Climate Action Tracker

Scaling up climate action

Key opportunities for transitioning to a zero emissions society

FULL REPORT

CAT Scaling Up Climate Action series

EUROPEAN UNION

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NewClimate Institute

Ecofys – A Navigant Company

Climate Analytics

CAT Scaling Up Climate Action series

The Climate Action Tracker (CAT) strives to support enhancing climate action in the context of the Paris Agreement implementation. This analysis contributes to the Talanoa Dialogue at COP24 and future revisions of mitigation targets, and aims at spurring an increase in climate mitigation actions, to close the gap between current emissions projections and required Paris-compatible pathways.

As part of this, we have been researching the potential for countries to scale up climate action in different focus areas. The analysis in this report is relevant to Parties considering revisions to their Nationally Determined Contributions (NDCs) to be submitted under the Paris Agreement by 2020, and also to their submission of long-term low greenhouse gas development plans, also due by 2020.

The result is our **Scaling Up Climate Action** country series, which identifies options for increased sectoral action that would move a country towards a pathway compatible with the Paris Agreement's long-term temperature limit and estimates the impact of those actions on emissions and other benefits.

The first round of our analysis covers **South Africa**, the **European Union**, **Indonesia**, **Turkey**, **Argentina**, and **Australia**.

The consistent method and similar structure for all six reports allows for country-specific insights, while enabling a cross-country comparison to draw general research findings and lessons learnt on global potentials.

www.climateactiontracker.org/publications/scalingup

Executive summary

Introduction and objectives

Under the Paris Agreement, governments have committed to holding temperature increase well below 2°C above pre-industrial levels and to pursue efforts to limit this to 1.5°C. Current efforts globally are by far insufficient: aggregate mitigation targets, according to Climate Action Tracker (CAT) estimates, result in global warming of about 3.2°C (Climate Action Tracker, 2017c). Implementation of the targets is falling short, with greenhouse gas (GHG) emissions under implemented policies leading to an estimated warming of around 3.4°C.

To stay below the Paris Agreement's 1.5°C limit, the IPCC Special Report on 1.5℃ finds that a very substantial increase in effort is required to peak global GHG emissions as soon as possible, reduce CO_2 emissions to net-zero around 2050 and total GHG emissions shortly thereafter (IPCC, 2018a).

This limit is highly relevant also for the EU: the IPCC Special Report on Global Warming of 1.5°C found that limiting warming to 1.5°C will reduce the negative impacts, e.g. from heat extremes (including heat waves and droughts) especially in Southern and Eastern Europe, or heavy precipitation in Northern European countries.

Rapidly falling technology costs, as well as increased awareness for other benefits, such as air quality improvements and employment benefits in low-carbon-oriented sectors, have made measures to reduce GHG emissions more attractive to policy makers and private investors.

We no longer live in a world where climate change mitigation is a burden per se, but where it increasingly becomes the most feasible option when considering all socio-economic aspects. For cost-efficient global mitigation, it will be essential to make those mitigation actions accessible to and overcome remaining barriers in all countries.

This report, the second country assessment in the Climate Action Tracker's Scaling Up Climate Action Series, analyses areas where the European Union could accelerate its climate action. The report illustrates GHG emissions reductions from such actions, along with other benefits.

Our analysis starts with an in-depth review of the European current policy framework and sectoral developments, comparing them with the comprehensive policy packages and the progress for sector indicators required under Paris Agreement-compatible pathways.

The report then focuses on three areas we have identified with promising potential to increase mitigation efforts and achieving a wide range of benefits: electricity supply, residential buildings, and passenger road and rail transport.

It identifies different options of accelerated climate action in each sector informed by insights from three categories: (1) studies and scenarios from EU institutions and EU based research institutes ("National Scenarios"), (2) practices implemented by regional or international frontrunners, and (3) sectoral developments in line with the Paris Agreement's long-term temperature limit.

1 **EU** SCENARIOS

2 **BEST IN CLASS** SCENARIOS

3 **1.5°C PARIS AGREEMENT COMPATIBLE** SCENARIOS

Sector transitions towards zero-carbon

In the EU, there is tremendous potential to scale up climate action in the three focus areas analysed in this report: electricity supply, residential buildings, and passenger road transport. Increasing climate action would initiate sectoral transitions towards a zero-emissions society relying on existing technologies while reducing reliance on energy imports, reducing air pollution, and creating additional employment.

Electricity supply

A swift transition away from fossil fuels towards renewables in the EU is essential for EU climate policy to be compatible with efforts to limit global warming to 1.5°C below pre-industrial levels, as established in the 2015 Paris Agreement.

Our findings for the EU show that under scenarios developed by European research institutions the share of renewables in the electricity sector could increase to between 45–60% in 2030 and 63–98% in 2050, leading to emissions reductions of between 77–99% below 1990. Accelerating the deployment of renewables in the sector to levels similar to that in Denmark between 2009 and 2015 would result in increasing the share of RES-E to 76%–95% in 2050 with corresponding emissions reduction by 89–98% in comparison to 1990.

The recent projections show the share of RES-E increasing to only 43% in 2030 and 55% in 2050. However, these projections don't yet reflect the most recent policy changes, especially the reform of the EU ETS and the adoption of the renewable energy directive (RED II).

The importance of the electricity sector as an enabler of decarbonisation in other sectors, combined with the decreasing costs of renewables, requires accelerated action leading to full decarbonisation of this sector by the middle of the century at the latest, with coal phased out by around 2030 in all EU member states.

Strengthening the EU Emissions Trading Scheme (EU ETS) post 2020, combined with the adoption of the Renewable Energy Directive II, as well as important developments in many EU member states to phase out coal in electricity generation, are steps in the right direction.

To be compatible with the Paris Agreement, the EU needs to exceed its renewable energy goal of 32% for 2030, which would result in increasing the share of RES-E to 55%, to allow for the share of renewable electricity to reach between 59–75% levels by 2030 and reach full decarbonisation by 2050.

