 $GtCO_2e$ in 2017 (IEA, 2019a). The IEA estimates that 72 % of these could be abated, with an estimated 38 % abated at no net cost.

3.2.4 Decarbonise transport: reduce demand, enable modal shift, emissions standards and electrification

Transport emissions represent close to 20 % of G20 country emissions (Climate Transparency, 2019f). Apart from the need for measures to reduce transportation requirements and for enabling a modal shift to non-motorised mobility, a key sectoral strategy both for passenger and freight transport on land is to aim for decarbonising these by 2050 through electrification. To reach decarbonisation by 2050, sales of new passenger vehicles must be zero-emission by 2035, and the freight sector would need to achieve mass market deployment of electric or fuel cell trucks driven by renewables-based fuels such as green hydrogen, biofuels, or synthetic fuels by 2030 (CAT, 2016a; Climate Action Tracker, 2018b; Kuramochi et al., 2017). Key proven policies include the introduction of vehicle emission standards, construction of charging stations, elimination of fossil-fuel subsidies, enabling modal shift to non-motorised mobility, shared and public transport for passengers through greater public transport investments (Climate

Transparency, 2019f; UNEP, 2019) and shifting freight transport to rail (Climate Action Tracker, 2018b).

An increasing number of countries are implementing targets for phasing out internal combustion engine (ICE) vehicles or conversely aiming at 100% zero-emission vehicle sales by 2035 or earlier, which is in line with the Paris Agreement. In line with the country targets, some vehicle manufacturers have also announced their plans to stop designing and manufacturing ICE vehicles.

Passenger car standards exist for a wide range of countries but with different levels of stringency. If the 2025 EU car standards were broadly applied, this could potentially reduce global emissions by 1.9 $GtCO_2$ by 2030 (Fekete et al., 2015). Only Japan, Canada, China and very recently the EU have introduced CO_2 or efficiency standards for heavy duty vehicles (UNEP, 2018b).

While shipping and aviation emissions account for 40 per cent of all transport-related emissions, international aviation and shipping are not covered by NDCs, and there is a significant lack of ambition and actions to reduce emissions at the level of national governments. Conversely, some non-state or subnational actors are undertaking initiatives, like for example Maersk, the world's largest container shipping company, which has committed to achieve net-zero carbon emissions by 2050, while Scotland is aiming to become a net-zero aviation region by 2040 (UNEP, 2019). In the aviation sector, which is still heavily subsidised, the main instrument used so far has been the introduction of a tax on passenger flights, such as in Germany and France, to push a modal shift from flight to rail (Climate Transparency, 2019f; UNEP, 2019). Decarbonisation of shipping, which has so far been inadequately addressed at the national level, has a strong potential through the use of advanced biofuels and synthetic fuels in the medium term with hydrogen fuel being a complementary solution in the longer term. Other levers to reduce emissions in the shipping sector include the implementation of energy efficiency measures (such as by optimizing vessel conception through size and materials), activity reduction and reducing vessels' speed (IEA, 2017; OECD, 2018).

3.2.5 Move to (near) zero emissions buildings: Efficiency and Renewable energy

The building sector is responsible for more than 50% of final electricity demand, and 23% of energy-related CO_2 emissions. Mitigation options in the building sector need to address both new buildings as well as refurbishment of existing building stock Taking into account an average expected lifetime of buildings and aiming for decarbonised building stock in 2050, a benchmark for near term action is to aim for all new buildings to be near zero-emission (Kuramochi et al., 2017). This is possible with phasing out of fossil fuels in heating and shifting towards the electrification of space and water heating, powered by renewable energy (Climate Action Tracker, 2018d; UNEP, 2019). Key areas of action to reduce emissions in this sector focus on reducing the energy intensity of buildings through retrofits and more ambitious codes for new construction, through behavioural changes by occupants, and through the electrification of equipment and appliances (heating, ventilation and air conditioning systems (HVAC)) (Climate Action Tracker, 2018a). However, the majority of NDCs do not explicitly cover buildings emissions relative to specific sector measures. If fully implemented, these sector specific mitigation targets would cover only about 60% of building related GHG emissions, excluding emissions included in economy wide targets (IEA/UNEP, 2018; UNEP, 2018a). Introducing targets for new buildings to be zero-energy by 2020 in OECD countries, and by 2025 in non-OECD countries, combined with deep renovation rates of 5% and 3% respectively, could bring the buildings sector onto a 1.5°C compatible pathway (Climate Action Tracker, 2016). Another key mitigation option in the buildings sector is material substitution and product light

weighting, which could lead to a saving of 8 to 10 % of GHG emissions in the G7 and China. This could be driven by the implementation of building codes (UNEP, 2019).

3.2.6 Industry: Energy and material efficiency and decarbonisation

The industry sector accounts for the largest share (25 %) of total global direct CO_2 emissions (Climate Action Tracker, 2018a). Reducing demand and increasing energy, material and process efficiency (e.g. through recycling and replacement of materials) is an important but not sufficient strategy to decarbonise the sector (Climate Analytics, 2019c).

Reducing material demand through recycling, material substitution and dematerialisation is increasingly studies as a mitigation option which could be enabled through circular economy strategies (UNEP, 2019). The recirculation of high-quality end-of-life materials as feedstock could significantly reduce electricity needs and it is estimated that resource efficiency and circular economy measures could halve the EU basic materials industry emissions by 2050 (Material Economics, 2019; Wyns et. al., 2019). A number of recent studies analyse the role of these strategies to achieve net zero emissions in the industry sector, in particular energy intensive and materials industry (Material Economics, 2019), driven by the objective to reach net zero emissions by 2050. New Production processes are estimated lead to emissions reduction from 143 to 241 $MtCO_2$ by 2050 (Wyns et. al., 2019).

Technical barriers and international competition for nationally economically relevant industries are the main obstacles for decarbonising energy intensive industry (UNEP, 2019).

Improving industrial processes like, for example, using zero carbon fuels and feedstocks for the production of cement and steel and introducing the use of hydrogen as a reducing agent in steel production are envisioned but still at an early stage of very dynamic technological development (IRENA, 2019). They are not yet captured in IAM or energy system scenarios, making them more conservative regarding the potential for decarbonisation of the industry sector. There are estimates that green hydrogen can be cost-competitive with existing industrial feedstocks such as natural gas by 2025 or with coal for steel production by 2030 (Bloomberg, 2019).

Another important strategy is substituting carbon intensive products (e.g., replacing steel or cement with wood, or plastic with textile fibres) (Climate Analytics, 2019c) which, combined with increasing material efficiency, could reduce demand for energy-intensive materials. This could represent a mitigation potential of up to a 40% emissions reduction from energy intensives industries in 2050 (UNEP, 2019).

An option with strong mitigation potential is the electrification of cement production (assuming decarbonisation of the power sector) which could lead to a 40% reduction in emissions by 2030 per tonne of cement produced, already under pilot phase (Climate Action Tracker, 2019e). Roughly half of cement-related emissions are due to clinker production (conversion of the limestone into clinker), an energy intensive process. A key mitigation option to reduce process-related emissions is to substitute clinker with alternative material to reduce the clinker/cement ratio in the process (Climate Action Tracker, 2017).

