Climate Action Tracker

10 STEPS

THE TEN MOST IMPORTANT SHORT-TERM STEPS TO LIMIT WARMING TO 1.5°C

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SUMMARY

Limiting global temperature increase to 1.5°C requires major transformations that need to begin immediately. We provide insights on the ten most important steps that need to be taken in specific sectors in the short term—to 2020 and 2025—if the Paris Agreement temperature goal is to be met.

We used modelled scenarios to provide guidance on what needs to happen in each sector. The stringency of the 1.5°C limit significantly constrains the levels of freedom to spread emission reductions across sectors, countries and over time.

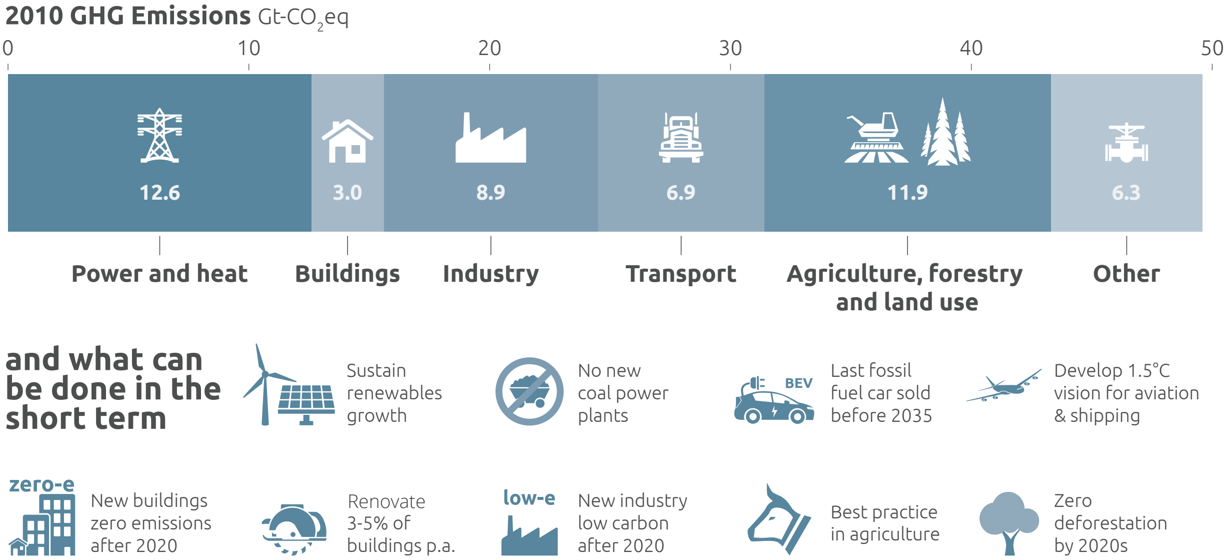
As a result of the limited carbon budget, combined with the inertia of energy, transport, industry technologies and systems, and the difficulty of reducing emissions in some sectors, global energy models find only limited pathways.

If a sector does less, in particular the energy, industry and transport sectors, it would leave a high-emissions legacy for several decades and would mean a failure to set in motion the system changes needed to achieve the required long-term transformation.

Efforts in all of these sectors that begin by 2020, and accelerate by 2025, will be needed to reach zero carbon dioxide emissions by mid-century, and zero greenhouse gas emissions overall roughly in the 2060s.

For all ten elements we show there are signs that the transition of this magnitude is possible: in some specific cases it's already happening. Achieving these ten steps in the period to 2020 and 2025 would put the world on a pathway to limit global temperature increase to 1.5°C.

Global GHG Direct Emissions by Sector



Source: Own elaboration based on emissions data from IPCC AR5 WG3. Chapter 1.

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10 STEPS

THE TEN MOST IMPORTANT SHORT-TERM STEPS TO LIMIT WARMING TO 1.5°C

1 ELECTRICITY: SUSTAIN THE GROWTH RATE OF RENEWABLES AND OTHER ZERO AND LOW CARBON POWER UNTIL 2025 TO REACH 100% BY 2050

All 1.5°C pathways foresee a fully decarbonised power system by 2050. This implies a power system consisting entirely of renewables and other zero and low carbon sources. Of the carbon-free options, renewables are showing the most promise, and their current growth must be sustained until 2025. Rapid action is required to ensure our power systems are ready for them. Policymakers can set boundary conditions and design electricity markets in a way that allows integration of high shares of renewables.

2 COAL POWER: NO NEW COAL PLANTS, REDUCE EMISSIONS FROM COAL POWER BY AT LEAST 30% BY 2025

To close the gap between current ambition and what is needed for 1.5°C, while simultaneously limiting stranded assets, no new coal-fired power plant can be built. There must be consistent efforts to reduce emissions from current coal-fired power plants—by at least 30% by 2025—through, for example early plant retirement or reducing the running time of existing power plants. By 2030, emissions from coal plants should be down by 65%. Fossil fuels often incur externalities, imposing negative effects (such as health-related and environmental damages) on unrelated third parties, and these need to be included in the price of energy. Fossil fuel subsidies should also be phased out (by the very latest) by 2030. The G20 has an opportunity in 2017 to act on both fronts: to follow the G7 in its commitment to end fossil fuel subsidies by 2025 and to introduce carbon pricing to address external costs.

3 ROAD TRANSPORT: LAST FOSSIL FUEL CAR SOLD BEFORE 2035

The sales of electric vehicles, which can be zero-emission if powered by non-fossil electricity, have skyrocketed in recent years in several countries. While they still represent only a small share of overall car stock, zero-emissions vehicles would have to constitute 100% of newly-sold vehicles worldwide before 2035 to be compatible with a 1.5°C vision. At the same time, strong modal shifts, as well as efforts to decrease emissions from freight transport, are needed to decarbonise the entire sector.

4 AVIATION AND SHIPPING: DEVELOP AND AGREE ON A 1.5°C COMPATIBLE VISION

The aviation and shipping sector is lacking coordinated efforts and ambition to develop emission reduction targets and drive mitigation. In fact, there appears to be no overall vision on how the aviation and shipping sector could decarbonise to be in line with 1.5°C pathways, which essentially means zero CO_2 emissions in a few decades. However, there is significant untapped potential through increased efficiency, the use of biofuels and a reduction in travel demand. Therefore, to be in line with 1.5°C, both sectors should drive adoption of existing technologies as well as develop and agree on a 1.5°C-compatible vision.

5 NEW BUILDINGS: ALL NEW BUILDINGS FOSSIL-FREE AND NEAR ZERO ENERGY BY 2020

A 1.5°C pathway demands rapid and near complete phase-out of direct emissions from buildings by 2050. It is easier and cheaper to build efficient buildings than to retrofit later. There is significant potential, especially for rapidly growing economies, to construct future-proof building stock now, but action is too slow. Policies can catalyse change through setting minimum building standards, extending obligations from public buildings to the whole economy, and through providing low-interest loans.

6 BUILDING RENOVATION: INCREASE RATES FROM <1% IN 2015 TO 5% BY 2020

A 1.5°C pathway demands rapid and near complete phase-out of emissions from buildings. Long lifetimes mean that only standards for new buildings—as described in the previous point—are not sufficient: existing stock also needs to be retrofitted. To transform the entire current standing building stock before 2050, we need to more than triple our current retrofit rates within five years. Governments can help through offering cheap loans and setting retrofit obligations.

7 INDUSTRY: ALL NEW INSTALLATIONS IN EMISSIONS-INTENSIVE SECTORS ARE LOW-CARBON AFTER 2020, MAXIMISE MATERIAL EFFICIENCY

In a 1.5 °C scenario, industrial emissions need to be reduced by well over 50% from current levels by 2050, while industrial production is expected to grow significantly. From 2020 onwards, all new installations need to be built according to the best available low carbon technology standard, which excludes building conventional blast furnaces. Also necessary is further development and rapid introduction of new technology, down to near-zero emission steelmaking. Similar approaches are needed for other sectors, like cement, ammonia and petrochemicals. The sector also needs to maximise material efficiency to reduce primary material production.

8 LULUCF: REDUCE EMISSIONS FROM FORESTRY AND OTHER LAND USE TO 95% BELOW 2010 LEVELS BY 2030, STOP NET DEFORESTATION BY THE 2020s

Policies to decrease emissions of LULUCF have to be part of an integrated approach, taking into account energy, land-use management and agriculture to optimise synergies. There are a variety of ways to address the issues of conflicts over land use, such as agroforestry, proper land tenure systems, alternatives for heating, and improving the international trade system to deal with illegal logging. Many solutions for LULUCF lie with community-based options. Financial support mechanisms must be urgently operationalised, and channels improved to finance and modernise agricultural systems (which should also lead to increased resilience to climate disasters and reduced pressure on forests). It is also clear that action in the LULUCF sector cannot be used as an excuse to do less in other areas. There is a long history, and on-going attempts, to use forest sinks to offset obligations to reduce emissions from energy, industry and transport sectors in a number of countries, such as Australia, Canada, New Zealand, Brazil and Indonesia.

9 COMMERCIAL AGRICULTURE: KEEP EMISSIONS AT OR BELOW CURRENT LEVELS, ESTABLISH AND DISSEMINATE REGIONAL BEST PRACTICE, RAMP UP RESEARCH

Emissions in agriculture are growing; the biggest contribution comes from livestock rearing (55%), followed by synthetic fertilisers (12%), and rice cultivation (10%). Even within regions, the large range of agricultural practices means there is significant emissions reduction potential (up to 20%) from adopting best practice within that region. There is additional potential from healthy diets, food waste reduction and advancing research and development.

10 CO_2 REMOVAL: BEGIN RESEARCH AND PLANNING FOR NEGATIVE EMISSIONS

In large part due to insufficient emissions reductions realised to date, negative CO_2 emissions will unfortunately be necessary at scale from mid-century to limit warming to 2°C, and even more for 1.5°C. As explained in all other sections of this report, early and rapid action now across the full range of mitigation options, and to protect and enhance natural ecosystems so that they can retain and store more carbon, are all needed to minimise the need for negative CO_2 emissions. If action to reduce CO_2 emissions slows in the near future, this will increase the need for negative CO_2 emissions technologies, but at this point it cannot be eliminated. Even the most rapid action plausible—to reduce CO_2 emissions to zero before 2050 and to significantly reduce other GHGs—will unfortunately not eliminate the need for sizeable negative CO_2 emissions after mid-century.

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INTRODUCTION

The Paris Agreement, adopted in December 2015 under the United Nations Framework Convention on Climate Change (UNFCCC), set the overarching goal of holding "the increase in the global average temperature to well below 2 °C above preindustrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels." To achieve this goal, global greenhouse gas (GHG) emissions urgently need to start declining (Luderer et al., 2013; Rogelj, McCollum, Reisinger, Meinshausen, & Riahi, 2013).

Governments submitted their post-2020 climate action plans for the Paris Agreement, i.e. (Intended) Nationally Determined Contributions ((I)NDCs, which henceforth we will call NDC's), but the aggregate of NDCs is far from sufficient. Emissions are expected to continue to increase towards 2030, and global average temperature is projected to increase by 2.8°C from preindustrial levels by 2100 (Climate Action Tracker update November 2016). Urgent action is needed to keep the door open for a 1.5°C pathway, but there are few studies that describe the transitions that need to happen at sector level around 2020–2025 to enable it.

Against this backdrop, this Climate Action Tracker report lays out the ten most important actionable steps to be taken by 2020–2025 to keep the window open for a 1.5 °C world. Across this report, we discuss the following for each (sub-) sector:

- What is the importance of the sector?
- What is needed for 1.5°C compatibility?
- What needs to be done by 2020 and 2025?
- Are there signs this is feasible?

We used existing emissions scenarios to provide guidance on what needs to happen in each sector. The stringency of the 1.5°C limit significantly constrains the levels of freedom to spread emission reductions across sectors, countries and over time.

As a result of the limited carbon budget, combined with the inertia of energy, transport, industry technologies and systems, and the difficulty of reducing emissions in some sectors, global energy models find only limited pathways. If a sector does less, in particular the energy, industry and transport sectors, it would leave a high-emissions legacy for many decades and would mean a failure to set in motion the system changes needed to achieve the required long-term transformation.

To maintain consistency on the analytical approach across sectors, the analyses conducted for energy supply and end-use sectors in this report refer to the sector-specific results of Rogelj et al. (2015) as the point of departure. Technology-specific assessments are based on various technical studies including the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC, 2014b), IEA Energy Perspectives 2016 (IEA, 2016b), and the Climate Action Tracker's own calculations.

Eventually, all global greenhouse gas emissions have to be reduced to zero, which means that a transition needs to be triggered in *all* sectors. We arrived at the ten most important short-term steps by scanning all sectors and the respective necessary transitions, and distilling the most important short-term actions for each. The ten steps cover more than 85% of total GHG emissions in 2010.

1. ELECTRICITY: SUSTAIN THE GROWTH RATE OF RENEWABLES AND OTHER ZERO AND LOW CARBON POWER UNTIL 2025 TO REACH 100% BY 2050

What is the importance of the sector?

The power sector emits over a quarter of global GHG emissions, around 12 $GtCO_2$ annually (Bruckner et al., 2014). According to energy system models, this sector needs to undertake the fastest transition to meet the Paris Agreement temperature goal.

What is needed for 1.5°C compatibility?