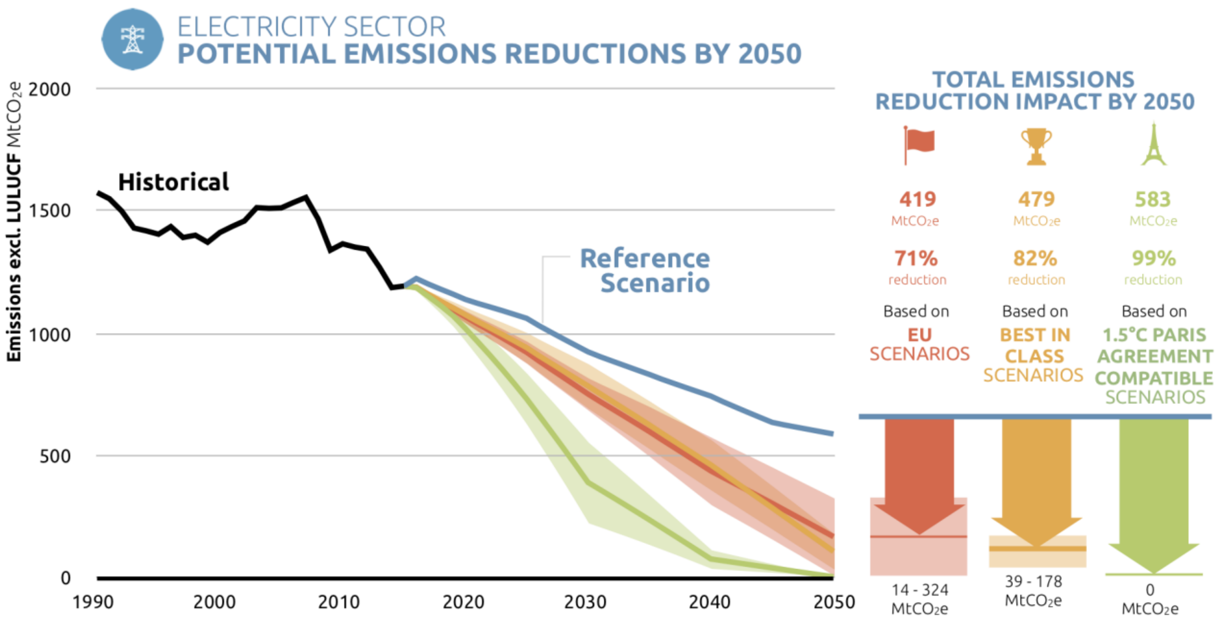


Figure 1: Overview of sectoral emission pathways under reference scenario and different levels of accelerated climate action in the European electricity supply. All sectoral projections towards 2050 done with the CAT PROSPECTS EU scenario evaluation tool. The electricity-related emissions from end-use sectors are included.

While replacing fossil fuels with renewables is essential for decarbonising the transport and buildings sectors, sectoral integration would also make it easier to increase a significantly larger share of variable renewables in the electricity sector. For this reason, accelerated action in this sector must be accompanied by stepping up action in the passenger road transport and residential buildings sectors.

Residential buildings

It is essential that the EU reduces emissions in the buildings sector in line with the Paris Agreement temperature limit. This is due to the long-term impact of existing buildings on future emissions, and the overall volume of emissions from this sector. With the renovation rate at around 1%, a variety of different Nearly Zero Emissions Buildings (NZEBs) standards for new buildings in different member states, and different depths of renovation, the EU needs to scale up action in this sector.

Applying best-in-class levels, currently adopted in Denmark, for energy consumption in new buildings at 20 kWh/m^2/year, renovation rates of between 1.5%–2%, efficiency improvement of renovated buildings between 45% and 89%, and average efficiency improvement of appliances between 1.5% and 1.8%, would result in emissions from the buildings sector decreasing by 52%–62% in 2030 and 76%–87% in 2050 below 1990 levels. Similar results can be found in a range of scenarios from EU research institutions.

Compatibility with the Paris Agreement requires going significantly beyond these parameters: we have estimated that it means increasing renovation rates to 5% annually, all new and renovated buildings being carbon neutral, and full electrification/phase out of fossil fuels for water and space heating.

The recast of the EU's Energy Performance of Buildings Directive (EPBD) adopted in 2018 requires that in 2050—in addition to all new buildings—all *existing* buildings are NZEBs. However, the suggested renovation rate of 3% is not sufficient to reach this goal and is below the level that is considered by CAT to be compatible with the Paris Agreement. At the same time the Eco-design Directive and the Energy Labelling Regulation make it possible for the Commission to accelerate improvements in the energy efficiency of domestic appliances.

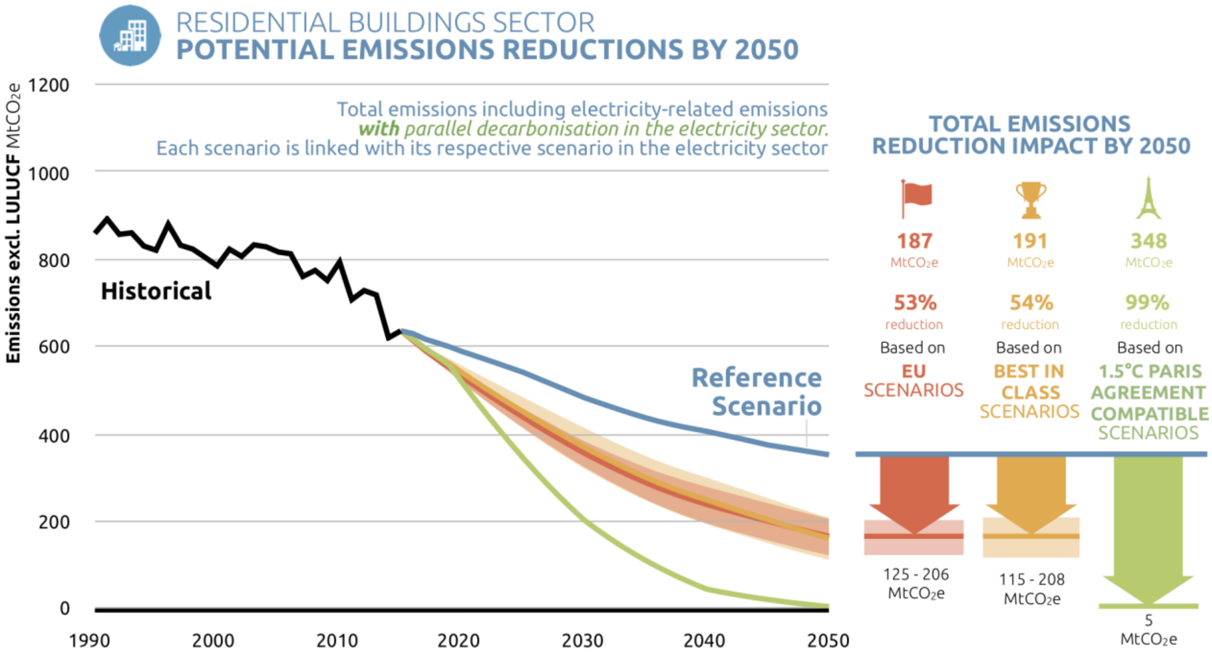


Figure 2: Overview of sectoral emission pathways under reference scenario and different levels of accelerated climate action in residential buildings sector in the European Union. All sectoral projections towards 2050 done with the CAT PROSPECTS European Union scenario evaluation tool.

An energy efficient, decarbonised building sector can also be instrumental in decarbonising the transport sector by powering passenger cars with clean electricity generated on the building's roof, and can also assist in providing advanced electricity management capabilities.

Passenger rail and road transport

The recent trends of increasing greenhouse gas emissions from the transport sector in the EU defy the need to decarbonise the transport sector by mid-century to be compatible with the Paris Agreement. The focus area analysed here looks at emissions from passenger road and rail transport. The main focus is on the impact of transport electrification. While the share of electric vehicles among new sales has been steadily increasing, in the first half of 2018 it remained close to only 2%.

To be compatible with the Paris Agreement, we estimate that the EU's passenger road and rail transport sector needs to be almost fully electrified using low carbon electricity by 2040, with the last new internal combustion car sold before 2035. Such a rapid uptake of electric vehicles will require faster action than scaling up experiences of the zero-carbon transport leader—Norway—to the European level. Decreasing costs of electric vehicles, along with the declaration of some member states to ban the sale of combustion cars, offer an opportunity to meet the Paris Agreement-compatible CAT benchmark. However, electrification of the transport sector needs to be accompanied by full decarbonisation of the electricity sector.