An option often considered in scenarios and analysis but not yet adopted is the mitigation of industry emissions through the deployment of Carbon Capture and Storage (CCS). Development of this technology, however, has proven to be slow and costly with only two large-scale industrial CCS projects in operation (Climate Action Tracker, 2018a; UNEP, 2019).

3.3 Land use: stopping deforestation, managing competing demands

An important benchmark for PA 1.5 mitigation pathways is a rapid reduction and reversal of carbon dioxide emissions from land use. The majority of PA 1.5 mitigation pathways achieve net

zero CO_2 land use emissions between 2025 and 2040, requiring a steep reduction in deforestation, and policies needed to conserve and rebuild land-based carbon stocks and protect natural ecosystems.

A key challenge is the need to balance many competing demands for land: food production, human settlement, bioenergy, carbon sequestration, maintenance of biodiversity and other ecosystem services. These demands depend on socio-economic conditions, as well as technological change. Near-term success in protecting and restoring forests and other land ecosystems will be important to avoid reliance on CDR. In addition, successfully decarbonising other sectors will reduce demand for CDR options such as carbon sequestration (Afforestation/reforestation) or bioenergy use with CCS. The majority of pathways consistent with the PA shows an increase in forested land by 2040-2050, with a decline in pasture land and cropland enabled by an increase in crop yields, an intensification of livestock production, and shifts in consumption patterns (Climate Analytics, 2019c).

3.3.1 Agriculture: Supply side and demand side measures

Agriculture accounts for roughly 10 % of global GHG emissions, and as much as 50% of global non-CO_2 emissions equating to between 5 and 6 $GtCO_2e$/year. The multiplicity of emissions sources and the variation of the agriculture sector between countries—with large-scale industrial agriculture dominating in some and small-scale subsistence farming in others—means that there is no "one size fits all" approach, and improved farming practices cannot easily be rolled out (Climate Action Tracker, 2018d).

Technical measures on the supply side do exist but their potential is limited (Climate Action Tracker, 2018d; UNEP, 2017). For instance, enteric fermentation and manure are the largest sources of agriculture emissions globally, but technical mitigation potential is limited for both (8-10 % of enteric fermentation/livestock management emissions and less than 10 % of manure emissions globally (Climate Action Tracker, 2018d; UNEP, 2017). Emissions from synthetic fertilisers can be reduced substantially through increasing efficiency, whereas emissions from rice paddies can be reduced through improved land use management. The IPCC SR15 shows good examples of win-win options that have benefits for both, adaptation and mitigation, including conservation agriculture, mixed crop-livestock systems, soil carbon sequestration and agroforestry (Climate Analytics, 2019c).

In aggregate, a global shift to healthier diets such as the diet recommended by the WHO could considerably reduce agricultural emissions in the order of – 0.37-1.37 Gt in 2030 (UNEP, 2017) or even 1.5 $GtCO_{2q}eq$/year by 2030 (Climate Action Tracker, 2018d). Another demand side measure is food waste reduction, with an estimated potential based on modelling of 0.79-2 Gt CO_2eq per year (assuming 45-75 % reduction in wasted food) (UNEP, 2017).

A potentially substantial co-benefit of demand side measures is the reduction of stress on land use for agricultural use, which can lower deforestation rates and allow natural ecosystems and forests to be restored.

Few countries have specific targets for agriculture (FAO, 2016) even though the agriculture sector is covered by many NDCs (Hönle et al., 2018).

3.3.2 Land management: Reducing emissions from deforestation and land degradation

About 12 % of global anthropogenic CO_2 emissions have been caused by the land use sector over the past 5 years, driven largely by deforestation (Climate Analytics, 2019c). The main options for reducing emissions in the forestry sector are halting deforestation and reducing forest degradation, options which have a cumulative mitigation potential of 0.41 – 5.8 $GtCO_2e$/year (Roe et al., 2019).

Mitigation options include reducing the conversion and degradation of natural ecosystems, which could be driven by conservation policies (e.g. the restoration of peatlands), and establishment of protected areas, as well as improved land tenure.

In addition, planting trees – afforestation and reforestation (AR) – can remove CO_2 from the atmosphere. The IPCC found that up to 3.6 $GtCO_2$/year of removals could be achieved sustainably through AR (IPCC, 2018), similar to Roe et al.'s estimate that 320 Mha of reforestation by 2050 could yield 3 $GtCO_2$/yr of removals (Roe et al., 2019).

An important constraint of land-based mitigation measures is competition over land. Afforestation and other restauration potentials are limited by agricultural production and land tenure. Addressing the drivers of land use change by focusing on other land use policies including food production, is therefore key for successful mitigation strategies. The IPCC SR on Climate Change and Land distinguishes between mitigation measures that require land use changes and response options that rely on additional land use change and could thus have implications on other policy areas (IPCC, 2019a).

Another caveat to these estimates is that mitigation potentials in the land-use sector come with great uncertainty. Key challenges include the risks of non-permanence (i.e. the reversal of carbon stored in land-based ecosystems as a result of land management changes or natural disturbances, such as drought and wildfires) and leakage (i.e. the displacement of land-use change and its associated emissions to other areas of land), as well as uncertainties in measuring land-based carbon fluxes. Efforts must therefore be made to improve monitoring and reporting of land-related emissions and to implement more robust and transparent accounting rules (Mace et al., 2018). Crucially, mitigation action on land must not be used to compensate for inaction elsewhere (IPCC, 2019a). In addition, environmental safeguards need to be implemented to avoid negative impacts on other ecosystem services (IPCC, 2019a).

Focusing on the drivers of deforestation is key to reduce deforestation. Globally, the implementation of an improved international wood tracking system and improved supply chain transparency as a mitigation option could help preventing illegal wood from entering the market and trace deforestation caused abroad by domestic consumption (Kuramochi et al., 2017) (Roe et al., 2019).

The land sector is included in 121 NDCs, but only eleven of these provide a fully quantitative target for land sector emissions and removals. The majority of NDCs (56) simply include land sector under their overarching mitigation target, with no clear information on how land-use and land-use change and forestry mitigation will contribute toward the target (Fyson & Jeffery, 2019). A key requirement relates to the importance of robust and transparent accounting rules, avoidance of double counting and ensuring environmental and safeguards are in place in relation to mitigation measures in the land use sector.

4 Role of G20 and multilateral cooperation

4.1 Ambition gap in G20 countries

There is currently a large gap between the level of policy ambition of most G20 countries and 1.5°C compatible benchmarks (Climate Transparency, 2019f). This is despite the fact that large opportunities have been identified in terms of synergies between ambitious climate policy and economic growth, including through redirection of investment (New Climate Economy, 2018; OECD, 2017). Moreover, G20 countries take a key role given their economic power and relative prosperity as well as their large share in emissions and investment flows (Climate Action Tracker, 2019a; Climate Transparency, 2019f).