The electricity generation sector will first need to make a rapid transition away from coal, and then, in the next few decades, from natural gas, towards renewables and other zero[1] and low[2] carbon energy sources to be in line with the Paris Agreement's stronger 1.5°C warming limit target.

Under the median outcome of 1.5°C scenarios, CO_2 emissions from electricity generation need to be reduced to around 7 $GtCO_2$ in 2020, 4 $GtCO_2$ in 2030 and 0 $GtCO_2$ in 2050 (Rogelj et al., 2015). This is true even under likely 2°C scenarios which also require complete decarbonisation of the power sector by 2050 although the trajectory for decarbonisation is a little less steep (Rogelj et al., 2015).

The requirement for full decarbonisation of power by 2050 implies a rapid transition to renewables and other zero[1] and low[2] carbon sources, such as renewable power, nuclear power or power with Carbon Capture and Storage (CCS). Of these options, renewables are the most promising as they show high growth rates, provide truly zero carbon power, and have by far the lowest environmental footprint.

In 2012, 32% of electricity was generated from all renewables and other zero and low carbon sources globally, most of it nuclear and hydropower, although there are large regional differences, ranging from 0% in Bahrain to 100% in Iceland (IEA, 2014b). Wind energy and solar power supplied 3% of total electricity demand and are growing at over 25% per year, spurred by the removal of barriers to market entry and falling costs of production.

However, under the median outcome of 1.5°C scenarios, the share of electricity generated by renewable, renewables and other zero and low carbon sources will need to reach around 50% by 2020 and 70% by 2030, and approach 100% by 2050 (Rogelj et al., 2015). Current and future shares are shown in Figure 1.

[1] Zero carbon refers, in addition to renewables, primarily to nuclear energy sources.
[2] Low carbon refers primarily to CCS-abated fossil energy sources.

What needs to be done by 2020 and 2025?

In absolute terms, renewables and other zero and low carbon generation has to increase significantly from current levels. Pathways able to limit warming to below 2°C typically foresee a five-fold increase in electricity generation over the coming four decades, as electrification of demand, combined with the decarbonisation of power, is one of the most promising emission reduction strategies (IIASA, 2015).

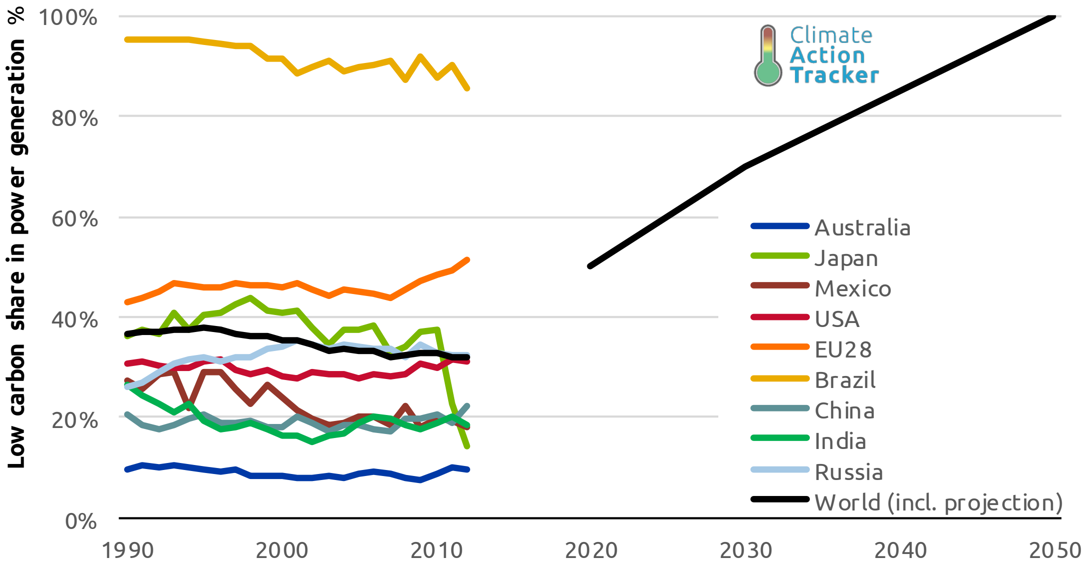

Figure 1 Share of renewables and other zero and low carbon sources low carbon power generation globally and by country and projections from emissions pathways for 1.5°C for 2020–2050 (Rogelj et al., 2015)

Current growth rates of these sources, especially renewables, are promising, with wind and solar production increasing by 25%–30% year on year and hydropower also still reporting growth of 2–4% per year. However, continued and urgent effort in the next few years is required to sustain these developments over the coming decades.

We estimate that if growth in solar and wind generation were to continue for another five to ten years at similar levels to those seen over the last decade, and then gradually relax to around 4–5% per year from 2025 until 2050, this would be sufficient to completely decarbonise the power sector, despite the projected increase in demand (see Figure 2).

Given the typical, 35-40 year (or more) technical lifetimes of coal, gas and oil power plants (Davis, Caldeira, & Matthews, 2010), were these to be constructed today, to keep within the Paris Agreement's warming limit, they simply could not be utilised to the end of their technical lifetime.

Demand and supply side variability require a power system that can operate flexibly. On the supply side, most existing power technologies can provide flexibility by adjusting supply to demand, although it is unlikely that CCS would be able to do so.

On the demand side, options include demand response in industrial facilities and buildings. Energy storage, for example through pumped hydro plants or batteries, will be necessary in a renewable-dominated system to provide additional flexibility. This will be expanded with the electrification of other sectors, e.g. electric vehicles and water heating.

Finally, extending the grid size provides flexibility as, for example, peaks in supply and demand can be absorbed better in a larger electricity market (Papaefthymiou, Grave, & Dragoon, 2014). All of these options can combine to enable power systems based on high or very high shares of flexible, renewable power sources (Child & Breyer, 2016; Delucchi & Jacobson, 2011; Tröster, Kuwahata, & Ackermann, 2011).

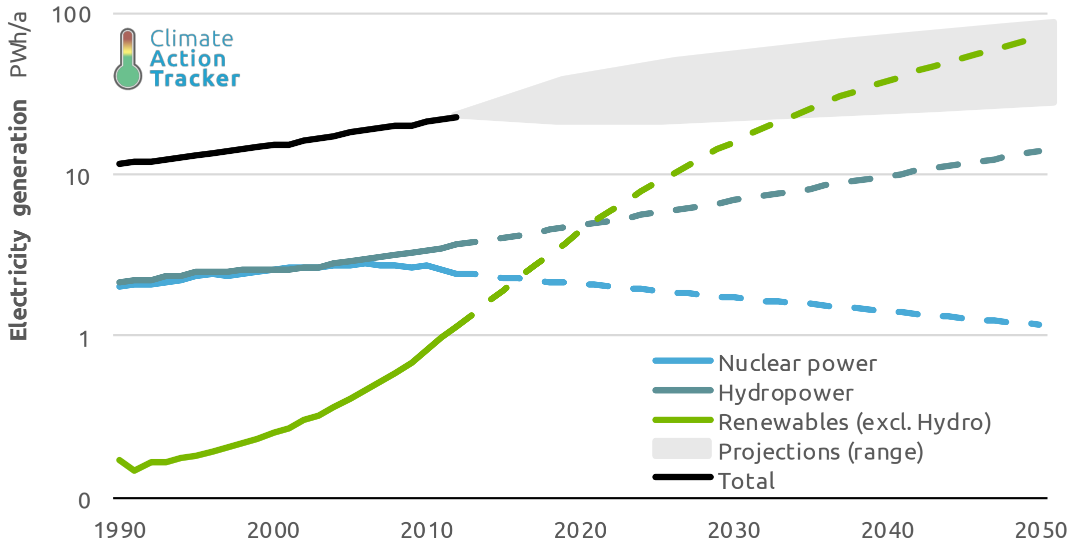

Figure 2 Absolute generation of power from low carbon sources and median projections from 2°C pathways (IIASA, 2015). Note the logarithmic scale, used to compare different orders of growth rates.

The trajectory of the power sector needed for a 1.5°C pathway has important consequences for the choices made on investments in the power sector today and in the near future, most critically with the technology choices to expand or replace existing power generation capacity, and enabling infrastructure. Delaying changes in investments means locking in carbon-intensive power plants that are inconsistent with the goals of the Paris Agreement, and the risk of creating large and costly stranded assets.

To facilitate the transition to a decarbonised electricity sector, however, policies are needed to transform technical systems, and market design and regulation. Electricity networks need to become more flexible and robust through, for example, strengthening electricity grids and integration of the heat sector. Markets need to support the transformation by facilitating access for renewables, and promoting grid development to facilitate flexibility. Where markets are biased towards fossil fuels, new measures are needed to level the playing field in the electricity market and accelerate the transition to flexible, robust electricity networks.

Direct financial support through production subsidies such as feed-in-tariffs, increasingly awarded through auctions, provide investors with reasonable assurance that a certain return on investment will be received, reducing the risks involved with financing projects and allowing project developers to access cheaper rates of finance.

Indirect financial support can be provided through policies such as carbon pricing, which internalise the external cost of conventional electricity generation. Finally, frameworks such as grid flexibility policies are needed to ensure that the power system's infrastructure is capable of handling increasing shares of renewable generation.

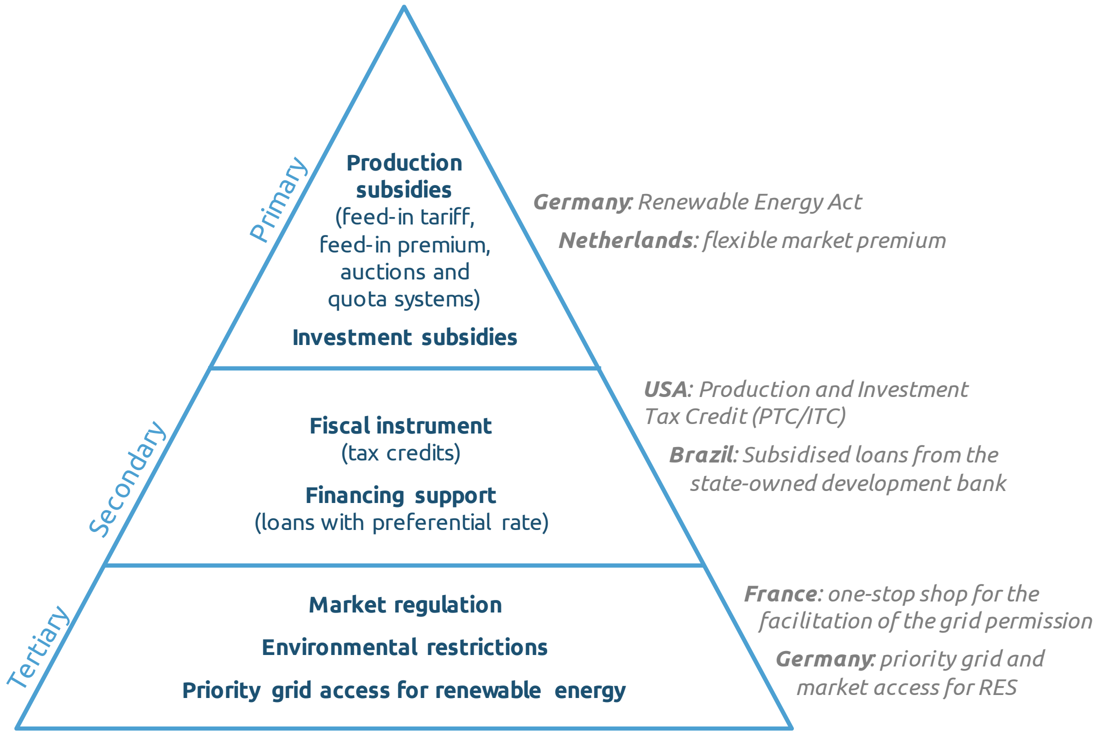

Figure 3 Schematic representation of policies to support renewable deployment

Are there signs this is feasible?

Renewable energy is already at price parity with conventional generation in some markets (IRENA, 2016) and continues to be deployed at growth rates consistently underestimated by analysts (Bloomberg, 2016b). The number of jurisdictions (countries, regions) with policy support for renewable energy is substantial: 110 have feed-in policies, 100 have renewable portfolio standard or quota policies and 64 have tendering/public competitive bidding for renewable energy (IRENA, 2016).

2. COAL POWER: NO NEW COAL PLANTS, REDUCE EMISSIONS FROM COAL POWER BY AT LEAST 30% BY 2025

What is the importance of the sector?

Electricity generation accounted for 59% of world coal consumption in 2012. In 2013, coal represented 29% of the world's primary energy supply but accounted for 46% of global CO_2 emissions due to its heavy carbon content per unit of energy released (IEA, 2015b).

At the same time, avoiding the worst impacts of climate change requires us to leave the vast majority of the world's reserves of fossil fuels in the ground: to stay below 2°C with a 60% chance (worse than a 'likely' chance), 88% of global coal reserves will have to stay in the ground (McGlade & Ekins, 2015). Its high emissions intensity, sheer scale, low rents per unit value and high local environmental costs make coal one of the most important action points in fighting climate change (Collier & Venables, 2014; IEA, 2015b).

What is needed for 1.5°C compatibility?