The reference scenario reflects the already adopted emissions standards for 2021 as well as announced policies and targets. The currently discussed target of reducing average emissions from new passenger, and small utility vehicles by at least 35% between 2021 and 2030, complemented with a quota for sales of electric vehicles of 35%, is a step in the right direction, with more stringent targets needed to support a faster transition to zero emissions transport.

Adoption of the proposed Clean Vehicles Directive, which includes minimum targets for clean vehicle procurement (e.g. buses, light duty vehicles) in 2025 and 2030, will accelerate electrification of public transport with benefits going beyond emissions reductions to areas such as health. However, keeping in mind the rapidly changing circumstances, the EU should keep the door open to increasing the respective goals similarly to the upward revision clause in RED II. Additional policies in member states to increase the share of public transport will also contribute to faster emissions reductions in line with the Paris Agreement.

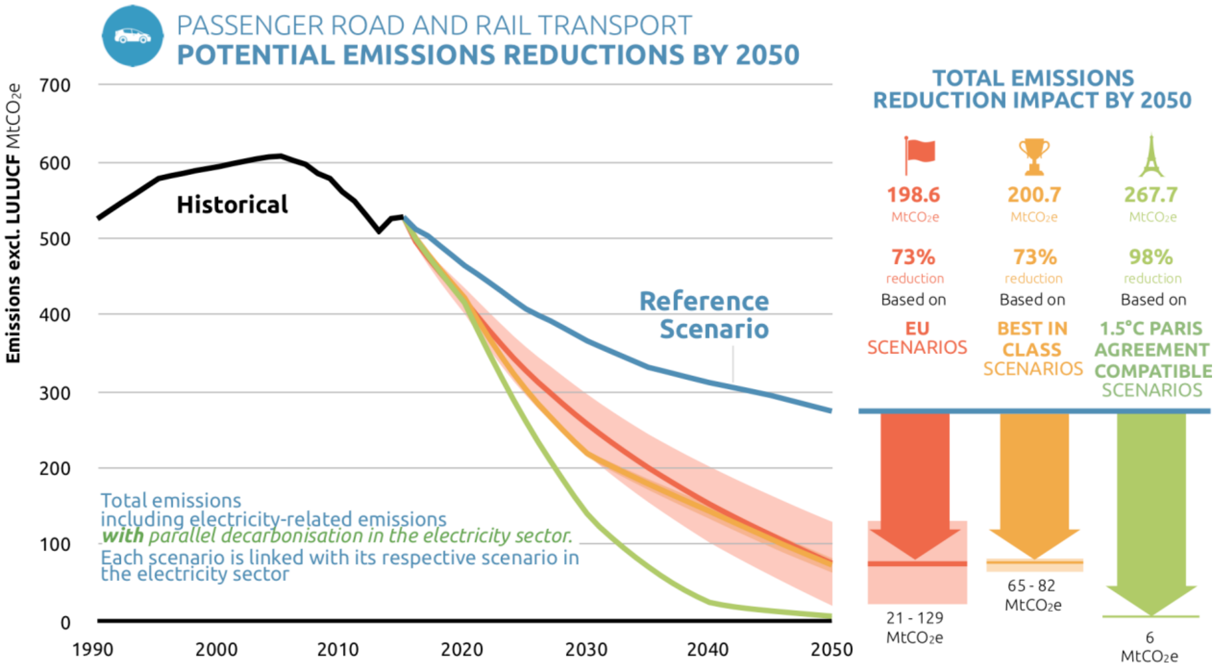


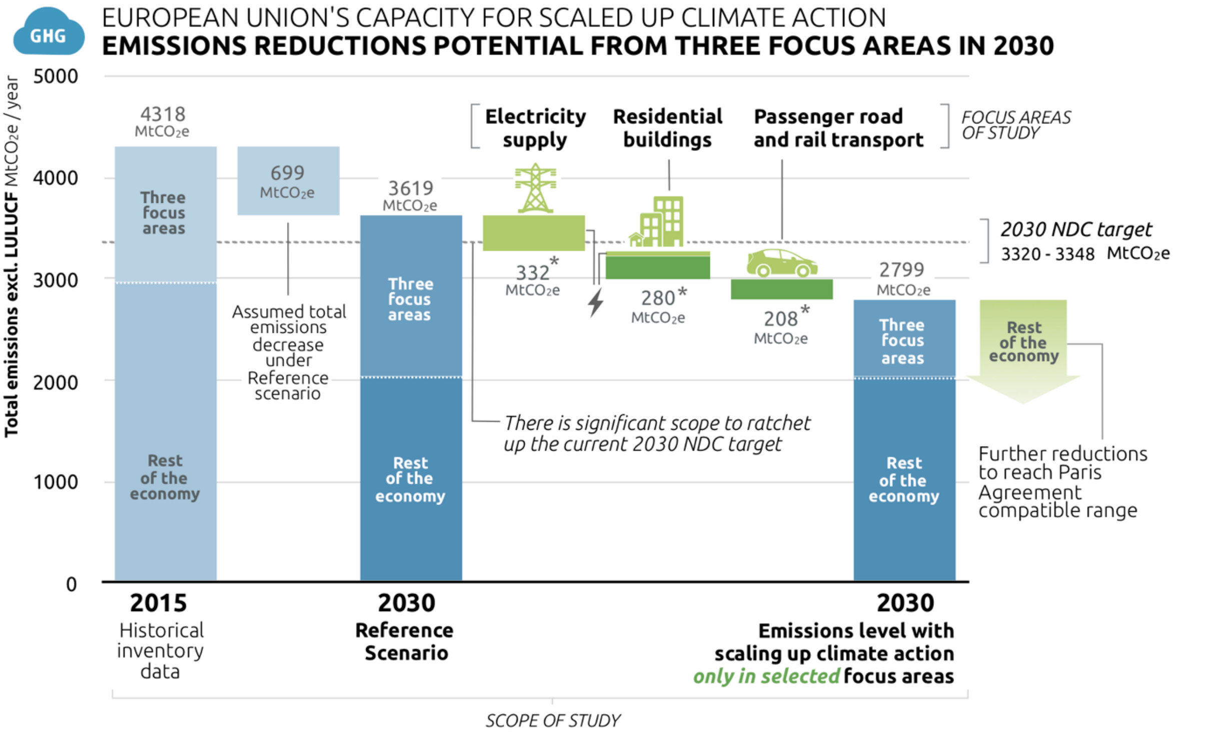
Figure 3: Overview of sectoral emission pathways under reference scenario and different levels of accelerated climate action in passenger road and rail transport sector in the European Union. All sectoral projections towards 2050 done in the CAT PROSPECTS European Union evaluation tool.

Accelerated climate action and the EU's emission reduction targets

Scaling up climate action in the EU's electricity supply, residential building and passenger road and rail transport alone—covering around 60% of total emissions in the EU—can reduce the EU's total greenhouse gas emissions by up to 52% in 2030 below 1990 levels, and 68% in 2050. The report also shows that these three sectors can be fully decarbonised by 2050.