G20 countries are not only responsible for about 80 % of global GHG emissions, but also account for 85 % of the global GDP, two thirds of global outward foreign direct investment flows, and the majority of the funds of multilateral development banks (Climate Transparency, 2019f). The decisions of G20 countries are therefore crucial to achieve the transformational change that is needed. There is ample space for improvement of ambition and action in G20 countries, with many targets far from consistent with the Paris Agreement Temperature Goal and many G20 countries not even on track to achieve their targets (Climate Action Tracker, 2019a; Climate Transparency, 2019f).

There is also a large ambition and action gap in relation to the implementation of mitigation options identified in Section 3, both in all aspects of energy and industry (fossil fuel) related emissions as well as in relation to land use and forestry related emissions.

While most G20 countries have RE targets for the 2030 timeframe (with exceptions being the US, Australia, Turkey, Russia, Mexico, and Argentina), these are generally not stringent enough to be 1.5°C compatible, and some analysis exists at the national level suggesting how much stringency needs to be increased, taking into account the need for electrification of end use sectors (CAT, 2018; Climate Action Tracker, 2018c, 2019c, 2019d).

So far, France (2022), Italy (2025) the UK (2025), Canada (2030) are the only G20 countries that have committed to 1.5°C compatible coal phase-out plans, and few others have one at all, while Germany would need to bring its coal phase out plan forward by eight years to 2030 to make it compatible (Climate Analytics, 2018).

Canada, France, Japan and the UK are the only G20 countries to have fossil fuel-powered vehicle bans in place, although all but the UK's are for 2040 and this would need to be brought forward to 2035 the latest to be 1.5°C compatible (Climate Transparency, 2019f).

The EU, its three G20 member states (Italy, France, Germany) and the UK have committed to ensuring all new buildings are near-zero energy by 2020, making them the only G20 members with 1.5°C compatible policies for new buildings. No G20 member has 1.5°C compatible building renovation policies, requiring a 5 %/yr for OECD countries and 3 %/yr renovation rate for non-OECD countries.

China and Japan both have mandatory energy efficiency policies covering over 50 % of industrial energy use, but this falls short of 1.5°C compatibility for the industry sector. This would require policies to reduce industrial CO_2 emissions by at least 65 % by 2050.

India, China, and Mexico are the only G20 countries that have policies and a national target for reaching net-zero deforestation. However, only India has committed to increasing its level of forested land making it the only G20 country with a 1.5°C compatible forestry policy.

4.2 How to close the ambition gap in G20 countries? Recommendations

4.2.1 Energy: Phasing out fossil fuels and accelerating renewable energy uptake

To ensure 1.5°C compatibility, a key policy recommendation for all OECD countries and therefore most of the G20 is a coal phase-out by 2030 (CAT, 2018; Climate Transparency, 2019a, 2019d, 2019c). Meanwhile the current expansion in the US, Australia, and Argentina of natural gas exports and in the EU of natural gas infrastructure is identified as requiring a strong intervention by government to halt their current trajectory (Climate Action Tracker, 2019b; Climate Transparency, 2019i, 2019h).

Another key action is to align renewable energy targets and respective policies with pathways consistent with the Paris Agreement, taking into account the critical role of the electricity sector to decarbonise end use sectors, leading to an increased demand in electricity, as well as recent technology developments. For example the call to ramp up deployment to double the rate of energy production in France and to achieve 100 % renewable energy in Australia in the 2030s. (Climate Transparency, 2019b, 2019e, 2019a).

All 10 key production countries analysed in the Production Gap report (SEI et al., 2019) are G20 countries, but none of the G20 countries have yet established any policies or leadership to close the production gap, with proposals for G20 countries such as the UK to impose a moratorium on current and new permits for oil and gas exploration and extraction (Climate Transparency, 2019b, 2019e, 2019a). This area is highlighted in SEI et al., (2019) as an opportunity to be addressed in the NDCs. International cooperation is also highlighted as being important to close the production gap, particularly in the winding down of fossil fuel production. SEI et al., 2019 also highlight the role of international financial institutions to accelerate the transition, as well as drawing from the inspiration of alliances of leading actors such as the Powering Past Coal Alliance to work together to raise targets and actions.

4.2.2 Transport: Strengthening standards and banning internal combustion engine vehicles

A key policy aim for G20 countries should be the accelerated electrification of their vehicle fleets (Climate Action Tracker, 2018b, 2018c, 2019c, 2019b). This aim can be achieved through different means, however the key policy that simultaneously embodies the scope required and provides the necessary certainty to industry is a ban of ICE vehicle sales. Countries should aim for a 2035 at the latest as timeframe of such a policy to be 1.5°C compatible (Climate Transparency, 2019i, 2019h). The adoption of electric vehicle purchase incentives policies and 100 % sales of emissions free cars targets by 2035 will be key to support the market penetration of EVs compatible with a 1.5°C pathway (Climate Transparency, 2019g). Electrification of the transport sector, however, needs to be accompanied by a full and rapid decarbonisation of the electricity sector to ensure 1.5°C compatibility.

Other important policy options that should be considered in tandem with an ICE vehicle sales ban by the G20 countries are: strengthening vehicle emission standards, funding the construction of a comprehensive charging network, shifting freight transport from road to rail, investment in the electrification of publicly owned mass transit vehicle fleets, and promotion of the use of public transport (UNEP, 2019). Modal shift together with shifting to car sharing could significantly contribute to reduce transport sector emissions and be supported by tax policies, parking fees and regulatory support for shared mobility (UNEP, 2019). Addressing the need to reduce emissions in international aviation and shipping which is not covered by NDCs is an important area where additional reductions can be achieved including through international cooperation.

4.2.3 Buildings: G20 countries can lead towards zero emissions buildings

A two-pronged approach to reducing emissions from buildings is needed for G20 countries; ensuring all new buildings are zero emission, and increasing the renovation rate of the existing building stock to between 3-5 % per year as soon as possible (CAT, 2016b; Kriegler et al., 2018).

To increase the rate of renovated buildings, the introduction of measures reducing the scale of the upfront investment to the end user is key. This could be concretely made possible by introducing lower interest rates or compensating the costs of efficiency measures with the savings on the heating costs at the development of zero emissions new buildings. The introduction of stringent buildings standards will support the development of zero emissions buildings (CAT, 2018).

The adoption of recognized certifications systems, such as Leadership in Energy and Environmental Design (LEED) and Building Research Establishment Environmental Assessment Method (BREEAM) into building codes by governments worldwide has proven to be an important policy driver for changes in construction practices, although still applied more to commercial buildings rather than residential. The use of building codes as policy instruments gives as well the opportunity to include material efficiency requirements for buildings which represent a significant mitigation option for the sector (UNEP, 2019).

4.2.4 Industry: G20 countries can lead on transformational approaches to net zero emissions

Most of the policies G20 countries have in place to reduce energy-related emissions in industry are energy efficiency measures, however the sector must achieve a fundamental transformation through electrification and substitution of fuels and processes including material demand reduction and circular economy approaches rather than just incremental improvements in energy efficiency (Climate Transparency, 2019f). The decarbonization of the industry sector could be driven by a comprehensive policy portfolio covering the following policy fields: supporting reduced energy and material demand through product substitution, recycling (circular economy), enhancing energy efficiency, financing scheme for the development of low carbon alternatives (CAT, 2018).