To limit warming to 1.5˚C, the global power sector needs to decarbonise ten years earlier than under a 2˚C pathway. 1.5°C scenarios assessed by the IPCC indicate this sector needs to reach zero carbon dioxide emissions globally around 2050 (Rogelj et al., 2015). **Emissions from coal-fired power stations must therefore be phased out globally before 2050**. **In 2025, power generation from coal should be reduced by at least 30%, and at least 65% by 2030.** This phase-out needs to happen at different times in different regions, and stands in strong contrast to current and planned coal capacity worldwide. Plans to continue and expand reliance on coal, such as in Turkey, the Philippines or Australia (Climate Action Tracker, 2016a), are incompatible with the Paris Agreement and risk the lock-in of investments for many decades.

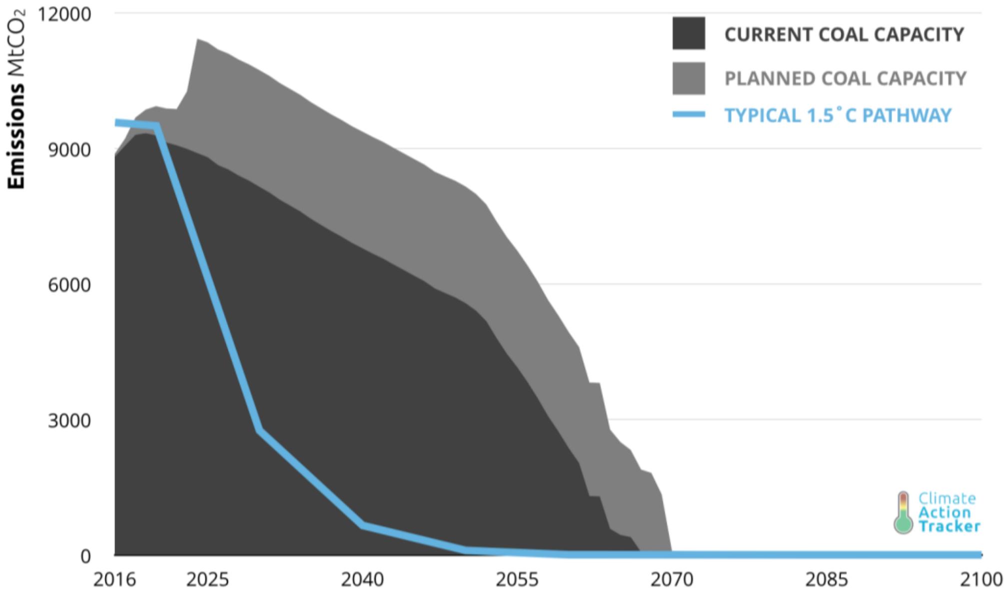

Figure 4: Potential CO_2 emissions from existing and planned coal capacity compared to a typical 1.5°C pathway (Global Coal Plant Tracker, 2016; Rogelj et al., 2015; Rogelj, McCollum, O'Neill, & Riahi, 2012)

What needs to be done by 2020 and 2025?

To close the gap between current ambition and what is needed for 1.5°C, while simultaneously limiting stranded assets, not one new coal-fired power plant can be built. There must be consistent efforts to reduce emissions from the current coal-fired plant fleet by at least 30% by 2025, for example through early retirement or reducing the running time of existing power plants.

Policy makers need to implement a dedicated and managed approach to phasing out coal in the near future, while banning the building of new coal plants from today. A coal phase-out would need to be accompanied by a solid strategy in each region to mitigate the socio-economic employment and social impacts that result from a coal exit. Any strategy should be on the principles of a just and fair transition.

The Paris Agreement "provides a clear signal to investors that the transition to the low-carbon, clean energy economy is inevitable and already underway" (Global Investor Coalition on Climate Change, 2016). In the short term, one of the clearest and most-needed steps Governments can take is to ensure that no more concessions for new coal plants are granted, thereby reducing (future) stranded assets. Existing plants would need to be phased out in a cost-efficient and socially acceptable manner, which assumes the need for a plant-by-plant shut down schedule, similar to Germany's nuclear phase-out plan.

Fossil fuels often incur negative externalities, imposing negative effects on unrelated third parties (e.g. through health and environmental damages not included in the price). The mainstream school of economics agrees that the role of policy makers is to address these market failures due to the undeniable costs to society, for example through the introduction of a "Pigovian" tax—a tax that is equal to the social and environmental cost of the negative externality (e.g. carbon price)—or regulation. Not accounting for these costs constitutes a de facto, so-called, post-tax consumer subsidy. The International Monetary Fund (IMF) estimates that in 2013, post-tax consumer subsidies accounted for USD$4.9 trillion (6.5% of global GDP).

The failure to address these negative externalities damages the environment, causes more premature deaths through local air pollution, exacerbates congestion and other adverse side effects of vehicle use, increases emissions, imposes "large fiscal costs, which need to be financed by some combination of higher public debt, higher tax burdens, and crowding out of potentially productive public spending, all of which can be a drag on economic growth (Coady, Parry, Sears, & Shang, 2015).

A more direct form of subsidy, or a so-called pre-tax consumer subsidy, are the fossil fuel subsidies that allow consumers to pay a price below the cost of supplying the energy. Fossil fuel subsidies in any form therefore not only stand in stark contrast to the objective of the Paris Agreement, but also with mainstream economic principles.

According to the IEA in 2014, the value of fossil-fuel consumption subsidies worldwide totalled USD$493 billion. Governments are thus spending almost five times as much on these subsidies than is needed to meet the climate-finance objectives set by the international community, which call for mobilising USD$100 billion a year by 2020. The IEA (2014a) has identified 40 countries as subsidising fossil-fuel consumption annually, with an average value of around 5% of GDP.

Subsidies on fossil fuel production in 2013 and 2014 from G20 countries alone are estimated to amount to nearly USD$78 billion a year in national subsidies, USD$286 billion in state-owned company investments and other public finance support worth USD$88 billion (Bast, Doukas, Pickard, van de Burg, & Whitley, 2015).

Pre-tax subsidies should be phased out worldwide; G20 governments have an opportunity in 2017 to follow the G7 in its 2016 pledge to end "inefficient" fossil fuel subsidies by 2025 (G7, 2016). However, there remains a question mark over the definition of "inefficient." This year's climate change conference host, Morocco, abolished gasoline and fuel oil subsidies at the start of 2014 and diesel subsidies at the start of 2015 (IEA, 2015e).

Fossil fuel subsidies hinder clean energy investment by making fossil fuels artificially cheaper (IEA, 2014a), increase the vulnerability of countries to volatile international energy prices, and constitute a highly inefficient tool to provide support to low-income households "since most benefits from energy subsidies are typically captured by rich households" (Coady et al., 2015). Scrapping these subsidies would thus be a necessity if the Paris Agreement's long-term temperature goal is to be taken seriously. Financing of coal plants is already becoming more difficult (see below), and a study by the IMF suggests that phasing out fossil fuels subsidies could cut global carbon emissions by 20% (Coady et al., 2015).

Moreover, if the subsidies were to be redirected to "investments in basic infrastructures over the next 15 years, substantial strides could be made in reducing poverty" (Edenhofer, 2015). Investment flows would need to be re-directed towards renewables and other zero and low carbon energy options and business development would need to be supported in designing readily employable investment packages for renewable energy to create a level playing field.

Are there signs this is feasible?

Examples of individual actions show that a phase-out of coal in power generation and reduction of emissions from existing coal fired power plants are feasible. Many plans for new coal plants have been cancelled as the market shifted in favour of renewable energy.

In June 2016, the Indian Energy Ministry proposed the cancellation of four coal-fired ultra mega power plants. Leading coal power producers appear to have suspended investments into coal in favour of scaling up investments in renewable energy, both in India and Australia (Climate Action Tracker, 2016b).

Several banks, including JP Morgan, Bank of America and, to a lesser extent, Deutsche Bank are moving away from coal in one way or another, though have not yet stopped. Both JP Morgan and Deutsche Bank are involved in a controversial coal project in Bangladesh near sensitive mangrove forests on the coast.

Analysts expect that the pullback from coal is not just another period of boom and bust, but a permanent downward shift (Korkery, 2016). The slowdown of growth in China, (plus other factors such as a market flooded with steel, the US switch to gas) has had a major impact on the US coal industry, leaving coal giants like Peabody Energy, Arch Coal and Alpha Natural Resources filing for bankruptcy protection (Nair, 2016).

Regional and national initiatives are also increasingly stepping away from coal: China set a cap on coal (Reuters, 2016). In the EU several countries (Belgium, Cyprus, Luxembourg, Malta, and Estonia, Latvia, Lithuania) are coal free (Darby, 2016), while others have or are in the planning of phasing out coal, such as UK, Portugal. In Canada, Alberta (Government of Alberta, n.d.) and Ontario phased out coal in 2014 (Harris, Beck, & Gerasimchuk, 2015) and in Australia South Australia switched off its last coal power plant in May 2016 (Parkinson, 2016).

3. ROAD TRANSPORT: LAST FOSSIL FUEL CAR SOLD BEFORE 2035

What is the importance of the sector?

The transport sector accounts for 14% of total global GHG emissions in 2010 (Victor et al., 2014). To ensure energy-related emissions are reduced to zero fast enough to hold warming below 2°C, the transport sector must begin to decarbonise in the next few years and move quickly towards zero-emission options. Accelerating action in this sector has been identified in the scientific literature as a key factor for the more rapid effort required to limit warming to below 1.5°C, rather than 2°C (Rogelj et al., 2015).

The transport sector is diverse, from personal and freight transport, to public transport on road and rail, along with aviation and shipping. In this section, we focus on the major shifts and changes necessary for the personal transport sector, which accounts for close to 30% of total transport sector emissions (IEA, 2016b),[3] to retain compatibility with the long-term goals of the Paris Agreement.

What is needed for 1.5°C compatibility?

The requirement that zero-emission vehicles should become the dominant mode of light transport is supported by many studies (Deng, Blok, & van der Leun, 2012; IEA, 2016c; Sims et al., 2014; Sterl et al., 2016).

According to the IEA's Energy Technology Perspective 2016 (ETP) sectoral pathways in a scenario compatible with a 50% chance of limiting global warming to 2°C (IEA, 2016b), the amount of person-kilometres taken by personal cars will still increase roughly twofold until 2050. This means the ETP predicts substantial emission reductions to come from deep decarbonisation of the actual cars and not from major changes in behaviour of drivers. The ETP's pathway towards 2°C compatibility requires a roughly 70% decrease of specific emissions (well-to-wheel, measured in gCO_2/pkm) in light road traffic by 2050 below current levels.

To meet the 1.5°C limit, this transition would need to be accelerated substantially over what is presently expected so that global CO_2 emissions would become zero by roughly 2050 to be compatible with limiting of global warming to 1.5°C above pre-industrial temperatures.

This means the rapid introduction of zero emission vehicles is the key for decarbonisation of passenger transport. To only have zero emission cars on the road by 2050, the last fossil fuel powered car would have to be sold roughly before 2035, assuming an average lifetime of 15 years. Such a transition will be much easier with a reduction—and modal shift—of demand for personal transport.

Of the options for zero emission vehicles, the electric car is the most promising. Unlike other zero emission car technologies, all manufacturers have electric cars in their portfolio, and developments are rapid. However, a move towards electric vehicles powered by zero-emission electricity or other types of zero-emission vehicles cannot be disconnected from the decarbonisation of the power sector. Indeed, in the context of decarbonisation, electric vehicles are an option only if the power sector decarbonises at the same time.

[3] Figure 2.2. The estimates include "2- and 3-wheelers" and "small and medium cars" for passenger transport and are on 2005 historical data and 2015 projections.

What needs to be done by 2020 and 2025?

In order to linearly ramp up new registrations of zero emission cars to 100% by 2035 from the current global level of 0.6% (EV-Volumes, 2016), there should be around 25% of newly-registered zero emission cars in 2020, and 50% in 2025.

Governments and the car manufacturing industry would need to begin a rapid transformation to electric vehicles (or other zero emission vehicles) and redirect investments in this direction to reach the required production capacities of EVs, battery storage systems, and the necessary infrastructure needed to have such numbers of EVs on the road. The power sector would also have to be largely decarbonised by that time, to allow the electricity demand from EVs to be met by low-carbon electricity.

So far, governments have primarily been focusing on vehicle emission standards and efficiency. Recent policy efforts in various countries have focused on different options aiming at improving fuel efficiency standards and/or setting more stringent emission standards (in gCO_2/vkm) for vehicles. For example, the EU, USA, China, India and Japan all have targets for the post-2020 period in either fuel efficiency or emission standards (ICCT, 2014). However, a gradual tightening of emission standards will not be sufficient for the 1.5°C limit, unless zero emission vehicles are introduced rapidly (Sterl et al., 2016).

Are there signs this is feasible?

The situation is changing more rapidly than expected, on both the technology and policy fronts.

So far, only a very small share of new cars are electric (including full electric vehicles, or EV, and plug-in hybrid vehicles, or PHEV), around 0.6% globally (EV-Volumes, 2016). Reasons include the limited supply of EVs from car manufacturers, their high cost compared with Internal Combustion Engine (ICE) vehicles, and user-level concerns, for example about driving ranges (Nijland, Geilenkirchen, van Meerkerk, 't Hoen, & Hilbers, 2016). However, the market is growing rapidly.