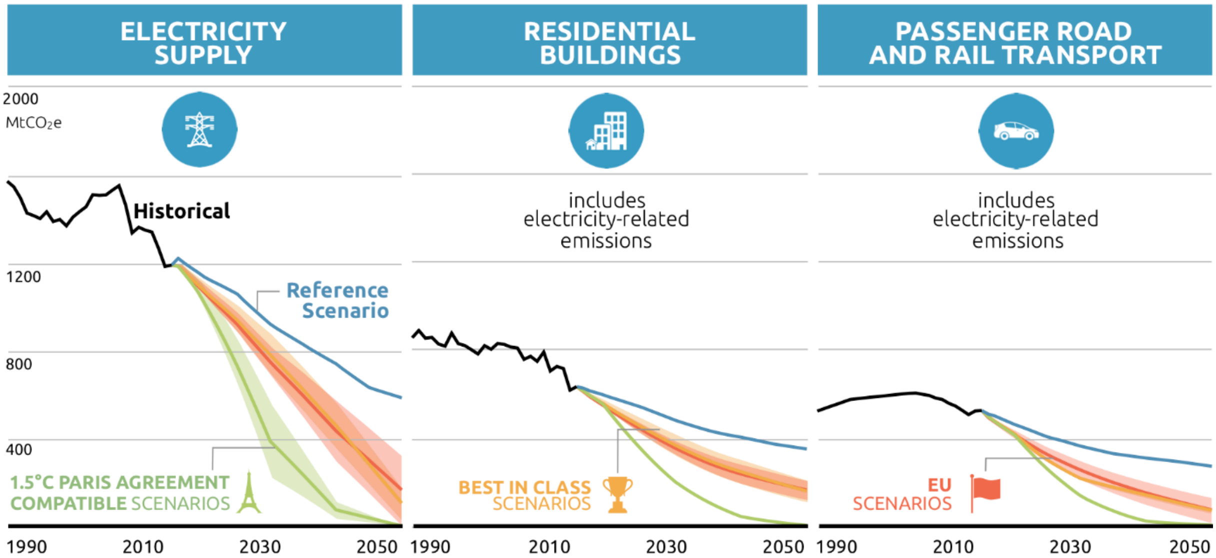
An important conclusion from these findings is that the EU can—and needs to—ratchet up its target for 2030 considerably to be consistent with the Paris Agreement and achieve a wide range of benefits. Corresponding scaled up action in other sectors not analysed in detail in this report is needed to achieve further reductions and a pathway toward an economy-wide decarbonisation by mid-century.

While the EU is already making good progress in the transition of its electricity sector, it will have to scale up action considerably in the buildings and transport sectors.



* Emissions reductions from electricity use are allocated to end use sectors, for example emissions from electricity use in buildings are allocated to the buildings sector and removed from the electricity supply sector total. The lighter green shade represents electricity related emissions. Total reductions from the electricity sector by 2030 equal 390 MtCO2e per year.

SCALING UP CLIMATE ACTION IN THE EUROPEAN UNION
POTENTIAL EMISSIONS REDUCTIONS IN THREE FOCUS AREAS BY 2050



ELECTRICITY SUPPLY

- **Accelerate RES-e growth** to increase share from 43% to at least 60-70% in 2030
- **Measures to support flexibility** of the grid (demand management, storage, Power-To-Gas)
- **Coal phase-out** in all relevant member states by 2030, combined with **just transition policies**

RESIDENTIAL BUILDINGS

- **Increased awareness on benefits of energy efficiency** in housing
- Measures **reducing scale of upfront investment** (e.g. lower interest rates, energy bill repayment schemes)
- **NZEBs standards for new buildings** to avoid carbon lock-in
- **Decarbonisation of space heating** no fossil-fuel based heating should be installed from 2030 on

PASSENGER ROAD AND RAIL TRANSPORT

- **Strenghten emissions standards** from 119 gCO2/vkm in 2016 to 57gCO2/vkm by 2030
- **Ban sales of combustion cars** by 2035 to send a clear signal to cars manufacturers
- **Electrify and double share of public transport** by 2030

Figure 4: Overview of emissions levels under different scenarios for the three focus areas. All electricity-related emissions reductions from the residential buildings and urban transport sectors are allocated as emissions reductions under these two end-use sectors.

The status of sectoral transitions: opportunities for accelerating climate action

The transitions towards zero-emissions in the EU's electricity supply, passenger road and rail transport and, residential buildings sectors have shown different levels of progress, with the decarbonisation of the former the most advanced, and transport and building sectors lagging behind.

Table 1 is an overview of this study's evaluation for the three sectors compared with sector-specific benchmarks. These benchmarks represent the most important short-term steps for limiting global warming to 1.5°C identified by the Climate Action Tracker (Kuramochi et al., 2018). The full results of this analysis for all sectors are detailed in the full report.

Table 1: Summary table for sectoral policy activity and gap analysis in the EU for electricity supply, transport and buildings sector. 1.5°C compatible benchmarks relate to most important short-term steps for limiting global warming to 1.5°C identified by the Climate Action Tracker (Kuramochi et al., 2018).

Sector	1.5 °C-consistent benchmark	Overall evaluation based on policy activity and gap analysis	Policy rating
Electricity supply	Sustain the global average growth of renewables and other zero and low-carbon power until 2025 to reach 100% by 2050	• Based on the implementation of policies adopted before 2015, the share of electricity from renewables is projected to increase from 29% in 2015 to 43% in 2030 and 55% in 2050. • The projections indicate a decreasing rate in the growth of low carbon sources of energy from 7% in the period 2010–2015 to 3.6% in the period 2045–2050. • There is an increasing political will in some EU member states (e.g. Spain, Germany, France, the Netherlands) to accelerate the development of renewables. • While the capacity increased, partly due to the decreasing unit costs, overall investment in renewables decreased in the EU in 2017 to the lowest level since 2006 (BNEF, 2018). • Achievement of the recently-adopted target of 32% share of renewable energy requires increasing the share of renewable power in the EU to around 55% in 2030. • While some EU countries have significantly increased the share of renewables, with Denmark the global leader in integrating variable renewable energy most EU countries need to accelerate action to prepare the power sector for significantly larger share of renewables	Partially Transitioned
	No new coal plants, reduce emissions from coal power by at least 30% by 2025	• There are 288 coal-fired power plants in the EU, with combined installed capacity of around 150 GW. Germany and Poland concentrate 50% of the installed capacity, with Poland still planning to increase coal capacity. • Many member states have a coal-free electricity mix and nine member states—Austria, Denmark, France, Finland, Italy, Portugal, Sweden, the Netherlands and United Kingdom—accounting for 26% of EU coal capacity—have announced phase out dates for coal ahead of 2030. The German government is expected to decide on a phase-out date by end of 2018, and the Spanish government is also discussing phasing out coal. • According to current projections share of electricity from coal is set to decrease from 26% in 2015 to 19.1% in 2025 and 6.2% in 2050 (European Commission, 2016g) • For a Paris Agreement-compatible pathway coal would need to be phased-out by 2030. Therefore, early retirement of current capacity and cancellation of planned capacity is required.	Picking Up Speed
Passenger road and rail transport	Last fossil fuel car sold before 2035	• In the mid-2030s the EU is projected to be a global leader in terms of the share of electric vehicles, expected to reach around 68% of newly-sold cars in 2040. • Ambitious goals to phase out combustion cars introduced in some member states (e.g. Netherlands by 2030, the United Kingdom and France by 2040). • Legislation introducing obligation to install charging stations in all new and refurbished buildings with more than 10 parking spaces. • Increasing share of electric cars in new registrations, from 1.2% in 2015, 1.3% in 2016 to 1.7% in 2017 and projected 2.4% in 2018. • Inter-institutional negotiations on the adoption of stricter emissions standards for passenger cars and vans for 2030 that would also include quotas for the share of low carbon vehicles.	Ambitious Plan