Policies having driven energy efficiency and low carbon alternatives include directives requiring to use the Best Available Technology (BAT) introduced by the European Union and mandatory measures to reduce energy use through energy efficiency, introduced by Japan, where companies covered by the scheme must take energy efficiency measures and report their energy use annually (CAT, 2018) (Climate Transparency, 2019f).

Some G20 countries have already implemented financial schemes (e.g. creation of innovation funds) to create incentives for the development of low carbon technologies, such as the European Union (CAT, 2018). The policies to drive decarbonization of the industry will need to cover a wide range of aspects, from carbon pricing, financial schemes, to international trade policies (as competitiveness plays a role in refraining decarbonization) and driving technological innovations including for material demand reduction which could be opportunities of cooperation for G20 countries. There is an increasing body of studies analysing options for decarbonising material industry including through circular economy strategies for example for the EU, motivated by the objective of reaching net zero emissions by 2050 (Wyns et. al., 2019).

4.2.5 Agriculture: G20 countries are key for demand and supply side mitigation

For many G20 countries fertiliser use is a key emissions source in the agricultural sector (Climate Action Tracker, 2018d), and market-based approaches have been proposed as likely to be necessary to achieve significant changes on the short timescales required. For instance, a

fertiliser tax to combat over-application has been tested (with varying success) in different EU countries (Climate Action Tracker, 2018d).

Another option that has been proposed is an emissions tax on food commodities, with exemptions for healthy foods. Springmann et al. (2017) suggest that such a tax could reduce global food-related emissions by almost 1 $GtCO_2e$ in 2020, mostly from reductions in beef and dairy consumption. Crucially for the public acceptability of such a scheme, the revenues should be used to protect vulnerable groups from food price increases and income losses (Climate Action Tracker, 2018d).

Some G20 countries are important agriculture exporters such as Argentina, Brazil, Australia, US, and protective of their agricultural sector/depending on contribution to GDP from agricultural exports. Some have sectoral policies or strategies, which Argentina has only just started to develop (Climate Action Tracker, 2019b). In the EU, the agriculture sector is included in the legally binding effort sharing targets at Member State level.

An example for a concrete proposal for action is the UK's Committee on Climate Change report to the UK government recommending that 1) direct agricultural emissions be reduced through e.g. methane inhibition in cattle, fertilizer management, productivity improvement, soil management, 2) reduce per capita consumption of meat and dairy products (20 % lower by 2050) and reduce food waste (20 % lower by 2030), and 3) use 10 % of agricultural land be for agroforestry and release other areas of agricultural land for reforestation, peatland restoration and bioenergy crop growth (Committee on Climate Change, 2020).

4.2.6 Land management: G20 countries need to address drivers for deforestation and degradation

Four G20 countries that host rainforest – Argentina, Australia, Brazil and Indonesia – have high deforestation rates, largely a result of demand for agricultural expansion and timber production (Climate Transparency, 2019f). Addressing the drivers of deforestation is essential for lowering land-based emissions. One option is to place a moratorium on unsustainable agricultural production and the conversion of natural ecosystems (Food and Land Use Coalition, 2019). For example, a moratorium on peatland drainage in Indonesia contributed to a drop in deforestation in 2017 in Indonesia (Climate Action Tracker, 2019c), and a three-year moratorium on new oil palm development was put in place in 2018 (Climate Action Tracker, 2019c). Other options include redirecting public subsidies away from the industries that drive deforestation, as was done in Brazil in the early 2000s (Climate Transparency, 2019f), and certification schemes for sustainable commodity supply chains (IPCC, 2019a) . The EU Renewable Energy Directive 2018 introduced sustainability criteria for biofuel production to be imported to EU including requirements for demonstrating that production does not lead to direct land use change and that the risk for indirect land use change is minimised.

The success of such policies is contingent on strong institutional capacities for monitoring and ensuring compliance. In Brazil, the weakening of authorities for monitoring deforestation contributed to elevated deforestation rates and the unusually large number of forest fires in 2019 (Climate Transparency, 2019f). Where deforestation leads to increasing prevalence of forest fires – as has occurred in Brazil (Silva Junior et al., 2018)) – fire prevention and management schemes are essential, along with adequate funding streams for their implementation.

In developing policies for land-based mitigation, G20 governments will need to consider how to maximise potential synergies with sustainable development, and minimize trade-offs (IPCC, 2019a). For example, reforestation and restoration projects should deliver resilient, biodiverse ecosystems, rather than monoculture plantations. Careful consideration must be paid to the

people living on and managing the land. Providing and protecting land tenure and stewardship opportunities for local and indigenous people, including women and young farmers in particular, can enable them to use their own knowledge and practices to protect and restore land-based ecosystems (Food and Land Use Coalition, 2019; IPCC, 2019a) . Long-term clarity on what policies and incentives will be rolled out in the future is also crucial for enabling farmers and land managers to deliver change (Committee on Climate Change, 2020).

Financial incentives and cooperative approaches can be used for protecting, restoring and planting forests. Examples include carbon trading schemes and REDD+. The growing demand for carbon offsetting provides finance for forest schemes and nature-based solutions, although governments and businesses in the G20 should be cognisant of the risks that come with purchasing such offsets, including impermanence (the re-release of sequestered carbon during natural hazards, such as forest fires), leakage (the displacement of land degradation elsewhere) and non-additionality (where a carbon offsetting project would have been implemented even in the absence of carbon-related finance) (Mace et al., 2018).

Upcoming opportunities for international collaboration in the land sector include the 15th Conference of Parties of the Convention on Biological Diversity (October 2020), where it is hoped that an ambitious agreement on goals for protecting ecosystems and biodiversity will be reached (Food and Land Use Coalition, 2019). Additionally, governments have been encouraged to bring forward more ambitious commitments under the Paris Agreement, offering an opportunity for them to provide greater clarity, transparency and ambition in the land sector (IPCC, 2019a).

4.3 Options for Multilateral Cooperation

While there is a long history of multilateral cooperation also in the G20 context, many of them do not address the need for transformational mitigation across all sectors. Recently, International cooperative initiatives of governments together with subnational and non-state actors are increasingly developing and can be useful to extend and broaden implementation best practice policies, enhance implementation through learning, and accelerate scaling up good practice (UNEP, 2018).

Here we provide some examples for options that have been identified for enhancing multilateral cooperation that relate to key mitigation options to close the ambition gap. An in-depth analysis of these options will be the subject of subsequent policy papers.

100 % Renewable Energy – regional cooperation and integration

A number of studies have shown that regional cooperation for grid transmission can support the integration of high shares of variable renewable energy sources, and eventually support the transition to moving to 100 % Renewable Energy. An example for opportunities identified and proposed in this area to facilitate transnational grid connections are the Asia Super Grid (Renewable Energy Institute, 2019), and the IRENA Greening ASEAN Power Grid Initiative building on the ASEAN Power Grid, which was originally not focused on increasing RE integration (Climate Analytics, 2019a).