Figure 5 shows how the yearly uptake of new (PH)EVs has grown and shifted from the United States and Europe to China as the dominant market (in absolute numbers) in recent years. In the United States, for example, the uptake of (PH)EVs grew strongly in the period 2010–2013 but has since slowed, while sales in China picked up the pace and have, since 2015, surpassed those in the US and Europe. Chinese stock additions of (PH)EVs were roughly a quarter of those in Europe in 2013, but rose so strongly that they are estimated to become roughly twice as high as those in Europe in 2016.

Before 2014, China's (PH)EV stock accounted for only around one-tenth of the global total; but by 2015 this figure had risen to one-quarter, as shown in the inset to Figure 5 (IEA, 2016c), and estimates indicate it could rise to more than one-third in 2016.

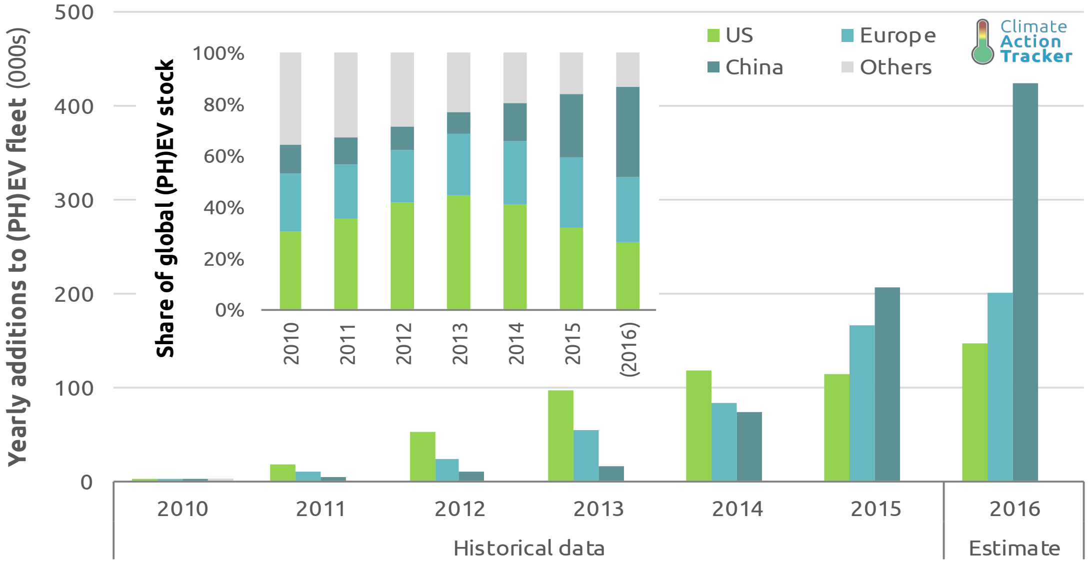

Figure 5: The yearly additions to the (PH) EV stock in the US, Europe and China. The 2010–2015 data was calculated from numbers in (IEA, 2016c)[4]; the data for 2016 represent estimates using data from (Pontes, 2016a, 2016b; Shahan, 2016)[5]. Inset: The share of global (PH)EV stock in the EU, US, and China, respectively, between 2010 and 2015 and with estimate for 2016[6].

Despite the still low overall share of (PH)EV sales in all new car registrations, a few countries have managed relatively high shares of (PH)EVs in new car registrations. Norway is the worldwide frontrunner, with (PH)EV registrations accounting for close to 30% of new cars. What sets Norway apart from EU member states is the high rate of EVs purchased by individuals as opposed to companies (Nijland et al., 2016). A combination of financial incentives (tax benefits) and behavioural incentives (allowing EV drivers onto bus lanes and giving them free public parking) have helped to boost EV sales (Figenbaum, Assum, & Kolbenstvedt, 2015).

Behind Norway, the Netherlands are second, but with a much smaller proportion (IHS, 2016), although the total amount of (PH)EVs on the road in the Netherlands is roughly equal to that in Norway. Sales in the Netherlands are largely driven by taxation structures that favour low-emission vehicles (Nijland et al., 2016). Examples of financial policies (including tax benefits but also purchase subsidies) helping to increase demand are also found in several other European countries/regions (Nijland et al., 2016) and in China (Hao, Ou, Du, Wang, & Ouyang, 2014).

There are also progressive financial and behavioural policies in California, with 30 cities where electric vehicles make up 6% to 18% of new vehicle sales. In the last five years, California has consistently accounted for roughly half of all new (PH)EV sales across the United States (Searle, Pavlenko, & Lutsey, 2016).

[4] Data labelled "Europe", where calculated from numbers in (IEA, 2016c), represents the aggregate of France, Germany, Italy, the Netherlands, Norway, Portugal, Spain, Sweden and the UK.

[5] EU and China numbers were taken from existing estimates (Pontes, 2016a, 2016b); US numbers were estimated by the authors from the sales figures in 2016 from January until October and applying the same ratio of sales Jan-Oct to sales Jan-Dec as in 2015 (Shahan, 2016).

[6] The estimate for 2016 was calculated by adding the assumed (PH)EV sales in 2016 for the US, Europe and China (as shown in Figure 5) to those regions' total electric car stock in 2015 (IEA, 2016c), and assuming their cumulative share in global EV stock will follow roughly the average trend between 2010-2015, estimated by a linear fit - likely a conservative estimate, in light of the strongly nonlinear growth in China.

Comparatively successful cases such as mentioned above are thus largely attributable to the vehicle taxation structure based on environmental performance (IEA, 2016b) as well as behavioural incentives. In the future, the fiscal durability of such taxation schemes could be enhanced by designing it to be revenue-neutral (IEA, 2016b). Continued support for research, development and deployment (RD&D), in particular comparative policy analysis and market research focusing on consumer preferences, would also be crucial (IEA, 2016b).

In China, stronger centralised measures appear underway than elsewhere: the Chinese government had already set a goal of 30% of all government-owned cars to be “alternative-energy” by 2016 (Bloomberg, 2014), and China is currently considering legislation that would require car manufacturers to sell a certain share of zero and low-emission vehicles, starting at 8% of total deliveries in 2018 and rising thereafter (Bloomberg, 2016a).

While there are also goals for total EV stocks and/or the share of EVs of new registrations in certain European countries, it is unlikely that actual “quotas” on similarly short timeframes as proposed in China would emerge here. Still, the future might hold more of such potential bans on ICE cars and/or quotas for EVs also in Europe. Earlier this year, the Dutch parliament called on the government to aim for a target of selling only EVs by 2025 (NRC, 2016), and in October 2016, the German Federal Council proposed that the sale of gasoline and diesel cars in Germany should be banned from 2030 onwards (Stockburger, 2016). If the latter were implemented in law, it would provide a platform for massive changes in the car industry, as Germany is one of the world’s leading car manufacturing countries.

As electric car stock rises worldwide, it is important not to lose sight of the necessary charging infrastructure, which will have to be kept up to par with the increasing EV take-up. There are already large discrepancies between the charger density and number of EVs per charging unit in West-European countries (Nijland et al., 2016).

There may be opportunities for synergies between distributed generation and electric vehicles, which could act as flexible load to mitigate load variations (Grahn, 2013; Kempton & Tomić, 2005; Tomić & Kempton, 2007). EVs could also become more important the higher the share of intermittent renewable sources in the power sector, which is crucial if the transport sector is to truly decarbonise.

4. AVIATION AND SHIPPING: DEVELOP AND AGREE ON A 1.5°C COMPATIBLE VISION

What is the importance of these sectors?

Aviation is responsible for around 2% of CO_2 emissions worldwide, and two-thirds of these are attributable to international aviation. As with international marine bunker fuel emissions, these are not assigned to countries under UNFCCC reporting guidelines, and were specifically excluded in the Kyoto protocol from national accountings (ATAG, 2010). Instead, the International Civil Aviation Organisation (ICAO) has been tasked with developing emission reduction schemes for international aviation and the IMO for international marine bunker fuel emissions.

However, aviation and shipping both continue to be exempt from various measures initiated in other sectors. For instance, international aviation is exempted from fuel taxes applied to conventional fuels, e.g. for cars, that could reflect the externalised environmental costs of the emissions caused by the use of these fuels (IMF, 2011).

In this section, we discuss the need for decarbonisation in the context of the aviation sector, but the issues are similar for the maritime sector.

The ICAO has forecast that global emissions from aviation in 2050 could be at least 300% higher than today's levels (ICAO, 2016a). Emissions from aviation are only 2% of global emissions now, but the demand in revenue tonne kilometre is likely to increase in the future on average at 5.3% per year between 2010 and 2030 for international aviation (ICAO, 2016b).

What is needed for 1.5°C compatibility?

Reducing emissions in the aviation sector requires action in three broad areas: aircraft efficiency, carbon content of fuels or energy source, and modal shifts in demand.

The IEA Energy Technology Perspectives (ETP) study offers some insights into the potential for the combined effects of these measures to reduce emissions in the sector when examining a 2°C pathway. In the ETP 2˚C pathways for the transport sector, the number of passenger-kilometres attributable to air transport increases by almost 140% by 2050 above 2013 levels, but the emissions from air transport decrease by 56% in the same period (IEA, 2016b).

This corresponds to a decrease in specific emissions from roughly 175 gCO_2/pkm (current levels) to 32 gCO_2/vkm in 2050. This 2°C pathway assumes strong increases in energy efficiency of airplanes, an increase in the use of low-carbon fuels (55% of the fuel demand by 2050), as well as shifting travel from aviation to high-speed rail as compared to a current-policy scenario.

For a 1.5°C compatible pathway, a similar—or even earlier and more stringent—decrease of aviation emissions may be necessary. Even if detailed studies on 1.5°C-compatible aviation scenarios are not yet available, **it is clear that the aviation sector will also have to eventually decline its emissions to zero. If the direct emissions cannot be reduced to zero, then emissions would have to be removed from the atmosphere through other means, not simply offset with reduction projects.**

Clearly, the current scenarios and developments are far from this goal.

The ICAO recently agreed on a proposal for the first-ever GHG emissions standard for new aircraft, and an even more recent proposal requiring airlines to offset most of their CO_2 emissions increase after 2020 (first voluntarily and later bindingly from 2027 onwards) (Tollefson, 2016). The Environmental Defense Fund has estimated that about 65% of the emissions growth above 2020 levels would be covered in the first phase and nearly 80% in the second phase (2027–2035)[7] (Petsonk, 2016).

The emissions standard will be mandatory from 2028 and is set at a level 4% lower (for cruise fuel consumption) than that of currently-sold aircraft (ICCT, 2016). This represents a slower energy efficiency improvement than is expected to happen anyway (Transport & Environment, 2016) and is far from the reduction assumed in the 2°C scenario by the IEA (36% improvement in efficiency by 2025 compared to 2013 levels, based on an assumed 2.6% yearly improvement), let alone the 1.5°C scenario. The offsetting is only foreseen for the emissions *increase*, not for current emissions. Questions also remain about the accounting of the offsetting and have sparked controversy und uncertainty (Fern, 2016). Given the uncertainties about where offset units will come from, their additionality, the structural relationship with NDCs under the Paris Agreement, and the fact that only growth after 2020 is covered, it is nearly impossible to quantify any global warming benefit of these measures at this stage.

Overall, these recent developments under ICAO are seen by many as a necessary but highly insufficient step to align the sector with the Paris Agreement long-term temperature limit, which would require the aviation sector to become net-zero emission within a few decades as well. Weak emissions standards for *new* aircraft and *voluntary* offsetting of emissions *increases* are wholly inadequate to tackle the challenges ahead.

What needs to be done by 2020 and 2025?

Energy efficiency of aircrafts will have to significantly increase. Together with biofuels, it would have to reduce emissions per km travelled by 23% by 2025, (ETP 2°C scenario) and even further for 1.5°C. There are still efficiency gains to be made, e.g. fuel consumption of *new* aircraft designs can be reduced by approximately 25% by 2024 (Kharina, Rutherford, & Zeinali, 2016).

This would need to be combined with a significant takeup of biofuels as aircraft fuel. According to some estimates, biofuels reduce the lifecycle emissions of aircraft fuel by more than half compared to fossil fuels (ATAG, 2009; Elgowainy et al., 2012). The use of biofuels was approved for commercial use in aviation in 2011 and has since been used by some airline companies, although not in great quantities.

The share of low-carbon fuels would need to increase to roughly 10% by 2020 and 14% by 2025 to meet the 21% and 34% reduction by 2020 and 2025, respectively, in emissions per km travelled in the ETP 2°C scenario as compared to 2013 values. (As mentioned above, this scenario already includes assumed aircraft fleet efficiency improvements of 2.6% per year.)

However, relying completely on first generation biofuels to decarbonise the aviation sector risks competition with other sectors for the resources needed to grow the necessary biomass. For this reason, focus has now shifted to the use of second-generation sustainable biofuels which are not derived from products that could also serve as food sources, and which could be grown in environments unsuitable for food production (ATAG, 2009; Ruppert, Kappas, & Ibendorf, 2013).

The aviation sector could be given preferential access to biofuels ahead of other sectors, as it has no other alternatives for reaching zero emissions.

[7] Coverage is not expected to be 100% as least developed countries, land-locked developing countries, and small island developing countries would be exempt (although they could opt in at any time).

Finally, there needs to be a reduction of growth in demand for air travel. The IPCC AR5 provides an overview of various demand reduction options proposed in the literature (Sims et al., 2014).