Residential buildings	All new buildings fossil free and near zero energy by 2020	• Emissions from residential buildings are projected to decrease by 25% and 33% by 2030 and 2050 respectively below 2005 levels. Emissions from non-residential buildings are projected to decrease by 33% and 43%, respectively. • Legislation facilitating an increase in energy efficiency in the building sector (Energy Performance of Buildings Directive (EPBD), Energy Efficiency Directive, and Renewable Energy Directive) is in place. • Adoption of a requirement for all new buildings to be near-zero emissions buildings (NZEBs) by the end of 2020. A clear definition of the NZEBs is lacking—the specification was left to the member states.	Picking Up Speed
	Increase building renovation rates from <1% to 5% by 2020	• Most estimates of current renovation rates for the EU are between 0.5% and 2.5% of the building stock/year.	Ambitious Plan

Co-benefits of upscaled climate action: employment in the electricity sector

Accelerated climate action in the European Union can generate significant socio-economic co-benefits. Decreasing reliance on—largely imported—fossil fuels will increase the EU's energy security and reduce cost of energy imports.

With over 400,000 Europeans dying prematurely annually due to air pollution, electrification of transport, higher energy efficiency of the residential buildings and coal-phase out will significantly improve air quality. Ambitious long-term emissions reduction goals will provide European companies with the necessary investment security and domestic market for their products, which can lead to development of new branches of industries, thus contributing to economic growth.

This study's quantification of employment impacts for several electricity supply sector scenarios up to 2030 indicates that scaling up climate change action through increasing renewable energy shares in the electricity sector would also yield substantial employment benefits for the EU.

In all analysed scenarios, the total number of direct jobs in the electricity sector from 2020 throughout 2030 is higher than the estimated total jobs under a reference scenario, with additional jobs created in renewable energy sectors outweighing job losses in fossil-fuel based electricity generation.

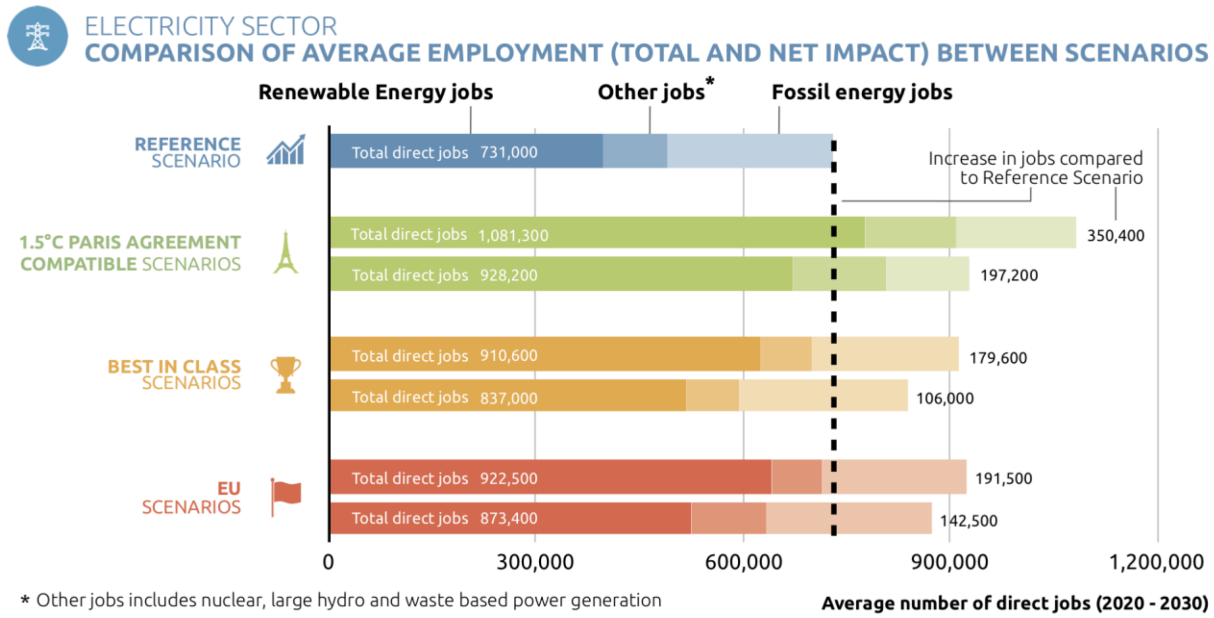


Figure 5: Average employment (total direct jobs) in the electricity sector for different scenarios analysed in this study, in period 2020-2030. The respective net direct employment impact compared to the reference scenario is also shown for each analysed scenario.

The most ambitious scenario in terms of emissions reductions also yields the highest employment benefits over time.

In the most ambitious climate policy scenario—the ‘1.5°C Paris Agreement compatible’ ambitious end pathway—we estimate about 370,000 more direct jobs in 2025 and about 270,000 more direct jobs in 2030 in electricity generation than in the reference scenario. This number would be much higher if indirect jobs were taken into consideration.

For power generation from renewable energy (RE) (excluding large-scale hydro), we estimate almost 400,000 (in 2025) and about 375,000 (in 2030) more direct jobs than under reference scenario, far outweighing job losses in fossil-based technologies. In 2025, the estimated direct job creation in renewable energy is six times higher than the reduction in fossil-based jobs for the same year compared to the reference scenario.