Joint Market Creation

The German government's recent establishment of the Power-to-X Secretariat, aimed at facilitating global cooperation on sustainable synthetic fuels and chemical feedstocks, is a new initiative aiming at scaling up technological innovations and market development at an international level (BMU, 2019). Encouraging the creation of coalitions of non-state actors can

also fast-track development of new technologies, like for example, the Hydrogen Council, a coalition of more than 50 multinational CEOs supporting hydrogen deployment.

Trade Agreements

Free trade agreements (FTA) are shaping up to be a new front in securing emission reduction outcomes. The EU is currently debating how and whether to use its considerable clout in FTA negotiations as leverage to ensure trading partners achieve their emission reduction targets (European Parliament, 2019). A current example is France's calls to demand "highly ambitious" action on climate change from Australia in their ongoing FTA negotiations with the EU. However there are concerns that the current form of trade agreements does not necessarily lead to an increase in the level of compliance with climate commitments and there are growing calls for the adoption of a WTO climate waiver to address this (Bacchus, 2018).

Fiscal Policy and carbon pricing

There already exists a wide range of initiatives for cooperation on fiscal policy, including on carbon pricing and the phasing out of fossil fuel subsidies which have widely been identified as key robust policies to achieve cost-effective reductions and help closing the 2030 gap.

Despite a commitment in 2009, over ten years ago, by the G20 to phase out subsidies to fossil fuels (G20, 2009), very little has been achieved thus far. This is a worrying trend of the G20 countries committing to act and not following up with implementation. Overall subsidies are estimated to have increased between 2016 and 2017 by 5 % to USD 340 billion (OECD/IEA, 2019). Increasing transparency on such subsidies is an important way to ratchet up pressure to follow through with this commitment, and in this regard, six countries (China, Germany, Indonesia, Italy, Mexico, USA), have completed the G20 voluntary fossil fuel subsidy peer-review process, while Canada and Argentina are in the preparatory phase of this process. A hard deadline for achieving the complete phase-out of fossil subsidies, like the 2025 deadline committed to by both the EU and G7, is a more concrete measure that could be adopted by the G20, however ensuring a broad definition of fossil fuel subsidies is included in such a commitment is critical.

According to the United Nations Environment Programme (SEI et al., 2019), no G20 member has implemented ambitious comprehensive CO_2 pricing in all sectors, but 9 G20 members have implemented carbon pricing as ETS or carbon tax with practical coverage. This is an area with opportunity for enhancing ambition and collaboration.

The German government has assumed a prominent role in the launch of the Carbon Pricing Leadership Coalition at COP21 and initiated the G7 Carbon Market Platform during its G7 presidency in 2015 (New Climate Institute; Öko Institut, 2017).

4.4 Summary: overview of key mitigation options to close the global 2030 gap relevant for G20 countries

The following table gives an overview of the key mitigation options and policy areas identified, with a focus on relevance for closing the global 2030 gap in particular for G20 countries, including through multilateral cooperation.

Table 1: Overview table of key mitigation options and their relevance for closing ambition gap in particular for G20 countries

Mitigation Option	Relevance for closing ambition gap	Relevance for G20 countries
Electricity generation: expanding Renewable Energy (RE), taking into account electrification needs	Very large mitigation potential with large benefits for sustainable development, established policies can be rolled out and accelerated. Most countries have RE targets, but mostly not in line with PA benchmarks	Some G20 countries are lacking 2030 RE targets, and others are not ambitious enough. G20 countries can play a critical role in enhancing regional and multilateral cooperation
Phase out fossil fuels: coal (globally by 2040) and gas	Phasing out coal most important step to achieve Paris Agreement. Increasing number of countries have adopted phase out targets Some not yet consistent with Paris Agreement Transition role of gas overestimated	Some G20 countries have adopted phase out targets in line with Paris Agreement (e.g. UK, Canada) others have targets not in line with PA (Germany – 2038), many are still relying heavily on coal and planning new capacity, lacking phase out plans or strategies (e.g. Japan, Korea, Indonesia, Australia) Many G20 countries are heavily investing in gas production and infrastructure, risking large stranded assets.
Phasing out Fossil fuel production	Production plans are not consistent with NDC targets, leading to the production gap being larger than the NDC ambition gap.	All 10 key production countries analysed in the Production gap report (SEI et al., 2019) are G20 countries, but none of the G20 countries has yet established any policies or leadership to close the production gap.
Electrification of end-use sectors: Direct (transport, buildings, industry processes) and indirect (green hydrogen/synfuels and feedstock production) - Sector coupling	Key strategy for decarbonisation of end-use sectors. Ban of sales of internal combustion passenger cars decided in increasing number of countries, some in line with Paris Agreement (2035). Only few countries have policies addressing need to decarbonise other transport.	Lack of policies to address emissions reductions in these sectors. Only a few G20 Countries have emissions standards for heavy duty vehicles (Canada, EU). Importance of policies to support scaling up technology deployment to reduce cost and bring forward competitiveness of zero emissions technology. Some G20 countries have large potential to supply excess RE (e.g. Australia, Saudi Arabia) for production of green hydrogen/synfuels/feedstocks for other G20 countries/other countries in their region
Energy efficiency and demand reduction across end-use	Large mitigation potential in short and midterm, with large	Some G20 countries are lacking policies (e.g. Australia) or do not have policies that are ambitious enough to close the gap.

Mitigation Option	Relevance for closing ambition gap	Relevance for G20 countries
sectors: Transport, buildings, industry	benefits for sustainable development. Established policies can be rolled out and accelerated.	
Decarbonise industry: material and energy efficiency, circular economy, product and process substitution	Few policies implemented, emerging policy area with increasing number of studies focusing on net zero emissions by 2050, with need to introduce policies in 2020s	Some G20 countries have adopted net zero emissions targets for whole economy (e.g. EU, UK) and have potential to accelerate innovation and transition including through multilateral cooperation
Agriculture: Supply and demand side mitigation options	Need to reduce (non $C0_2$) emissions from agriculture in addition to $C0_2$ emissions reductions in energy and land use. Existing but limited potential for technical mitigation measures. Larger potential for demand side measures, not yet addressed systematically	Some G20 countries are important agriculture exporters such as Argentina, Brazil, Australia, US, and protective of their agricultural sector/depending on contribution to GDP from agricultural exports. Only few countries are starting to develop strategies including demand side measures, e.g. UK.
Forestry: Halt deforestation, increase afforestation and deforestation	Main options for reducing emissions in the forestry sector are halting deforestation and reducing forest degradation. In addition, increasing afforestation and reforestation has relevant mitigation potential.	Four G20 countries that host rainforest – Argentina, Australia, Brazil and Indonesia – have high deforestation rates, largely a result of demand for agricultural expansion and timber production

5 Conclusions

The key characteristics of Paris Agreement 1.5 pathways highlight the urgent need for transformational change in all sectors to close the ambition gap and keep the PA LTTG within reach. Two key characteristics of mitigation pathways in line with the PA LTTG are relevant for the identification of effective policy areas and cooperation initiatives to close the gap:

- All sectoral transformations have to happen in parallel and in an integrated manner. There is no space for offsetting one against the other, given the urgency to achieve additional emission reductions to close the 2030 ambition and action gap.
- Energy and land use transformations need to be carefully planned and managed, taking into account both linkages between sectoral transformations (e.g. biomass use for energy and for achieving negative emissions through BECCS), and policies selected in order to maximise synergies with sustainable development.