There is potential for emissions reductions through a modal shift on short-distance flights. This could be achieved through policies favouring fast trains over airplanes—e.g. through price signals and provision of infrastructure. The EU example suggests that taxing fuels, tickets or emissions could be particularly effective where there are good railway options (Sims et al., 2014).

A similar shift for freight from air to rail may also require increased rail capacity. Business travel could be substituted by videoconferencing and reduced by combining trips, but the potential of such alternatives is limited, as business travel represents a minority share in passenger air traffic. There are no alternative modes of travel for long-distance passenger flights.

Are there signs this is feasible?

The lack of ambitious targets on how the aviation and shipping sectors should be decarbonised shows that the potential measures we have outlined are currently mainly options on paper. Encouraging examples include the EU, which is responsible for 35% of global aviation emissions and which has attempted to include aviation into its Emissions Trading System, or China which is building many high speed train lines (Sims et al., 2014).

The immediate pathway to lead towards decarbonisation for the aviation and shipping sector should consist of the following main points:

- Immediately implement and scale-up current options for mitigation in the sector and standardise best practice already occurring;
- Agree on the long-term vision for aviation and develop 1.5°C-compatible scenarios for the aviation sector and related technology roadmaps;
- Carry out research activities to help the sector implement the necessary far-reaching measures.

5. NEW BUILDINGS: ALL NEW BUILDINGS FOSSIL-FREE AND NEAR ZERO ENERGY BY 2020
6. BUILDING RENOVATION: INCREASE RATES FROM <1% IN 2015 TO 5% BY 2020

What is the importance of the sector?

In 2010, the building sector was responsible for almost one fifth of global GHG emissions: 9 $GtCO_2e$ (Lucon et al., 2014). Emissions in buildings consist of direct and indirect emissions. The largest and fastest-growing share comes from indirect emissions, primarily electricity use (6 $GtCO_2e$) (Lucon et al., 2014).

Direct emissions represent a smaller share (3 $GtCO_2e$), and are stagnant. Energy use and related emissions may double or potentially even triple by mid-century, which can be avoided if today's cost-effective best practices and technologies are broadly diffused (Lucon et al., 2014).

What is needed for 1.5°C compatibility?

Scenarios with a likely—or very likely—chance of limiting warming to less than 2°C require a 70–80% reduction of direct emissions from the building sector by 2050 (Rogelj et al., 2015). For scenarios consistent with no more than 1.5°C the required emissions reductions increase to 80–90% (Rogelj et al., 2015). Indirect emissions, primarily from electricity, are treated in the energy sector in these scenarios and also require full decarbonisation by mid-century (see the chapter titled Electricity: sustain the growth rate of renewables and other zero and low carbon power until 2025 to reach 100% by 2050).

What needs to be done by 2020 and 2025?

Growth in large and small appliances and an increasing share of buildings that are equipped with air conditioning are the main driver of indirect emissions (IEA, 2013). Bearing in mind that most new buildings are being constructed in developing countries, coupled with a growing share of buildings with air conditioning, improved cooling systems represent one of the biggest opportunities to reduce future energy consumption from buildings in regions with warm climates (IEA, 2013). Additional emissions reductions could be achieved through higher energy efficiency in appliances.

Here, we have assessed two possible major actions that could achieve the deep emissions reductions required for direct building emissions:

1. Implementation of stringent building standards for new buildings and
2. Extensive efforts to retrofit existing, inefficient housing stock.

To assess the timing and level of action required for these two measures, we used a simple building stock model that tracks the energy intensity and floor area of the building stock from 1990 to 2050.[8] We find that to bring the building sector onto a pathway consistent with a maximum temperature increase of 1.5°C, action needs to start immediately. 2020 and 2030 emissions reductions required for 1.5°C are only possible to achieve with actions indicated by the 'immediate action pathway' shown in Figure 6, e.g.

- 100% of new buildings to be zero emissions (i.e. fossil free and near zero energy) by 2020 in OECD and 2025 in non-OECD regions

[8] For more detail see our recent publication Constructing the Future: Will the building sector use its decarbonisation tools?, available at climateactiontracker.org

- Annual retrofit rates of existing stock to increase from <1% to 5% in OECD regions and to 3% in non-OECD regions by 2020, with 90% direct emissions reduction per retrofit (Boermans, Bettgenhäuser, Offermann, & Schimschar, 2012).

The 2050 emissions level of 80–90% below 2010 can still be achieved if action is delayed by up to five years compared to the timelines above, but this would require additional reductions in transport, industry or LULUCF, or additional negative emissions, to still be in line with 1.5°C, as it is the cumulative emissions until 2050 which need to be constrained. Figure 6 indicates the urgency of immediate action in the building sector to keep a 1.5°C pathway within reach ('Immediate Action'). The pathways of delayed activities are shown in comparison.

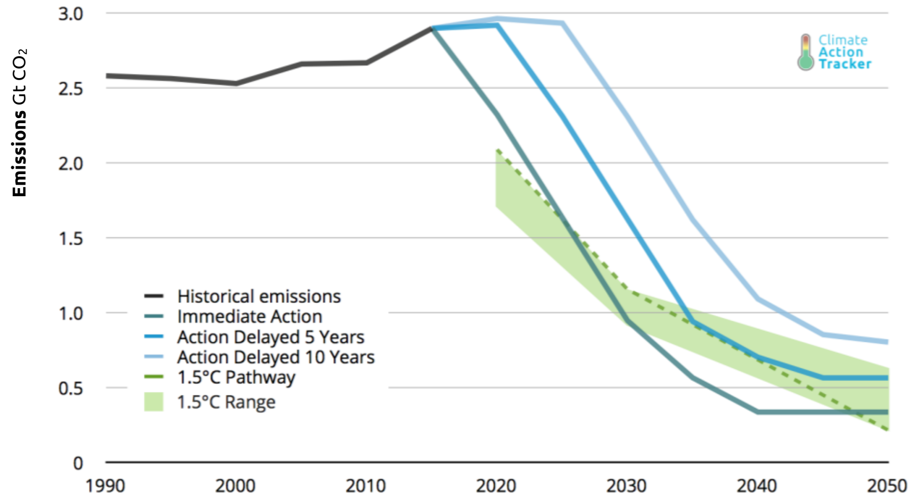

Figure 6 Direct emissions from buildings in three different scenarios shown in comparison with the range dictated by 1.5°C scenarios in Rogelj et al. (2015)

Given the long lifetimes and associated lock-in of emissions from inefficient building stock, action needs to be taken for both, new and existing stock, in all regions. However, arguably, action on retrofits should play an even larger role in developed economies, whereas the abatement potential from new buildings is primarily found in developing economies (see Figure 7).

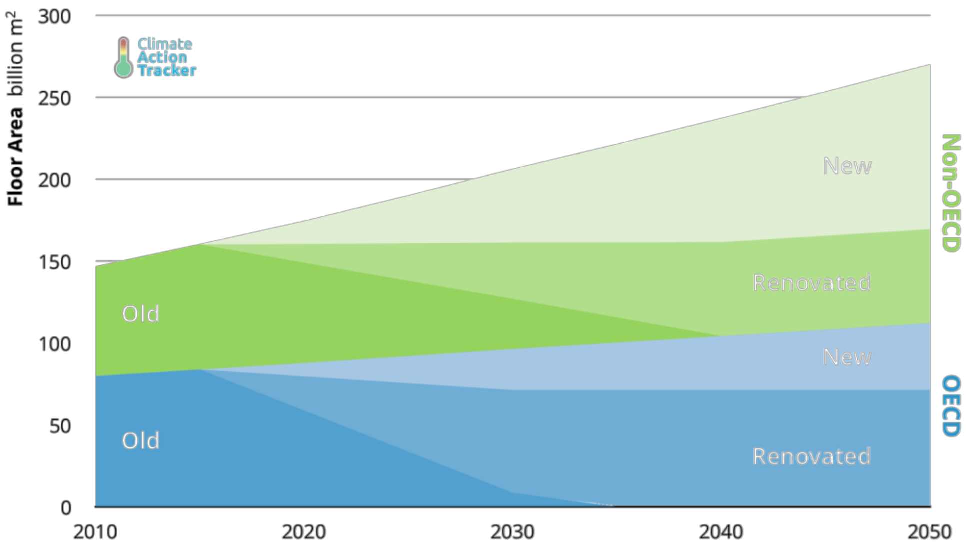

Figure 7 Development of building stock composition based on IEA (2013)

Are there signs this is feasible?

With a combination of best available technologies and policies that provide the right incentives to overcome typical market failures such as the split incentive between tenant and investor, it is possible to achieve emissions reduction that are in line with a 2°C or 1.5°C-pathway (IEA, 2013).

A global, ambitious policy drive to achieve this action has been lacking in the past, but there are a few national policy 'frontrunners' emerging, both on retrofitting and (new) building standards. Located in different regions, we show promising examples of well-implemented buildings policies in Box 1.

Key instruments include loans with preferential rates, required minimum building performance standards and direct subsidies for additional investment costs. While applying those instruments are steps in the right direction, few of these policies are ambitious enough to achieve a 2°C or 1.5°C pathway.

The exception is the EU's Energy Performance of Buildings Directive (EPBD) policy for new buildings, which specifies new buildings to be nearly zero energy by the end of 2020, which is in line with a 1.5°C pathway. However, the envisaged retrofit rate in the EPBD is 3% instead of the required 5% estimated in our immediate action scenario.

Box 1 Examples of promising building policies in different world regions

➔ **China:** the **Energy-Efficiency Retrofits of Existing Buildings** aims to increase the efficiency of existing buildings to the level required for new construction. The government strengthened its obligation by requiring a 10% reduction in energy consumption per square metre for commercial buildings and a 15% reduction for large commercial buildings that have more than 20,000 square metres of floor area (EIA, 2016).

➔ **EU:** the **Energy Performance of Buildings Directiv**e (EPBD, 2010) and the **Energy Efficiency Directive** (EED,2012) are the EU's main legislative tools to reduce the energy consumption of buildings. The EPBD requires all new buildings to be nearly zero energy by 31 December 2020 (public buildings by 31 December 2018) and mandates standards for the renovation and retrofit of existing buildings. The EED aims to increase the rate of renovations to at least 3% a year of buildings owned and occupied by central government (European Commission, 2016b).

➔ **USA:** the programme **Assisted Housing Stability and Energy and Green Retrofit Investments** provides modest grants or loans with a budget of USD$250 million for energy retrofits and "green" investments to property owners (U.S. Department of Housing and Urban Development, 2014). Incentives are provided for owners to undertake energy or green retrofits, including fees to cover investment oversight and implementation by the owner. A physical and financial analysis of the property forms the basis for the amount of each grant and loan that the receiving property owner must spend within two years (IEA, 2015a). The **Better Building Challenge,** one key element of the US Climate Action Plan, aims to increase the energy efficiency of commercial, industrial, and multi-family buildings by at least 20% by 2020. It also aims to reduce emissions by at least 3 $GtCO_2$ cumulatively by 2030 through efficiency standards for appliances.

➔ **Brazil:** the goal of the programme **Procel EPP (energy efficiency in public building)** is to reduce energy consumption by implementing demonstration projects in public buildings (IEA, 2015c). In 2010, projects that are part of the programme achieved an energy saving of 6.16 TWh, equivalent to 1.5 % of Brazil's total annual energy consumption or emissions reductions of 316 $MtCO_2$ (Magalhães, 2012).

➔ **Mexico:** through the **Green Mortgage Programme (Hipoteca Verde)** Mexico has improved the energy efficiency of millions of buildings by providing a "green mortgage" (SITRA, 2015). This mortgage has a low interest rate and is available from state-owned banks for buildings that can prove compliance with energy efficiency standards. The green mortgage programme targets both refurbishments of old buildings and construction of new buildings.

7. INDUSTRY: ALL NEW INSTALLATIONS IN EMISSIONS-INTENSIVE SECTORS ARE LOW-CARBON AFTER 2020, MAXIMISE MATERIAL EFFICIENCY

What is the importance of the sector?

The industry sector accounted for more than 40% of global total GHG emissions (excluding agriculture, forestry and land use: AFOLU) in 2010. 85% of the industry GHG emissions is CO_2. Emissions arise mainly from the conversion of natural resources or other raw materials into material stocks and then into products; 44% of the CO_2 emissions in 2010 was from the production iron and steel and non-metallic materials (predominantly cement) alone (Fischedick et al., 2014).

What is needed for 1.5°C compatibility?

There are a limited number of studies specific on 1.5°C-compatible emission pathways for the industrial sector. One of the few studies available, Rogelj et al. (2015) shows that in comparison to the emission reduction levels in a typical (medium) 2°C scenario, reductions in 2030, 2040 and 2050 will need be reached roughly 10 years, 15 years and 20 years earlier under the 1.5°C scenario, respectively.[9]

For a 430-530 ppm CO_2e stabilisation, which covers varying levels of probability to keep global temperature increase within 2°C, the IPCC 5th Assessment Report (Fischedick et al., 2014) shows that the total direct and indirect GHG emissions from the industrial sector reduce by about 50%–75% by 2050 below 2010 levels (25th – 75th percentile range for 120 scenarios). 1.5°C-compatible scenarios are likely at - or below - the lower bound of this emissions reduction range,[10] as scenarios with a >50% probability of staying below 1.5°C in Rogelj et al. (2015) showed CO_2-equivalent concentrations reaching 420-440 ppm CO_2e in 2100.