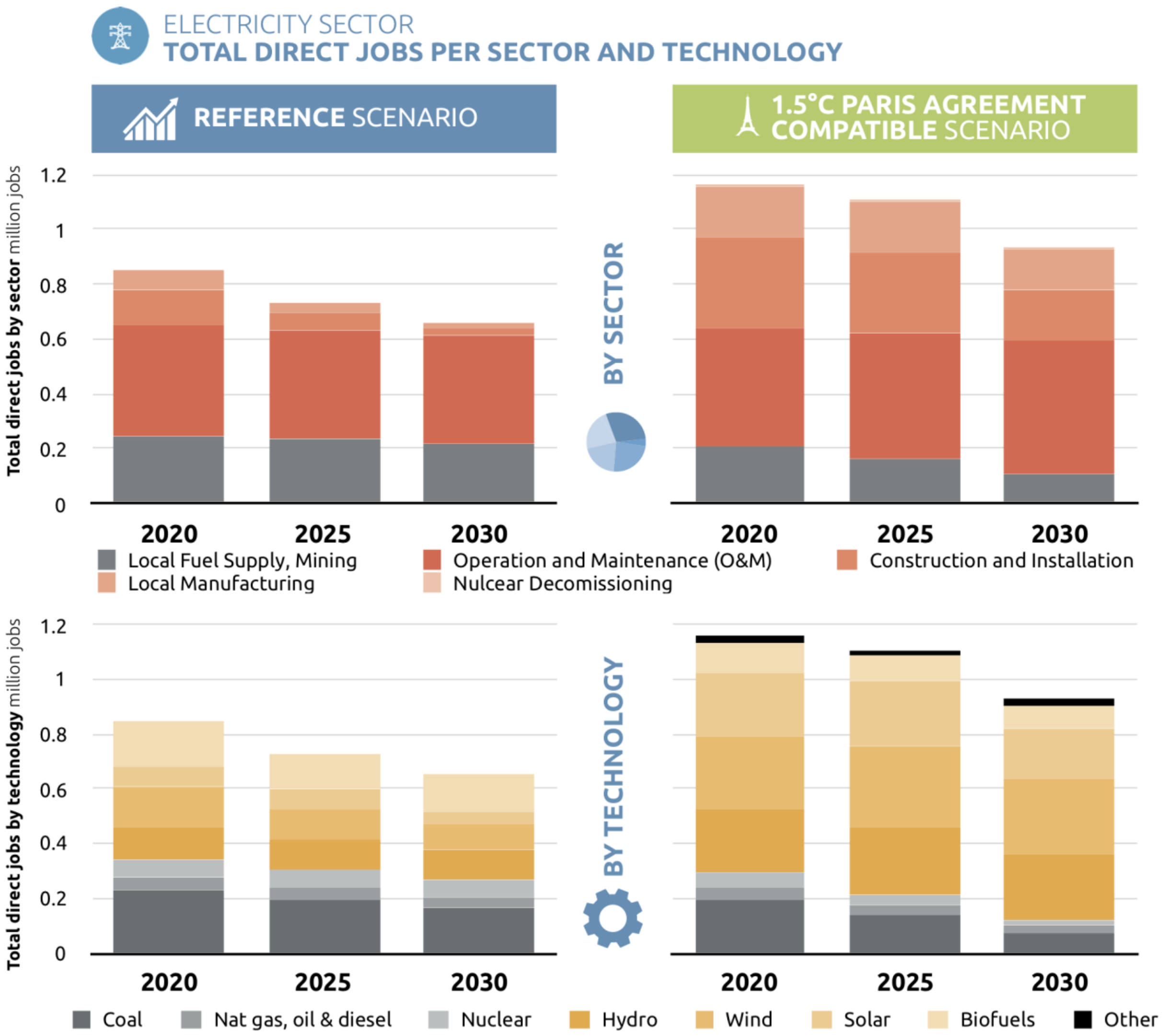


Figure 6: Total direct jobs per employment sector and total direct jobs per generation technology for the reference scenario (graphs on left) and the 1.5°C Paris Agreement compatible scenario (graphs on right) for the EU electricity supply sector. Note: 'other' comprises geothermal, marine and waste.

The benefits in job creation due to climate policy also depend on the choice of technologies to achieve decarbonisation. Wind and solar energy play an important role in both successful decarbonisation and in job creation. The construction and installation of renewable energy facilities is an important driver for job creation in the EU.

Scenarios with a stronger reliance on natural gas or nuclear power create fewer jobs than scenarios that are more ambitious in terms of building up new renewable energy capacities, especially in solar and wind energy, as manufacturing as well as construction and installation of renewable energy facilities is generally more job intensive.

While the number of *local* jobs depends on the share of local manufacturing and bioenergy supply, a sensitivity analysis shows that the employment impact would still remain substantial for lower local shares. At the same time, this also illustrates that measures supporting local expertise and skills for manufacturing and the development of a local manufacturing value chain could support the transition away from coal and the generation of local high quality jobs in the renewable energy sector. The distributed character of renewables may be expected to enhance the impact on the creation of local jobs, especially in rural areas.

Abbreviations

CAP	Common Agricultural Policy
EU ETS	European Union Emissions Trading Scheme
F-gases	Fluorinated Gases
GHG	Greenhouse Gases
GWP	Global Warming Potential
LCOE	Levelised costs of electricity
LULUCF	Land use, land-use Change and Forestry
NDC	Nationally Determined Contribution
RES	Renewable sources of energy
RES-E	Renewable electricity
vRES	Variable renewable sources of energy

Contents

Introduction

Background and objectives

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To stay below the globally agreed limit, the IPCC Special Report on 1.5℃ finds that an increase in efforts is required to peak global GHG emissions as soon as possible, reduce CO_2 emissions to net-zero around 2050 and total GHG emissions shortly thereafter (IPCC 2018a).

In recent years, measures to reduce GHG emissions have, in many cases, become more attractive to policy makers and private investors, both because of falling technology costs, as well as increased awareness for other benefits, such as air quality improvements and employment benefits in low-carbon-oriented sectors.

We no longer live in a world where climate change mitigation is a burden per se, but where it increasingly becomes the most feasible option when considering all socio-economic aspects. For cost-efficient global mitigation, it will be essential to make those mitigation actions accessible to and overcome remaining barriers in all countries.

This report, the first country assessment in the Climate Action Tracker's Scaling Up Climate Action Series, analyses areas where the European Union (EU) could accelerate its climate action. The report illustrates GHG emissions reductions from such actions, along with other benefits.

Approach

The analysis starts with an in-depth review of the EU's current policy framework and sectoral developments, comparing them with the comprehensive policy packages and the progress of the kind of sector indicators required under Paris-compatible pathways.

The report then focuses on three areas we have identified with promising potential to increase mitigation efforts, also considering national and even local circumstances: electricity supply, road passenger transport, and residential buildings.

For these areas, we research different pathways which go beyond current efforts, explain the feasibility of such increased action, and quantify resulting emission reductions and – for the electricity sector - employment benefits. We consider three types of scenarios: (1) Outputs from national research institutions analysing alternative scenarios to current government projections, (2) Paris-compatible benchmarks from international sources such as the IPCC Special Report on 1.5°C (IPCC 2018b) or the CAT's report on short-term steps (Kuramochi et al. 2018), and (3) Best-in-class levels from regional or global frontrunners (compare (Fekete et al. 2015b; Roelfsema et al. 2018).

The external scenarios provide trajectories of sectoral indicators, for example for the share of renewable energy. For the quantification of sectoral and total emission trajectories until 2050, the Scaling Up Climate Action series uses the CAT's PROSPECTS scenario evaluation tool. To estimate domestic employment impacts of different electricity supply sector development, we use a spreadsheet-based economic model developed by NewClimate Institute under the "Ambition to Action" project, the Economic Impact Model for Electricity Supply (EIM-ES).

A methodological annex presenting the tools' methodologies and key assumptions for data filling can be accessed under **www.climateactiontracker.org/scalingup/methodology**.