A large volume of literature including analyses at regional and national levels shows how the 2030 ambition and action gap can be closed with existing technologies and to a large extent with proven policies that can easily be replicated and adopted more broadly, in particular through management of a energy and land transition. Some transformations are well underway, supported by dynamic technology developments such as the expansion of renewable energy and electric mobility, but need to be accelerated to close the 2030 gap. Other mitigation options analysed need to be addressed with new policies such as decarbonisation of industry processes or freight transport (sometimes referred to as "hard-to-abate" sectors, see for example the ECT Mission Possible report (2019) where there is a need for new near term policy development to achieve longer term deep emissions reductions towards full decarbonisation.

The energy sector transformation with large mitigation potential to close the 2030 ambition and action gap is critically dependent on three strongly linked elements:

- Fast decarbonisation of electricity generation, in particular through phasing out fossil fuels and shifting to renewable energy
- Reduction of energy use and increasing energy efficiency across all end use sectors
- Decarbonising end use sectors through direct or indirect electrification (sector coupling).

While the overall energy sector and in particular the transformation of electricity generation and efficiency have been covered extensively both with analyses and well proven policies, it is still an area with a large potential for additional mitigation given the rapid technology advances and reductions in costs in particular for wind and solar PV, and potential for increasing stringency and breadth of adoption of well proven policies in particular in G20 countries.

A promising policy area that is still in its infancy and that can build on recent dynamic development in technology is the indirect electrification of "difficult to abate" subsectors such as some industry processes and freight and long-haul transport, where direct electrification may reach technical or economic limits. An important technical mitigation option that has only very recently started to gain interest in the policy area is the field of synthetic fuels based on the production of green hydrogen from electricity generated with renewable energy. Given the very dynamic technological advances including technologies to produce hydrogen (electrolysers), this is emerging as a key policy area to enhance mitigation ambition and action already at the timescale relevant for 2030. These also provide synergies for the decarbonisation of electricity

generation, through their role of providing storage and flexibility options for integrating variable renewable energy.

In the area of land-use, two policy areas need to be highlighted to achieve the key benchmarks for closing the gap:

- Agriculture: Demand side measures (reducing food waste and dietary changes) can provide additional mitigation potential, but have not been covered yet broadly in policies.
- Forestry: The need to halt deforestation through protection of existing forests and increase afforestation is a key policy area.

6 List of references

Argus Media. (2019): Analysis: China struggles to hit 2020 gas demand target. https://www.argusmedia.com/en/news/1971763-analysis-china-struggles-to-hit-2020-gas-demand-target (02.03.2020)

Bacchus, J. (2018): The Content of a WTO Climate Waiver. CIGI Papers, 204

Bloomberg. (2019): How Hydrogen Could Solve Steel's Climate Test and Hobble Coal. https://www.bloomberg.com/news/articles/2019-08-29/how-hydrogen-could-solve-steel-s-climate-test-and-hobble-coal

BMU. (2019): BMU sets up international knowledge and networking platform for synthetic energy sources based on green electricity. https://www.bmu.de/en/pressrelease/environment-minister-schulze-we-need-a-global-strategy-for-green-hydrogen/

Brouwer, A. S. (2015): Capturing Low-Carbon Power System Dynamics. Energy and Resources Group.

Carbon Tracker Initiative. (2018): Powering Down Coal: Navigating The Economic and Financial Risks in the Last Years of Coal Power. November.

CAT. (2016a): THE ROAD AHEAD : HOW DO WE MOVE TO CLEANER CAR FLEETS ? In CAT Decarbonisation Series. https://climateactiontracker.org/documents/46/CAT_2016-08-26_DecarbTransportations_CATAnalysis.pdf

CAT. (2016b): The ten most important short-term steps to limit warming to 1.5°C (Issue November). http://climateactiontracker.org/publications/publication/266/The-ten-most-important-short-term-steps-to-limit-warming-to-1.5C.html

CAT. (2017): Manufacturing a low-carbon society: How can we reduce emissions from cement and steel? CAT Decarbonisation Series, October.

CAT. (2018): Scaling up climate action: Key opportunities for transitioning to a zero emissions society. www.climateactiontracker.org/publications/scalingup

CAT. (2019): Warming Projections Global Update: December 2019. In: Climate Action Tracker.

Climate Action Tracker. (n.d.): CAT Decarbonisation memo series. https://climateactiontracker.org/publications/decarbonisation-memo-series/ (07.07.2019)

Climate Action Tracker. (2016): Constructing the future: Will the building sector use its decarbonisation tools? CAT Decarbonisation Series. In: CAT Decarbonisation Series, 8. http://www.ecofys.com/files/files/climate-action-tracker-2016-decarbonation-series-buildings.pdf

Climate Action Tracker. (2018a): For the Talanoa dialogue : Steps towards global decarbonisation in key emitting sectors (Issue October). https://climateactiontracker.org/documents/394/2018-Oct_TalanoaSubmission_ClimateActionTracker_FINAL.pdf

Climate Action Tracker. (2018b): Highway to Paris: Safeguarding the Climate by Decarbonising Freight Transport. In: CAT Decarbonisation Series, May, 1–13. https://climateactiontracker.org/documents/353/CAT_20180522_DecarbSeries_FreightTransport.pdf

Climate Action Tracker. (2018c): Scaling up climate action: South Africa (Issue November). https://climateactiontracker.org/documents/398/CAT_2018-11-27_ScalingUp_SouthAfrica_FullReport.pdf (17.07.2019)

Climate Action Tracker. (2018d): What's on the table? Mitigating agricultural emissions while achieving food security. In: CAT Decarbonisation Series, January. http://climateactiontracker.org/assets/publications/briefing_papers/CAT_20180123_DecarbonisationSeries_Agriculture.pdf%0Ahttp://climateactiontracker.org/news/293/Reducing-food-waste-and-changing-diet-could-drastically-reduce-agricultural-emissions-.html

Climate Action Tracker. (2019a): Governments still showing little sign of acting on climate crisis.

Climate Action Tracker. (2019b): Scaling up Climate action: Argentina. In: CAT Scaling Up Climate Action series. https://climateactiontracker.org/documents/540/CAT_2019-09-05_ScalingUp_ARGENTINA_FullReport_ENG.pdf

Climate Action Tracker. (2019c): Scaling Up Climate Action: Indonesia.

Climate Action Tracker. (2019d): Scaling Up Climate Action: Turkey. In: CAT Scaling Up Climate Action series (Issue September).

Climate Action Tracker. (2019e): Transformation Points: Achieving the Speed and Scale Required for Full Decarbonisation. In: CAT Decarbonisation Series, April, 1–21. https://databank.worldbank.org/data/home.aspx

Climate Analytics. (2018): Science based coal phase-out pathway for Germany in line with the Paris Agreement 1.5°C warming limit. October. https://climateanalytics.org/media/germany_coalphaseout_report_climateanalytics_final.pdf

Climate Analytics. (2019a): Decarbonising South and South East Asia. May.