What needs to be done by 2020 and 2025?

The industrial sector can only achieve such substantial emissions reduction towards the mid-21st century by applying a broad set of mitigation options (Fischedick et al., 2014). The effects of these options are cumulative, and many of these need to start soon to have the desired long-term benefits (Fischedick et al. 2014):

- Increasing energy efficiency
- Emission efficiency (fuel switching and, for some specific sectors, carbon capture and storage may be an option),
- Material efficiency, including
    - Material use efficiency (e.g., reducing demand through improved end-product design),
    - Recycling and reuse of materials,
    - Product service efficiency (e.g., car sharing, longer life for products), and
- Demand reductions (e.g., reducing demand for steel-based products through behavioural shifts).

The industry sector is heterogeneous and the challenges for long-term decarbonisation differ significantly across subsectors. This section focuses on energy and process-related CO_2 emissions.[11]

For illustration, we focus on the iron and steel subsector for the following reasons:

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[9] Linear interpolation between 2020 and 2030

[10] 1.5 °C-compatible scenarios in Rogelj et al. (2015) lie within the range of 420-440 ppm CO_2e.

[11] A separate Climate Action Tracker brief on HFC reductions under the Montreal Protocol is in preparation.

1. it is one of the most energy-intensive and CO_2-emitting subsectors,
2. it involves large process CO_2 emissions which are more difficult to reduce compared with energy-related emissions,
3. it is one of the subsectors that requires long-term investment decisions, due to the long lifetime and the large scale of facilities,
4. it is one of the subsectors with a comparatively mature recycling system.

The iron and steel subsector alone accounts for more than 25% of total CO_2 emissions from the industry sector[12] (authors' own calculation based on the 2013 data reported in: IEA 2016a), and is expected to play a particularly important role in the world staying on the emissions trajectory that is consistent with the Paris Agreement goals.

For example, in the 2DS scenario from the IEA Energy Technology Perspectives (ETP) 2016 report (IEA, 2016b), which gives at least a 50% chance to limit mean temperature increase below 2°C,[13] the largest emissions reduction comes from the iron and steel subsector, accounting for 36% of cumulative emissions reduction compared to the current trends (6DS) scenario between 2013 and 2050.

In the ETP 2016's 2°C scenario, CO_2 intensity per tonne of crude steel is projected, by 2035, to halve from 2013 levels. Total CO_2 emissions from the iron and steel sector are projected to halve around 2040.[14] These mitigation milestones would have to be achieved even earlier to be compatible with a 1.5°C pathway.

Among the mitigation options described above, policymakers need to go beyond energy efficiency improvement to strengthen efforts for material efficiency improvement and the large-scale deployment of decarbonised processes to realise such drastic emissions reductions compatible with 1.5°C. There have been strong improvements in energy and process efficiency in the industry sector in the last two to three decades, and energy efficiency improvement could reduce the GHG emission intensity of the industry sector by about 25% from current levels (Fischedick et al., 2014), but this alone will not be sufficient for the industry sector to stay on track for 1.5°C.

Few policies around the world have specifically pursued material or product service efficiency to date (Fischedick et al., 2014), but the potential is large. For the iron and steel subsector, Milford et al. (2013)[15] investigated scenarios to reduce CO_2 emissions by 2050 through energy efficiency and material efficiency[16] improvement measures. The target emissions level for 2050 in Milford et al. is roughly consistent with the trajectory of industrial process emissions under the 1.5°C scenario in Rogelj et al. (2015). The results show that, by 2050, enhanced material efficiency could possibly deliver emissions reductions equivalent to 50% of the total CO_2 emissions from the iron and steel subsector in 2010.

Large-scale deployment of low-carbon steelmaking technologies, including carbon capture and storage (CCS), also needs to take place immediately. In the 50% reduction scenario by 2050 investigated by Milford et al. (2013), the last conventional blast furnace would be built by 2020 and all new primary iron-making facilities installed afterwards would be innovative low-carbon technologies, such as top gas recycling blast furnace and direct reduction using

[12] Including process- and electricity use-related emissions, and includes emissions from coke ovens.

[13] The 2DS scenario shows a reduction of the industry sector emissions from 8.4 $GtCO_2e$ in 2011 to 6.6 $GtCO_2e$ in 2050, which is consistent the medium 2 °C scenario in Rogelj et al. (2015).

[14] Including emissions related to electricity use.

[15] Innovative processes such as top gas recycling blast furnace and electrolysis technologies were considered, but CCS was assumed not to be directly applied to ironmaking but only in conjunction with electricity production.

[16] Options considered were: reduced metal use per service demand, more intense use of products, life extension, fabrication scrap diversion, reuse of end-of-life scrap, and fabrication yield improvements.

gas as well as advanced smelt reduction and electrolysis in the longer term, if the 50% reduction target is to be achieved in 2050.

Are there signs this is feasible?

Recent studies indicate that the demand for primary steel is unlikely to grow significantly up to 2050 as observed in the previous two decades under business-as-usual scenarios, largely due to the increased use of recovered steel scrap, which will result in an increased share of steel production by electric arc furnace (EAF) process. Nevertheless, new blast furnaces will continue to be built. Oda et al. (2013) project a 10-15% increase from current levels by 2050. Pauliuk et al. (2013) project a peaking of primary steel production around 2025, but also project that new blast furnaces will continue to be installed in India, the Middle East, Latin America and Africa after 2020 in a highly regionalised steel market, even as China and Western Europe decommission large numbers of uneconomic steel plants.

Having no new conventional blast furnaces after 2020 is therefore an ambitious target, but it is technically and economically feasible. First, there is significant untapped mitigation potential through material efficiency improvement. Not only is steel scrap recovery expected to increase considerably in the next few decades (Oda et al., 2013; Pauliuk et al., 2013), Milford et al. (2011) also found that 26% of global liquid steel in 2008 was lost as process scrap, and its minimisation could have reduced CO_2 emission by 16%. A literature review on steel scrap recovery projections (Kuramochi, 2016) strongly indicated that higher demand for steel scrap increases the amount of steel scrap recovery and supply.

Second, the development of low-carbon primary steelmaking technologies is advancing. CCS technology for conventional blast furnaces is expected on the market at some point in the future, and costs could potentially be attractive (Kuramochi, Ramírez, Faaij, & Turkenburg, 2012), but there is no commercial-scale demonstration plant in operation to date. Innovative low-carbon steelmaking technologies equipped with CCS may become available from 2025 (IEA, 2015d).[17] To capture this potential, however, voluntary efforts by the iron and steel industry will not be enough. For example, in 2013, ArcelorMittal planned a commercial-scale top gas recycling blast furnace plant with CCS in Florange, France, but abandoned the plan for financial reasons (IEA, 2015d).

While low-carbon primary steelmaking technologies with CCS could play an important role in reducing emissions from the iron and steel subsector, this role should not be overemphasised given its development status. Therefore, it is crucial that efforts for energy efficiency and material efficiency improvement is strengthened to the maximum extent possible. Other emission saving options such as enhanced uses of waste plastics and tyres as coke substitutes can widely be implemented (Kuramochi, 2016).

The governments of major steel-producing countries need to significantly scale up their support for research, development, demonstration and deployment (RDD&D) of low-carbon steelmaking technologies. Sector-specific carbon-pricing agreements could also potentially be effective if it is implemented in a harmonised manner across major steel producing countries to level the carbon playing field (Zhang, 2012).

Third, the on-going international efforts to resolve the current excess capacity problem for blast furnaces in China[18] (OECD, 2016) could potentially reduce the need for new installations in other regions during the next ten-year period, when the availability of low-carbon primary steelmaking technologies are not fully certain.

[17] IEA ETP 2015 (IEA, 2015d) has estimated that CCS for conventional steelmaking processes will be available from 2016, but, as of early November 2016, this has not yet taken place.
[18] China produces more than 60% of steel from blast furnaces today (World Steel Association, 2016).

There are indications that no new capacity for primary steel production may be needed until 2060 in a fully integrated global steel market (Pauliuk et al., 2013)**. Therefore, internationally coordinated efforts involving both governments (not only of the current major steelmaking countries but also emerging economies such as India and Brazil) and steel producers will be crucial to address both the overcapacity problem and the CO_2 emissions reduction in a comprehensive manner.**

8. LULUCF: REDUCE EMISSIONS FROM FORESTRY AND OTHER LAND USE TO 95% BELOW 2010 BY 2030, STOP NET DEFORESTATION BY THE 2020S

What is the importance of the sector?

Emissions from land use, land-use change and forestry (LULUCF) accounted for about 11% of emissions in 2010, according to the IPCC WG3 (Smith et al., 2014).[19] Estimates vary significantly due to the uncertainty of estimating CO_2 emissions, as well as human-induced uptake, from forests and land areas subject to deforestation, degradation or other land use changes.

The causes of emissions in the LULUCF sector are manifold; according to the FAO over the period 2010–2016. Burning biomass,[20] on average, accounted for 38% of LULUCF emissions, closely followed by forest land[21] with 36%. Cropland[22] accounted for 25% of emissions and grassland for 0.8% (FAOSTAT, n.d.).

The main deforestation/forest degradation drivers are agriculture expansion, timber logging, firewood collection and, to a lesser extent, mining and urban expansion (Kissinger, Herold, & De Sy, 2012), although drivers vary across time and regions.

Agriculture is the largest driver of deforestation worldwide; according to the FAO (2016), large-scale commercial agriculture accounts for around 40% of deforestation in the tropics and subtropics, local subsistence agriculture for 33%, though considerable regional differences persist. Whereas commercial agriculture accounts for almost 70% of deforestation in Latin America, it only accounts for one-third in Africa, where small-scale agriculture is a more significant driver (FAO, 2016).

Firewood and charcoal production are one of the main forest degradation drivers for the African continent, together linked to about 48% of total degradation (Hosonuma et al., 2012; Kissinger et al., 2012); the Democratic Republic of the Congo, for example, meets 80% of its energy needs through wood (Allianz, 2015; Counsell, 2006).

Legal and illegal logging account for more than 70% of total forest degradation in Latin America and Asia (Hosonuma et al., 2012; Kissinger et al., 2012); 35–72% of logging in the Brazilian Amazon, 22–35% in Cameroon, 59-65% in Ghana, 40–61% in Indonesia and 14–25% in Malaysia are deemed illegal (Chatham House, 2016; Sam Lawson & MacFual, 2010).

As a consequence, it is estimated that almost 40% of all palm oil, 20% of all soy, nearly 33% of tropical timber, and 14% of all beef traded internationally comes from land that has been illegally deforested (S Lawson et al., 2014).

[19] The IPCC calls this FOLU (Forestry and Other Land Use) but specifies in its glossary that this is the same as LULUCF: "FOLU (Forestry and Other Land Use) — also referred to as LULUCF (Land use, land-use change, and forestry) — is the subset of AFOLU emissions and removals of greenhouse gases (GHGs) resulting from direct human-induced land use, land-use change and forestry activities excluding agricultural emissions" (IPCC, 2014b).

[20] "Greenhouse Gas (GHG) emissions from burning of biomass consist of methane and nitrous oxide gases from biomass combustion of forest land cover classes 'Humid and Tropical Forest' and 'Other Forests', and of methane, nitrous oxide, and carbon dioxide gases from combustion of organic soils."

[21] "Annual net CO_2 emission/removal from Forest Land consist of net carbon stock gain/loss in the living biomass pool (aboveground and belowground biomass) associated with Forest and Net Forest Conversion."

[22] "Greenhouse gas (GHG) emissions data from cropland are currently limited to emissions from cropland organic soils. They are those associated with carbon losses from drained histosols under cropland."

What is needed for 1.5°C compatibility?

Forest and land use change emissions in scenarios underlying the conclusions on 1.5°C in the IPCC's AR5 WGIII and Synthesis Reports, supplemented by the most recent modelling of 1.5°C scenarios ((Luderer et al., 2013; Rogelj et al., 2012, 2013,Rogelj, pers. comm.), contain a considerable degree of uncertainty. Nevertheless, all show lower emission levels than at present: 0.2 (range -1.2 to 4.4) $GtCO_2$/yr in 2030 (average over the 2025-35 period), compared to 4.6 (range 2.6 to 7.2) $GtCO_2$/yr in 2010 (average 2005-2015). This implies emission levels reduce on average across the scenarios by 95% (range 40 to 145%) below 2010 by 2030. An essential element in achieving these reductions is that, by the 2020's, net global deforestation stops, or reverses (where global forest area starts to increase again).

Reducing emissions from this sector must not be an alternative to reducing fossil fuel CO_2 emissions—action in this area is best seen as an essential protection of the natural storage reservoirs of carbon, as the ability of forests to act as on-going carbon sinks is limited, especially compared to the scale of fossil fuel emissions.

Unfortunately, there is a long history of attempts to use forest sinks to offset against obligations to reduce emissions from energy, industry and transport sectors in a number of countries. The large range of examples includes experiences with LULUCF accounting under the Kyoto Protocol (e.g. Australia, Canada, New Zealand) and content of NDCs under the Paris Agreement (e.g. New Zealand, Brazil, Indonesia).

Stronger reductions could be feasible, but should not lead to weaker efforts in other sectors. Inadequate action in other sectors, in particular energy, industry and transport, would leave a high-emissions legacy for many future decades and would mean a failure to set in motion the system changes needed to achieve the required long-term transformation.