1 Context for raising ambition in the European Union

Since the 1990s the European Union has been considered the leader in the fight against climate change (Parker, Karlsson, and Hjerpe 2017; Ugur, Dogan, and Aksoy 2016). Already in October 1990 the Council of Environment and Energy Ministers agreed to stabilize the emissions of the Community – the EU predecessor – by the year 2000 at the 1990 levels under the conditions that “other leading countries undertake similar commitments” (Council of the European Communities 1993). During the negotiations that led to the adoption of the Kyoto Protocol, the EU agreed to take on a more ambitious target of reducing emissions by 8%, much higher than the average 5% for the industrialized countries. It has also pushed for the adoption of the Kyoto Protocol after the US decision to withdraw in 2002 (Afionis 2017). While adopting its 2020 emissions reduction target of 20% in 2008 (together with corresponding renewable Energy and energy efficiency targets) the European Council expressed its willingness to increase it to 30% if an ambitious and comprehensive global agreement on climate change was agreed in Copenhagen in the following year (Council of the European Union 2008). To implement the 2020 target, the European Union has developed a comprehensive package of legislation across sectors, including renewable energy directive with binding Renewable Energy targets for member states, energy efficiency directive with binding measures to achieve the goal of increasing energy efficiency by 20% in comparison to projections, and reform of the EU ETS for Phase 3 (2013-2020).

The European Union was also taking the lead in the operationalization of the UNFCCC’s objective of preventing “dangerous anthropogenic interference with the climate system” by setting already in 1996 the limit of 2 degrees warming above pre-industrial levels (The Council of Ministers for Environment 1996). The EU was also instrumental in including a reference to this temperature limit in the Copenhagen Accord and Cancun Agreements (UNFCCC 2009, 2011). As one of the leading members of the High Ambition Coalition, the EU helped to strengthen the temperature limit to 1.5°C in the Paris Agreement (European Commission 2015b).

To reduce the increasing discrepancy between ambitious goals and their implementation (Britta Labuhn 2011), the EU adopted an encompassing set of policies aiming at emissions reduction in different sectors (Delreux and Happaerts 2017). Adoption of support policies for renewable sources of energy by the member states as required by directive 2001/77/EC, as well as introduction of the EU Emissions Trading Scheme (EU ETS) in 2005, contributed to emissions reduction, except for in 2010 when economic recovery has led emissions to increase by 2.7%.

However, since then a series of crises distracted the EU, which initiated the Euro crisis following the 2008/2009 financial meltdown; all from the refugee crisis to Brexit and the discussions about the future of the EU. In the second decade of the 2000’s there was a noticeable lack of engagement from the most influential EU member states such as Germany, France and the Netherlands - quite opposite that of the first decade (Bals et al. 2014). At the same time, some Eastern European Countries, especially Poland, blocked any attempts to significantly increase the level of ambition of the EU climate policy. In 2011 the Commission came forward with two documents presenting EU’s long term energy and climate policy: the Roadmap for moving to a competitive low carbon economy in 2050 indicated emissions reduction by 80% by the middle of the century in comparison to 1990 (European Commission 2011a), whereas the Energy Roadmap 2050 referred to the goal of emissions reduction by 80-95% already adopted by the Council in 2009. The latter goal was made conditional on similar action by developed countries (Council of the European Union 2009b; European Commission 2012). Both documents were rejected by the Polish government (Ancygier 2013; Council of the European Union 2012).

The threat of another veto limited EU’s readiness to adopt much higher emissions reduction goals for 2030 (Global News 2014). While at the end, in October 2014 all EU member states agreed to a goal of reducing EU’s emissions by “at least 40%” in 2030 in comparison to 1990 (European Council 2014), already by then EU’s emissions decreased by around 22% (EEA 2018b) while the rapid decrease in the costs of renewables could accelerate emissions reduction in the future. But for the EU the trend of decreasing emissions reversed in 2015 when the emissions increased by 0.7%. After a slight decrease by 0.6% in 2016, EU’s emissions increased in 2017 by 0.56% (European Environment Agency 2018) .

In late 2016 the Commission presented a package of proposals titled "Clean energy for all Europeans" with a number of measures that would allow it to reduce emissions by at least 40%, increase the share of renewables to 27% and improve energy efficiency by 27% in 2030 (European Commission 2016b). During the interinstitutional negotiations that ended in June 2018 the renewable energy and energy efficiency goals have been increased to 32% and 32.5% respectively (European Parliament and the Council of the European Union 2018e, 2018f). The CAT estimates that if those targets are implemented it would result in emissions reduction of 47.5%-49.7% below 1990 levels – above the European Commission estimates of about 45% (Climate Action Tracker 2017a). In early 2019 the Commission will also present a proposal for a long-term emissions reduction strategy that reflects the adoption and ratification of the Paris Agreement (Council of the European Union 2018a).

The new goals are yet to be reflected in the practical measures to reduce emissions. The projections of the European Environmental Agency based on member states' projections based on policies adopted until 2016 – and for some countries 2017 - indicate emissions to decrease by 0.73% annually between 2015-2030 with existing measures and 0.92% in the same period with additional measures (EEA 2017b). This is below the average rate of decrease since the beginning of the century, which was slightly above 1% (Eurostat 2018j). This slowdown of emissions reductions indicates an urgent need for new policies that would allow the EU to live up to its potential and ambition as the leader in climate action and to reflect the new targets for Renewable Energy and Energy Efficiency.

This need is strengthened by the increasingly negative impacts of climate change on the European countries. Over the period 1980-2016 climate-related extreme weather events accounted for €436 billions of economic losses in the EEA countries (which in addition to the EU member states also includes Iceland, Lichtenstein and Norway) (EEA 2018a). While an exact attribution of the extreme weather events to climate change is challenging (National Academies of Sciences Engineering and Medicine 2016), there is a general agreement that a warmer climate will change precipitation patterns in Europe by making wet regions in Europe wetter, and dry regions drier. An increase in extreme flooding events and the number of drought hotspots has already been observed in the European countries (EEA 2016). A significant threat to the low-lying areas in Europe results from the rising sea level. While all coastal regions have experienced an increase in absolute sea level, the northern Atlantic and Baltic Sea coast experience considerable land rise due to post-glacial rebound. This does not include the most populous areas, such as coastal parts of Netherlands or Belgium, where the relative sea level rise has been occurring at between 2-4 mm annually in the period 1970-2015 (EEA 2017a). It is projected that the speed of the sea level rise will accelerate significantly leading to an overall increase in the sea level by between 0.26 and 0.83 meters in 2100 (IPCC 2013).

Population in the EU countries are made more susceptible to the rising temperatures, especially in the cities, due to an increasing share of the ageing population and progressing urbanization (EEA 2016). The EU will also be affected by the impacts of climate change on non-European countries. While trade in agricultural products will be influenced by climate-related crop price volatility (EEA 2016), a significant increase in the streams of migration resulting from more heatwaves, droughts, floods and rising sea levels (Missirian and Schlenker 2017), may have significant political and social repercussions.