Climate Analytics. (2019b): How can Paris Agreement commitments be improved now to close the gap to 1.5°C. https://climateanalytics.org/media/ndc_closing_the_gap_to_1p5c.pdf

Climate Analytics. (2019c): Insights from the IPCC Special Report on 1.5°C for preparation of long-term strategies. https://climateanalytics.org/media/climateanalytics_ipcc-lt-leds_report_april_2019.pdf

Climate Transparency. (2019a): Ambition Call - Australia.

Climate Transparency. (2019b): Ambition Call - France.

Climate Transparency. (2019c): Ambition Call - Japan.

Climate Transparency. (2019d): Ambition Call - Mexico. September 2019.

Climate Transparency. (2019e): Ambition Call - UK (Issue September 2019).

Climate Transparency. (2019f): Brown to Green Report 2019. http://www.climate-transparency.org/g20-climate-performance/g20report2018

Climate Transparency. (2019g): Call for more ambition ahead of the UN Climate Action Summit. https://www.climate-transparency.org/call-for-more-ambition-ahead-of-the-un-climate-action-summit

Climate Transparency. (2019h): The Ambition Call - EU. https://doi.org/10.1111/j.1467-6346.2007.00779.x

Climate Transparency. (2019i): The Ambition Call - USA. https://www.climate-transparency.org/wp-content/uploads/2019/08/USA_Ambition_Call.pdf

Committee on Climate Change. (2020): Land use: Policies for a Net Zero UK. January, 123.

Creutzig, F.; Agoston, P. ; Goldschmidt, J. C. ; Luderer, G.; Nemet, G. ; & Pietzcker, R. C. (2017): The underestimated potential of solar energy to mitigate climate change. Nature Energy, 2. https://doi.org/doi:10.1038/nenergy.2017.140

Dyson, M.; Glazer, G. ; & Teplin, C. (2019): PROSPECTS FOR GAS PIPELINES IN THE ERA OF CLEAN ENERGY: How Clean Energy Portfolios Are Reducing US Power Sector Demand for Natural Gas and Creating Stranded Asset Risks for Gas Pipeline. https://rmi.org/insight/clean-energy-portfolios-pipelines-and-plants

Energy Transitions Commission. (2018): Mission Possible report - Reaching Net-Zero Carbon Emissions From Harder to Abate sectors by Mid-Century. http://www.energy-transitions.org/mission-possible

European Parliament. (2019): Using trade policy to tackle climate change (Issue October). https://www.europarl.europa.eu/RegData/etudes/ATAG/2019/642231/EPRS_ATA(2019)642231_EN.pdf

FAO. (2016): The Agriculture Sectors in the INDCs: Analysis. http://www.fao.org/3/a-i5687e.pdf

Fekete, H. ; Roelfsema, M. ; Höhne, N. ; den Elzen, M., ; Forsell, N. ; Becerra, S. (2015): The impact of good practice policies on regional and global greenhouse gas emissions. https://newclimateinstitute.files.wordpress.com/2015/07/task2c_goodpracticeanalysis_july_2015.pdf

Food and Land Use Coalition. (2019): Growing Better : Ten Critical Transitions to Transform Food and Land Use. The Global Consultation Report of the Food and Land Use Coalition, September. https://www.foodandlandusecoalition.org/wp-content/uploads/2019/09/FOLU-GrowingBetter-GlobalReport.pdf

Fyson, C. L.; Jeffery, M. L. (2019): Ambiguity in the Land Use Component of Mitigation Contributions Toward the Paris Agreement Goals. Earth's Future, 2019EF001190. https://doi.org/10.1029/2019EF001190

G20. (2009): G20 Leaders Statement: The Pittsburgh Summit.

Grubler, A. ; Wilson, C. ; Bento, N. ; Boza-Kiss, B. ; Krey, V. ; McCollum, D. L. ; Rao, N. D. ; Riahi, K. ; Rogelj, J. ; De Stercke, S. ; Cullen, J. ; Frank, S. ; Fricko, O. ; Guo, F.; Gidden, M.; Havlík, P.; Huppmann, D.; Kiesewetter, G.; Rafaj, P.; Valin, H. (2018): A low energy demand scenario for meeting the 1.5 °c target and sustainable development goals without negative emission technologies. In: Nature Energy, 3(6), p.515–527

Hare, W.; Brecha, R.; Schaeffer, M. (2018): Integrated Assessment Models: what are they and how do they arrive at their conclusions? Climate Analytics. https://climateanalytics.org/publications/2018/integrated-assessment-models-what-are-they-and-how-do-they-arrive-at-their-conclusions/ (18.04.2019)

Hönle, S. E.; Heidecke, C.; Osterburg, B. (2018): Climate change mitigation strategies for agriculture: an analysis of nationally determined contributions, biennial reports and biennial update reports. In: Climate Policy, 2018, p. 1-15

Hydrogen Council. (2020): Path to hydrogen competitiveness: A cost perspective. January

IEA/UNEP. (2018): Global Alliance for Buildings and Construction, 2018 Global Status Report. 325 https://doi.org/https://doi.org/10.1038/s41370-017-0014-9

IEA. (2019a): Methane Tracker. https://www.iea.org/reports/methane-tracker/country-and-regional-estimates (02.03.2020)

IEA. (2019b): Status of Power System Transformation 2019; Power system flexibility. https://doi.org/10.1787/9789264302006-en

IEA. (2017): Energy Technology Perspectives 2017. https://doi.org/10.1787/energy_tech-2017-en

IRENA. (2018): Hydrogen from renewable power: Technology Outlook for the energy transition. http://irena.org/publications/2018/Sep/Hydrogen-from-renewable-power

IRENA. (2019): Hydrogen: A renewable energy perspective. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_Hydrogen_2019.pdf

IPCC. (2018): Summary for Policymakers. Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change.

IPCC. (2019a): Summary for policymakers. In Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. https://www.ipcc.ch/site/assets/uploads/sites/4/2019/12/02_Summary-for-Policymakers_SPM.pdf

IPCC. (2019b): Summary for Policymakers. IPCC Special Report on the Ocean and Cryosphere in a Changing Climate.

IRENA. (2019a): Electrification with Renewables: Driving the transformation of energy services PREVIEW FOR POLICY MAKERS. https://irena.org/-/media/Files/IRENA/Agency/Publication/2019/Jan/IRENA_RE-Electrification_SGCC_2019_preview.pdf

IRENA. (2019b): Renewable Energy in the NDCs. https://www.irena.org/Statistics/View-Data-by-Topic/Climate-Change/Renewable-Energy-in-the-NDCs

IRENA. (2019c): Renewable Power Generation Costs in 2018 https://www.irena.org/publications/2019/May/Renewable-power-generation-costs-in-2018

Jacobson, M. Z.; Delucchi, M. A.; Bauer, Z. A. F.; Goodman, S. C.; Chapman, W. E.; Cameron, M. A.; Bozonnat, C.; Chobadi, L.; Clonts, H. A.; Enevoldsen, P.; Erwin, J. R.; Fobi, S. N.; Goldstrom, O. K.; Hennessy, E. M.; Liu, J.; Lo, J.; Meyer, C. B.; Morris, S. B.; Moy, K. R.; Yachanin, A. S. (2017): 100% Clean and Renewable Wind, Water, and Sunlight All-Sector Energy Roadmaps for 139 Countries of the World. Joule 1.1 (2017), p. 108-121.