Ensuring the integrity—and promoting the enhancement—of natural carbon sinks provides immense co-benefits (e.g. reduced air pollution from biomass burning), resilience to climate change, and is directly linked to the sustainable development goal 15, which aims to sustainably manage forests, combat desertification, halt and reverse land degradation and halt biodiversity loss (UN, n.d.).

What needs to be done by 2020 and 2025?

At least three mechanisms must be operationalised for financial support to eliminate deforestation and forest degradation.

Firstly, the REDD+ initiative is not yet operational at a large scale, due to very limited funding. At its 14th meeting, in October 2016, the Board of the Green Climate Fund (GCF), following guidance from the COP in Paris, started to consider how the Fund can support REDD+ activities. The GCF Board recognised the need to complement other existing sources and types of financing for REDD+, and agreed the Fund can support the development of national REDD+ strategies and investment plans through its Preparatory and Readiness Programme, as well as support the implementation of these plans. The GCF is expected to launch a call for proposals for REDD+ results-based payments in early 2017.

Secondly, non-market mechanisms must be developed further and supported financially though the GCF and other channels, as market mechanisms are not suitable for all contexts and not all recipient countries support the use of market-based mechanisms (e.g. Bolivia and Columbia). Particularly important here is the approach to value and preserve forest-related ecosystem services in a broad perspective, far beyond the role of forests as a carbon sink and not linked to international carbon markets, for which approaches are also under development at the GCF.

Thirdly, the root causes of deforestation can be addressed via policies not directly related to forest-land management, focusing at some of the drivers of deforestation. A prime example is to stimulate the modernisation and intensification of agricultural practices, and to invest in the resilience of these systems to natural disasters and adaptation to climate change. This would reduce the incentives for deforestation activities. A main means to achieve this could be awareness raising by FAO. Intensification can also mean a shift to cash crops, if those crops prove to be more resilient in a particular situation.

To reduce deforestation, where there are good national land-use monitoring systems in place, land-use management, planning and policies must be strengthened at national and regional levels. Essential is resolving land tenures, so that ownership is unambiguous regarding deforested land (Robinson, Holland, & Naughton-Treves, 2014). While legislation to stop deforestation has been improved strongly in most countries, enforcement is still limited on the ground, in particular in countries with large forest coverage (Agrawal, Chhatre, & Hardin, 2008). In these cases, emphasis can be placed on improving export regulation and enforcement (Dooley & Ozinga, 2011).

Solutions are more limited in countries with very limited national land-use monitoring systems. In these cases, policy in the next decade should focus on community awareness raising and implementation of community forest management, transferring land tenure to local communities (Agrawal & Angelsen, 2009; Hayes & Persha, 2010). Crucial here is to engage with - and protect - local communities in efforts to address illegal logging activities (Chhatre & Agrawal, 2009; Gibson, Williams, & Ostrom, 2005). Also in this case, emphasis can be placed on improving export regulation and enforcement, including by putting the burden of proof of legally harvest wood products on exporters, via international private tracking and certification systems (Levashova, 2011).

In light of the areas of action described above, land-related mitigation policies would have to be based on an integrated approach, taking into account energy and agriculture in order to "help optimise synergies and mitigate negative effects" (Smith et al., 2014). Agroforestry offers one avenue for planting trees outside of forests, that addresses conflicting interests of land use, while simultaneously increasing crop yields and the diversity of products grown (Jose, 2009; Schroeder, 1994; Van Noordwijk & Minang, 2014).

Clean-cooking stoves and developments in renewable energy access offer great potential to reduce the need for firewood while simultaneously addressing the high level of indoor air pollution, which was responsible for 4.3 million deaths in 2012 (World Health Organisation 2016). Worldwide, around three billion people still cook and heat their homes using solid fuels, such as wood, charcoal or coal and, according to the IEA, 1.8 billion people will still not have access to clean cooking devices by 2040 (IEA, 2016a).

Demand-side mitigation options should focus on the international wood trading system, especially regarding implementation of an improved wood tracking system to prevent illegal wood from entering the market. Both public and private actors' initiative is needed to address this global problem on all fronts.

Illegal logging is becoming increasingly advanced due to better organisation of cartels; in recent years illegal logging has moved to more advanced methods of concealment and timber laundering. Some estimate that 15% to 30% of the volume of wood traded globally has been obtained illegally and its economic value including processing is its economic value including processing is estimated to be worth between US$ 30 and US$100 billion (10–30% of global wood trade) (Nelleman, 2012).

Are there signs this is feasible?

Reducing deforestation has been a global goal for many years, and recent developments give signs of hope that actions have finally been successful and can even be enhanced. For example, Brazil reduced its deforestation by 80% as a result of effective policies implemented over the last decade to fight deforestation that have—in absolute terms—reduced the annual deforested area by roughly 80% from 27,772 km^2 in 2004 to 5,891 km^2 in 2013 (Ministry of Science Technology and Innovation of Brazil, 2016)

An alliance of companies, governments and civil society initiated practical means of realising existing international commitments, with the “aspiration” to restore 150 million hectares of the world's deforested and degraded lands by 2020 and 350 million hectares by 2030 (Bonn Challenge, n.d.). Likewise, in 2014 such an alliance endorsed a timeline to end natural forest loss by 2030 (New York Declaration on Forest, 2014).

Essential is that the Green Climate Fund is now defining approaches to support projects focused both on market-based mechanisms (REDD+) and non-market mechanisms (ecosystem-services approaches).

9. COMMERCIAL AGRICULTURE: KEEP EMISSIONS AT OR BELOW CURRENT LEVELS ESTABLISH AND DISSEMINATE REGIONAL BEST PRACTICE, RAMP UP RESEARCH

What is the importance of the sector?

Agricultural GHG emissions, consisting primarily of methane and nitrous oxide, have seen a steady increase of around 15% over the last 20 years. In 2010, they accounted for around 5.2–5.8 $GtCO_2eq/yr$ (Smith et al., 2014), equivalent to a tenth of global emissions. Emissions from agriculture are closely linked to emissions from other land-based activities, notably forestry, and, depending on sectoral definition boundaries, sometimes include carbon storage in the soil.

Figure 8 shows the contribution of different agricultural activities to overall agricultural emissions for 1990 and 2014, respectively (FAOSTAT, 2016). In both years, livestock rearing (enteric fermentation and manure left on pasture) dominated emissions, followed by synthetic fertilisers and rice cultivation. However, the percentage increase in emissions during the last 25 years was higher for synthetic fertilisers and livestock than rice cultivation (FAOSTAT, 2016).

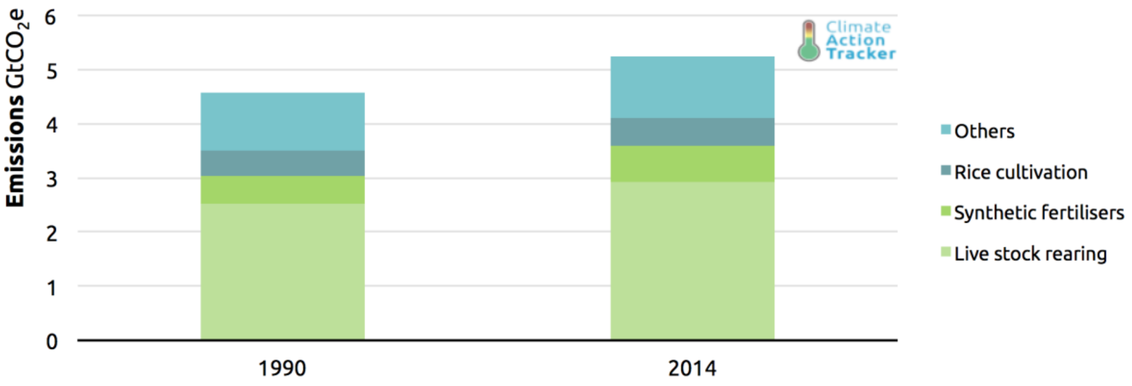

Figure 8 Percentage contribution of GHG emissions from different sub-sectors in 1990 and 2014 (FAOSTAT, 2016)

What is needed for 1.5°C compatibility?

Under a 2°C pathway (Wollenberg et al., 2016) non-CO_2 emissions from agriculture can be expected to rise by 6–50% by 2030 above 2010, assuming substantial emissions decreases were achieved in other sectors, as identified elsewhere in this report. This increase represents an emissions abatement effort of around 1 $GtCO_2eq/yr$ by 2030 (from livestock, manure, rice cultivation and other croplands) below the corresponding projected baseline of 7.5–9.0 $GtCO_2eq$ in 2030.

The emission benchmarks identified above for the agriculture sector in 2°C -compatible scenarios (RCP 2.6) are relatively high, with agriculture contributing only about 5% of total emissions abatement.

There is substantial potential for further, low cost global emissions reductions, which, could be achieved via soil carbon storage options, reduced food loss and waste, and shifting diets.

This could result in a more comprehensive and ambitious benchmark for non-CO_2 agriculture emissions abatement of around 2.3–4.6 $GtCO_2eq/yr$ below baseline by 2030 (Wollenberg et al., 2016), resulting in 2030 emissions levels similar to today's. Mobilising this larger potential will contribute substantially to achieving a 1.5°C pathway.

What needs to be done by 2020 and 2025?

There are a variety of different technical options to mitigate agricultural emissions, but the challenge lies in driving a large and dispersed number of actors to adopt them. Measures have a strong local component, and practices and measures for reducing emissions in a particular region might not have the same impact in another region, due to differences in climatic conditions and production technologies. Even within a given region, a range of agricultural practices can prevail which can result in large differences in productivity and emissions intensity.

Gerber et al. (2013) estimated the potential for emissions abatement from livestock rearing to be as high as 20% below baseline, simply by adopting best practice within a region. The study considered emissions from the total livestock supply chains (feed production, livestock production and post-farm transport and processing).

For non-CO_2 emissions, it found a relatively high emissions abatement potential of 0.8–1.3 $GtCO_2eq/yr$ against baseline emissions of 5.2 $GtCO_2eq$[23] (Gerber et al., 2013). This potential is comparable to the abatement in the 2°C scenarios of Wollenberg et al. (2016). Producers could achieve these emissions reductions in a given system, region and climate by adopting the practices currently applied by the 10 to 25 percent of producers who have the lowest emission intensities.

A variety of ongoing technological and breeding developments offer promising ways to reduce emissions, such as the use of methane inhibitors for dairy cows, cattle breeds that produce less methane, cereal varieties that inhibit nitrous oxide emissions and high-tech soil management practices that sustain soil organic matter (Wollenberg et al., 2016). However, most of these options are still under development and/or remain unaffordable without further financial support and coordinated research development (Wollenberg et al., 2016).

There should also be significant potential for mitigating emissions from other agricultural emissions streams: the US EPA (2013) estimated the potential for abatement from rice paddies to be around 200 $MtCO_2eq$ in 2030, or around a quarter of projected emissions.

Further research and development can also help to find practical and economically viable mitigation techniques that can be more widely applied (Gerber et al., 2013).

Currently, policy instruments to reduce emissions in agriculture are sparse and developing. Herrero et al. (2016) recently highlighted the large uncertainty surrounding their economic affordability, which could hinder their near term adoption. The challenge is to reduce emissions while maintaining and increasing food production. The sector is also facing many practical challenges to introduce measures that result in tangible emission reductions. For instance, there are a number of emission sources in the sector which make monitoring and

[23]From the information given in the study, we infer that baseline emissions and mitigation potential both refer to the same year, i.e. 2005. We have adjusted both baseline emissions and mitigation to exclude emissions from fossil-fuel combustion to avoid double counting across sectors.

verification of compliance of certain measures difficult, as in the case of emissions linked to Nitrogen Use Efficiency (NUE) (Macleod, Eory, Gruere, & Lankoski, 2015).

The effectiveness of many of the available measures is further reduced due to their inherent nature, such as the non-permanence of enhanced carbon stocks in agricultural soils, human and natural interaction with cropland management, as well as displacement of emissions to other regions when trying to improve land use management locally (Smith et al., 2008).

Devising policies that reduce emissions—while maintaining and improving revenues for producers—is a continuous struggle, but it is important that the policies reflect the cost-effectiveness of measures, account for displacement effects, and are tailored to the needs of producers and consumers (Macleod et al., 2015).

Are there signs this is feasible?

So far, the agriculture sector has remained outside of emissions trading schemes. As of 2015, there are 17 emissions trading systems (ETS) in force across the world (Serre et al., 2015). Only Korea explicitly included agriculture in its ETS in 2015 but it is too early to assess its success (Macleod et al., 2015). In the European Union (EU) it is up to individual Member States to decide on targets to reduce emissions in non-ETS sectors including agriculture. There are no ambitious global or regional policies on agricultural emissions, but there are a few programmes that are noteworthy in terms of promotion of best practices and reducing GHG emissions, which we discuss below.

Under the EU's Common Agriculture Policy (CAP), the Rural Development Programme promotes six common EU priorities to shift towards a low carbon and climate resilient economy in agriculture, including resource efficiency and reducing emissions. The CAP has introduced 'green direct payments' which make up 30% of the EU member states' direct payment budget, and reward farming practices that conserve the environment and contribute to addressing greenhouse gas emissions (European Commission, 2016a).

The EU is also investing in "climate smart agriculture:" EUR 3.6 billion have been allocated for the period 2014–2020 to support research and innovation in food, agriculture, forestry and marine sectors under the Horizon 2020 programme (Michalopoulos, 2016).