Kriegler, E.; Bertram, C.; Kuramochi, T.; Jakob, M.; Pehl, M.; Stevanović, M.; Fekete, H.; Hilaire, J.; Höhne, N.; Luderer, G.; Luna, L.; Minx, J.; Popp, A.; Steckel, J.; Sterl., S.; Yalew, A. W.; Dietrich, J.-P.; & Edenhofer, O. (2018): Short term policies to keep the door open for Paris climate goals. In: Environmental Research Letters, 2018, 074022

Kuramochi, T.; Höhne, N.; Schaeffer, M.; Cantzler, J.; Hare, B.; Deng, Y.; Sterl, S.; Hagemann, M.; Rocha, M.; Yanguas-Parra, P. A.; Mir, G.-U.-R.; Wong, L.; El-Laboudy; T., Wouters, K.; Deryng, D.; & Blok, K. (2017): Ten key short-term sectoral benchmarks to limit warming to 1.5°C. In: Climate Policy, 2017. https://doi.org/10.1080/14693062.2017.1397495

Lazarus, M.; & van Asselt, H. (2018): Fossil fuel supply and climate policy: exploring the road less taken. Climatic Change, 2018, 150(1–2), p. 1–13.

Löffler, K.; Hainsch, K.; Burandt, T.; Oei, P. Y.; Kemfert, C.; & Von Hirschhausen, C. (2017): Designing a model for the global energy system-GENeSYS-MOD: An application of the Open-Source Energy Modeling System (OSeMOSYS). In: Energies, 2017, 10(10)

Mace, M. J.; Fyson, C. L.; Schaeffer, M.; & Hare, W. L. (2018): Governing large-scale carbon dioxide removal: are we ready? 2018, November

Material Economics. (2019): Industrial Transformation 2050: Pathways to Net-Zero Emissions from EU Heavy Industry.

New Climate Economy. (2018): Unlocking The Inclusive Growth Story Of The 21st Century: Accelerating Climate Action in Urgent Times.

New Climate Institute; Öko Institut. (2017): Germany 's international cooperation on carbon markets : Status and prospects in selected partner countries.

OECD/IEA. (2019): Update on Recent Progress In Reform of Inefficient FosOECD/IEA. (2019). Update on Recent Progress In Reform of Inefficient Fossil Fuel Subsidies That Encourage Wasteful Consumption. (April), 18–19.sil Fuel Subsidies That Encourage Wasteful Consumption. April, 18–19.

OECD. (2017): Investing in Climate, Investing in Growth.

OECD. (2018): Decarbonising Maritime Transport. International Transport Forum, 86. https://www.itf-oecd.org/sites/default/files/docs/decarbonising-maritime-transport.pdf

Parra, P. A. Y., Ganti, G., Brecha, R., Hare, B., Schaeffer, M., & Fuentes, U. (2019). Global and regional coal phase-out requirements of the Paris Agreement: Insights from the IPCC Special Report on 1.5°C. https://climateanalytics.org/media/report_coal_phase_out_2019.pdf

REN21. (2019): Renewables 2019. Global Status Report. https://wedocs.unep.org/bitstream/handle/20.500.11822/28496/REN2019.pdf?sequence=1&isAllowed=y%0A http://www.ren21.net/cities/wp-content/uploads/2019/05/REC-GSR-Low-Res.pdf

Renewable Energy Institute. (2019): Asia International Grid Connection Study Group Interim Report. Renewable Energy Institute, Tokyo, Japan, July.

Roe, S.; Streck, C.; Obersteiner, M.; Frank, S.; Griscom, B.; Drouet, L.; Fricko, O.; Gusti, M.; Harris, N.; Hasegawa, T.; Hausfather, Z.; Havlík, P.; House, J.; Nabuurs, G.J.; Popp, A,: Sánchez, M. J. S.; Sanderman, J.; Smith, P.; Stehfest, E.; & Lawrence, D. (2019): Contribution of the land sector to a 1.5 °C world. In: Nature Climate Change, 2019, p.1–12.

Rogelj, J.; Schaeffer, M.; Meinshausen, M.; Shindell, D. T.; Hare, W.; Klimont, Z.; Velders, G. J. M.; Amann, M.; & Schellnhuber, H. J. (2014): Disentangling the effects of CO2 and short-lived climate forcer mitigation. In: Proceedings of the National Academy of Sciences, 2014, 111(46), p.16325–16330. https://doi.org/10.1073/pnas.1415631111

SEI; IISD; ODI; Climate Analytics; CICERO; UNEP. (2019): The production gap report 2019. 24. https://doi.org/10.1049/ep.1978.0323

Silva Junior, C.; Aragão, L.; Fonseca, M.; Almeida, C.; Vedovato, L.; & Anderson, L. (2018): Deforestation-Induced Fragmentation Increases Forest Fire Occurrence in Central Brazilian Amazonia. In: Forests, 2018, 9(6), 305

Singh, R., & Sundria, S. (2018): Smog-Choked Cities Get No Relief as Modi's Gas Goals Stall. Bloomberg. https://economictimes.indiatimes.com/news/politics-and-nation/smog-choked-cities-get-no-relief-as-narendra-modis-gas-goals-stall/articleshow/66875243.cms?from=mdr (02.03.2020)

Springmann, M.; Mason-D'Croz, D.; Robinson, S.; Wiebe, K.; Godfray, H. C. J.; Rayner, M.; & Scarborough, P. (2017): Mitigation potential and global health impacts from emissions pricing of food commodities. In: Nature Climate Change, 2017,7, 69–74

UNEP. (2018a): A Guide for Incorporating Building Actions in NDCS. December, 44.

UNEP. (2018b): Emissions Gap Report 2018. https://www.unenvironment.org/resources/emissions-gap-report-2018

UNEP. (2019): Emissions Gap Report 2019. https://doi.org/10.18356/ff6d1a84-en

UNEP. (2017): Emissions gap report 2017. https://doi.org/10.18356/ff6d1a84-en

UNFCCC. (2016): Decision 1/CP.21 III. 1–37

UNFCCC. (2020): Decision 1/CMA.2 Chile Madrid Time for Action

van Vuuren, D. P.; Stehfest, E.; Gernaat, D. E. H. J.; van den Berg, M.; Bijl, D. L.;de Boer, H. S.; Daioglou, V.; Doelman, J. C.; Edelenbosch, O. Y.; Harmsen, M.; Hof, A. F.; & van Sluisveld, M. A. E. (2018): Alternative pathways to the 1.5 °C target reduce the need for negative emission technologies. In: Nature Climate Change, 2018, 8, p. 391-397

Wood Mackenzie. (2019): China renewables competitiveness report 2019. https://www.woodmac.com/our-expertise/focus/Power--Renewables/china-renewables-lcoe/

Wyns et. al. (2019): Industrial Transformation 2050: Towards an Industrial strategy for a Climate Neutral Europe, IES, IES. https://www.ies.be/node/5074