The EU Nitrates Directive mandates nutrient application rates and timing and, if fully implemented, is expected to cut N_2O emissions by 6% from 2000 levels by 2020 (European Commission, 2010).

Using regulations and statutory instruments to prohibit activities harmful to the climate can be effective but, as highlighted earlier, monitoring and validation of the compliance of these measures can be an issue. Developing mitigation policy is an ongoing commitment, and further research is needed to devise effective policy options to reduce emissions in the agriculture sector.

In the US, the Conservation Reserve Programme provides payments to farmers to retire sensitive cropland. This helps in reducing carbon fluxes into the atmosphere while also improving water quality. The Scottish government's initiative "Farming for a Better Climate" aims to strengthen farm businesses while devising ways to reduce greenhouse gas emissions. The government has looked into a number of practical measures that will help farmers earn more revenues while reducing the climate impact of their practices.

The importance of introducing sustainable practices as well as reducing emissions in agriculture sector has been recognised by international community, and climate change mitigation is starting to appear in regional and governmental policies on agriculture although the current trajectory for emissions reductions is slow due to numerous challenges the sector is currently facing. However, as part of the ongoing changes in the policies and institutional frameworks in developing countries, there is an opportunity for the diffusion of good practices and innovative technologies to support climate change mitigation and adaptation in agriculture (Smith et al., 2014).

10. CO_2 REMOVAL: BEGIN RESEARCH AND PLANNING FOR NEGATIVE EMISSIONS

What is the importance of the sector?

In large part due to insufficient emissions reductions realised to date, negative CO_2 emissions will unfortunately be necessary at scale from mid-century to limit warming to 2°C, and even more for 1.5°C.

Early and rapid action now, as explained in all other sections of this report, across the full range of mitigation options and to protect and enhance natural ecosystems so that they can retain and store more carbon, are all needed to minimise the need for negative CO_2 emissions. If action to reduce CO_2 slows in coming years, this will increase the need for negative CO_2 emissions technologies, but at this point it cannot be eliminated. Even the most rapid action plausible—to reduce CO_2 emissions to zero before 2050 and to significantly reduce other GHGs—will unfortunately not eliminate the need for sizeable negative CO_2 emissions after mid-century.

Rapidly reducing deforestation, and embarking on ecological restoration, can reduce the amount of negative CO_2 emissions needed, and forests, soils and other vegetation may be able to sequester substantial amounts of carbon. However, these measures will not be sufficient to meet the scale of negative CO_2 emissions now required. The amount of carbon that the biosphere can reasonably sequester is smaller than the amount of carbon that must be taken from the atmosphere in order to limit warming to 2°C, and even more for 1.5°C.

The deployment of fossil power with carbon capture and storage (CCS), envisaged in many of the Integrated Assessment Models examining 1.5ºC and 2ºC pathways, tends to increase the amount of negative CO_2 emissions storage needed. CCS abated fossil power will still emit sizeable amounts of CO_2 because not all combusted carbon is perfectly captured. If fossil power, even with CCS, can be avoided entirely, the need for negative CO_2 emissions technology can be reduced.

The feasibility of large-scale deployment of negative emissions technologies,[24] as well as more broadly carbon dioxide removal (CDR) methods[25] is not yet established. The groundwork in terms of research and trial deployment will need to be made soon to be equipped with the necessary tools later.

Political decisions and support are needed to trigger a broader investigation of the different options and their wider implications (environmental, social, legal, legislative), as well as actual investments in scaling up projects from pilot to commercial scale.

[24] Defined here as technological means of taking CO_2 from the atmosphere and storing it in a geological reservoir or storage repository. In this approach we are not considering measures that store CO_2 in the terrestrial or marine biosphere or active carbon cycle.

[25] The IPCC AR5 glossary has attempted to define this as "a set of techniques that aim to remove CO_2 directly from the atmosphere by either (1) increasing natural sinks for carbon or (2) using chemical engineering to remove the CO_2, with the intent of reducing the atmospheric CO_2 concentration. CDR methods involve the ocean, land and technical systems, including such methods as iron fertilisation, large-scale afforestation and direct capture of CO_2 from the atmosphere using engineered chemical means. Some CDR methods fall under the category of geoengineering, though this may not be the case for others, with the distinction being based on the magnitude, scale and impact of the particular CDR activities. The boundary between CDR and mitigation is not clear and there could be some overlap between the two given current definitions (IPCC, 2014a).

What is needed for 1.5°C compatibility?

The vast majority of 1.5°C and 2°C scenarios in the scientific literature peak global emissions around 2020 and require global negative CO_2 emissions in the second half of the century (Schleussner et al., 2016). For 1.5°C emissions pathways that begin steep reductions after 2020, the median carbon budget over the 21st-century is around 200 $GtCO_2$ (2015–2100). This is equivalent to around five years of present global emissions, or an emissions budget that would reduce emissions linearly to zero by 2025. Clearly this is infeasible.

The fastest technically and economically feasible approach to zero emissions in the scientific literature involves emitting around 760 $GtCO_2$ between now and 2050. After 2050, around 560 $GtCO_2$ are then required to be extracted from the atmosphere via negative CO_2 emissions and stored in secure geological repositories.

The cumulative negative CO_2 emissions required by 2°C and 1.5°C emissions pathways are very similar. The main difference between 2°C and 1.5°C scenarios is that faster emissions reductions in the short term are needed, rather than more negative CO_2 emissions later on in the century. In general, 1.5°C pathways require renewables, zero and low-carbon technologies to be deployed around 10–20 years earlier than 2°C scenarios (Rogelj et al., 2015; Schaeffer et al., 2015).

The more we delay mitigation actions, the more strongly will we have to depend on negative CO_2 emissions technologies and other CDR approaches in the future. This is shown clearly in Figure 9 where the higher the emissions are in 2030, the greater the need for total negative emissions.

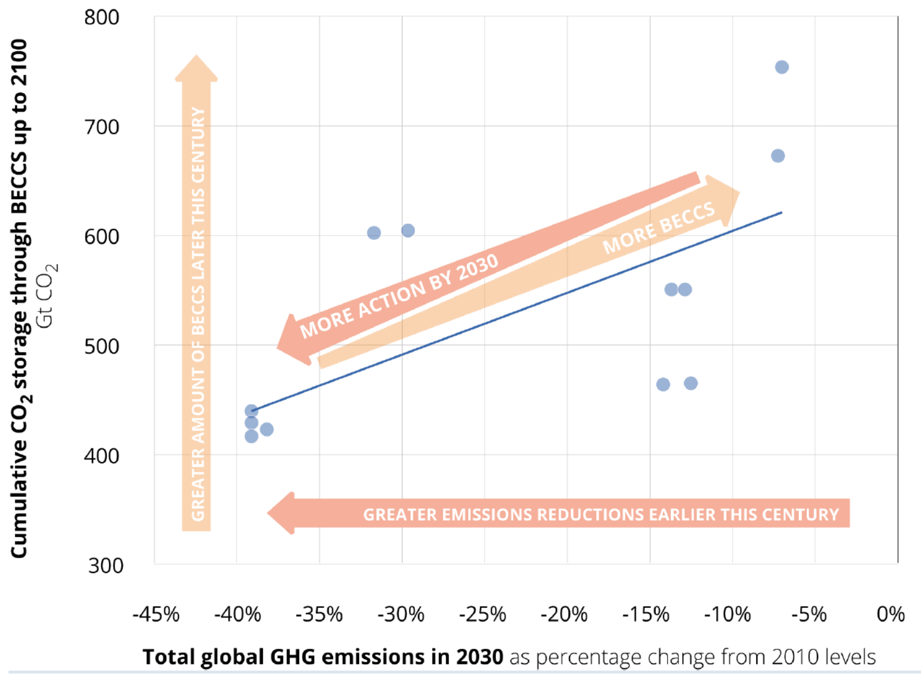

Figure 9: GHG Emission levels by 2030 in percentage from 2010 levels and cumulative negative emissions from BECCS under a selection of 2°C scenarios (about 70% chance of holding warming below 2°C by 2100) that in 2020 approximate global total GHG emissions levels estimated from Copenhagen pledges (Rocha et al., 2016).

As this figure uses emissions scenarios assessed in the IPCC AR5 they are limited to the example of Bioenergy with Carbon Dioxide Capture and Storage (BECCS), which is the main negative emissions technology deployed in present models (Clarke et al., 2014). Although there are other promising approaches, the scientific literature around the current 1.5°C and 2°C scenarios sees BECCS as the main negative CO_2 emissions technology likely to be practicably available in the medium term in terms of potential and technical and economic feasibility.

Land-based activities such as afforestation and protections of ecosystems are also important in reducing, but not eliminating, the requirement for negative emissions technologies (Clarke et al., 2014).

What needs to be done by 2020 and 2025?

Advancing preparation in the next 5–10 years for deployment of negative CO_2 emissions technologies at scale by mid-century involves a number of steps.

- **Take all measures needed to minimise the need for negative CO_2 emissions.** Early and rapid action now—as explained in all other sections of this report—to reduce fossil fuel CO_2 emissions to zero, avoid and/or minimise fossil CCS deployment, bring deforestation to a halt as soon as possible, reduce emissions from agriculture and industry as fast as possible, and protect and enhance natural ecosystems, so that they can retain and store more carbon.
- **Ensure that the prospect of negative CO_2 emissions technologies is not used as an excuse for inaction today.** These technologies are unfortunately necessary to achieving the mitigation required to prevent dangerous climate change and need to be accompanied by stronger short-term emission reductions, which are desirable anyway due to their lower mitigation cost compared to "delayed" scenarios.
- **Political decisions are needed to trigger a broader investigation of the different options, as well as their wider implications.** The technical, engineering and sustainability challenges require substantial research and development.
- From a national legislative and legal perspective**, liability issues associated with the transport and storage of CO_2 need be resolved** (Schaeffer et al., 2015).
- Irrespective of whether any BECCS technology is ever deployed measures are needed to deal with the growing role of bioenergy, including strengthening of integrated land management, stimulating nature conservation alongside second and third generation bioenergy. This is needed to minimise competition with food crops for land and water resources, typical of first-generation biomass (see e.g. IPCC AR5 WGIII chapters 6 and 11; (Schaeffer et al., 2015)).

Are there signs this is feasible?

Deployment of negative CO_2 emissions at the scale required to meet the 1.5˚C limit in the Paris Agreement hinges on the feasibility of both emission reductions and measures to enhance natural sinks and storage of $CO_{2,}$ as well as the feasibility and sustainability of negative CO_2 emissions technologies themselves.

BECCS features very prominently in present-generation 1.5°C and 2°C pathways. This technology is currently deployed only at a pilot scale of maximum one million tonnes CO_2 per year (Carbon Brief, 2016). While all elements of this technology are, in principle, available, and demonstration plants are already functional, very rapid upscaling of this technology would be required in both 1.5°C and 2°C pathways in the 2030–2050 period. The feasibility of such large-scale deployment of this technology is not yet established and needs further research and larger scale deployment in the near term to understand the issues that will arise.

BECCS of course relies upon biomass energy systems. The bioenergy demand for a 1.5°C limit is not higher than for a 2°C limit, but needs to be introduced faster. All energy-economic scenarios, even without these temperature limits, see a rapid growth of bioenergy, due to an anticipated continued competitive development of modern bioenergy options, technologies and infrastructure.

Large-scale deployment of bioenergy is therefore not unique to 1.5ºC and 2°C scenarios and in all cases must rely primarily on "second generation" options. Second generation biomass is derived from lignocellulosic crops, agricultural and forestry residues, dung and organic waste and thus can help reduce risks to food security from high reliance on "first generation" bioenergy, derived from food crops. Such risks can largely be eliminated by using "second generation" bioenergy with high net useful energy production per unit of land area, including bioenergy derived from agricultural and forestry residues, dung and organic waste.

Scientific research available to date shows few indications that the risk of land use conflicts is larger for 2°C than for 1.5°C due to bioenergy use. In addition, IPCC Working Group III noted in its Fifth Assessment Report in Chapter 11 that a "model comparison study with five global economic models shows that the aggregate food price effect of large-scale lignocellulosic bioenergy deployment (i.e. 100 EJ globally by the year 2050) is significantly lower (+5 % on average across models) than the potential price effects induced by climate impacts on crop yields (+25 % on average across models (Lotze-Campen et al., 2014)). Possibly hence, ambitious climate change mitigation need not drive up global food prices much, if the extra land required for bioenergy production is accessible or if the feedstock, e.g., from forests, does not directly compete for agricultural land" (Smith et al., 2014).

Comprehensive policies can safeguard against any remaining risks. However, in any consideration of food security, it must never be ignored that even present-day climate extremes pose very large risks to food security in many countries, due to crop losses and spikes in food prices, and that these risks are set to increase with temperature increases under 1.5°C and more rapidly on our way to 2°C or higher.

While biomass energy systems with carbon capture and storage (BECCS) features very prominently in present-generation 1.5°C pathways, this is by far not the only negative emissions technology. Other options, such as direct air capture of CO_2 plus storage, or the land-based approaches such as soil carbon enhancement or deployment of biochar, have been shown to be technically feasible and may also play an important role in a portfolio of solutions for negative emissions. However, in our understanding, none of these technologies has the potential to fully replace the biomass energy systems with carbon capture and storage (Smith et al., 2016).

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