An accelerated reduction in emissions would result in significant co-benefits. With almost 54% of energy used in the EU coming from imports, decreasing reliance on fossil fuel could reduce EU's energy dependence and thus the energy bill, which in 2017 amounted to €272 billion (Eurostat 2018d, 2018f). Climate change mitigation would also have a positive impact on air quality and significantly reduce the number of premature deaths attributable to air pollution currently estimated at around 0.5 million (European Environment Agency 2017a). Replacement of combustion cars by electric alternatives and clean public transport, improving energy efficiency of the building sector and decarbonisation of electricity generation would help to reduce the issue with the smog, which costs the EU around 2.9% of its GDP every year and save Europeans at least €185 billion between 2018 and 2025 (InnoEnergy 2018). Finally, accelerated development of renewables would lead to about 350.000 more direct jobs in the electricity sector in the EU between 2020 and 2030[1] and lead to development of new industries, thus contributing to lasting and sustainable economic growth.

Overarching climate policies targeted at reduction of GHG emissions, such as national climate strategies or national emission reduction targets, aim to align and coordinate sectoral climate action of the member states. But so far neither the historical, nor the projected rate of emissions reduction will allow the EU to meet its obligations resulting from the adoption of the Paris Agreement.

Table 2 provides an overview of the EU's major climate change policies.

Table 2: Overview of implemented climate change policies in the EU (as of November 2018)

GHG OVERARCHING CLIMATE CHANGE POLICIES OF THE EUROPEAN UNION

GHG reduction targets

- **EU 2020 emissions reduction target:** In January 2010, the EU and its member states confirmed their willingness to be associated with the Copenhagen Accord with the 20% emissions reduction target by 2020 compared to 1990 levels. They also repeated their offer to increase this goal to 30% conditional on comparable emissions reduction by developed countries (Council of the European Union 2010).
- **EU 2030 emissions reduction target:** In October 2014 the EU's heads of states adopted a goal reducing emissions by "at least 40%" in comparison to 1990 (Council of the European Union 2014). This target was also included in the EU's Intended National Determined Contribution (INDC) submitted in March 2015 (European Council 2015). The adoption of the more ambitious renewable energy and energy efficiency targets in June 2018 would result in emissions reduction of between 47.5 – 49.7% (Climate Action Tracker 2017a), however at the time of writing no decision on an updated NDC target has not been formally adopted by the EU's heads of the states.
- **EU 2050 emissions reduction target:** European Council adopted an objective of emissions reduction by 80-95% in 2050 in its position for the Copenhagen Climate Conference in December 2009. This level of emissions reduction was to take place "in the context of necessary reductions (…) by developed countries as a group" (Council of the European Union 2009a, 2009b).

Climate Change Packages, Strategies and Roadmaps

- **2020 Climate and Energy Package** presented by the European Commission in January 2008. It included proposals of legislation aiming at reaching the emission reduction targets as well as renewable energy and energy efficiency targets ("20-20-20 targets") adopted by the European Council in March 2007. After a compromise reached in December 2008, these proposals were adopted by the European Parliament and the Council in early 2009 (Council of the European Union 2007, 2008; European Commission 2008). This goal was divided into 21% emissions reduction in the EU ETS sector and 10% emissions reduction in the non-EU ETS sector in comparison to 2005.
- **2030 Climate and Energy Framework** included a "Winter Package" consisting of five regulations, four directives and two decisions presented by the European Commission under the heading "Clean energy for all Europeans" in November 2016. Those measures, as well as the reform of the EU ETS and the division of the non-EU ETS emissions reduction goal between the EU member states in the Effort Sharing Regulation, aimed at reaching the targets adopted by the Council in October 2014. After lengthy negotiations between the European Parliament and the Council, most of the legislative proposals were adopted in 2018 (Council of the European Union 2014; European Commission 2016a).
- **A Roadmap for moving to a competitive low carbon economy in 2050** and **Energy Roadmap 2050** included emissions reductions targets by 80% and 80-95% respectively (European Commission 2011a, 2012). Differently from the aforementioned 2020 Package and 2030 Framework, these documents didn't find expression in EU's binding documents, but were used for the adoption of the 2030 targets. At the time of writing the EU is discussing Commission's proposal of the EU's long-term strategy which includes emissions pathways resulting in net zero greenhouse gas emissions in 2050 (European Commission 2018a).

Relevant EU institutions

- **DG CLIMA (Directorate-General CLIMA)** is a department of the European Commission responsible for developing and carrying out Commission's policies on climate action. However, other DGs are also contributing to this policy.
- **ENVI Committee** (Committee for Environment, Public Health and Food Safety) of the European Parliament is drafting and adopting resolutions relevant to climate change policy which are later discussed, amended and voted upon by the plenary.
- **Council of the European Union** (also referred to as "European Council") adopts general goals in terms of emissions reduction and decides about the overall direction of the European energy and climate policy. These goals are the basis of legislative proposals prepared by the **European Commission** and adopted by the **Council of Ministers** and the

[1] This refers to the estimated net employment impact in the electricity sector comparing the estimated direct jobs averaged over 2020 to 2030 for the most ambitious 'Scaling up climate action' scenario with the reference scenario (see section 4.1.2.3).

European Parliament.

Financing domestic climate action

- In February 2013 the EU heads of states agreed that at least **20% of the EU spending in Multiannual Financial Framework (MFF) 2014-2020 should be spent on the achievement of the climate action objectives** (European Council 2013). This would amount to around €206 billion. While share of the climate funding increased from 13.6% to 19.8%, the EU is set to miss this goal (European Commission 2018k). European Commission proposes increasing the share of the EU spending dedicated to climate action in the **MFF 2021-2027 to 25**% (European Commission 2018b).
- **NER300 Programme** funds investment in low-carbon energy demonstration projects from the sale of 300 million emissions allowances (European Commission 2018g). The reform of the EU ETS (see below) extended this programme under the name **Innovation Fund**, which should be funded from the sale of 450 million emissions allowances (European Parliament and the Council of the European Union 2018a).
- The **Modernization Fund** aims at modernizing the energy sector, improvement of energy efficiency and electrification of other sectors, e.g. transport. It will be fed from the auctioning of 2% of allowances in the period 2020-2030. The funding will only be available to those member states, whose GDP per capita in market prices in 2013 didn't exceed 60% of the EU's average (European Parliament and the Council of the European Union 2018a).
- **Horizon 2020** funds research and innovation in a number of areas, including climate action (European Commission 2018f).

EU ETS Covers around 45% of the EU's emissions mainly from the power sector and large industrial plants	Non-EU ETS Covers remaining emissions, mainly from the buildings, transport and agriculture sectors, with separate treatment of LULUCF
• Entered into force on 2005 based on directive 2003/87/EC (European Parliament and the Council of the European Union 2003). • Reform of the EU ETS adopted in 2009 implemented the -21% emissions reduction by 2020 (in reference to 2005) as part of the EU's overall 20% emissions reduction. For this purpose, emissions were to decrease by 1.74% annually (European Parliament and the Council of the European Union 2009e). • Decision 2015/1814 aimed at solving the issue of significant oversupply of emissions allowances by creating Market Stability Reserve (MSR). According to it, 12% of the allowances of circulation were to be placed in the reserve starting in 2019 as long as their amount exceeds 833 million (European Parliament and the Council of the European Union 2015a). • Reform of the EU ETS from March 2018 prepared a groundwork for the EU ETS functioning after 2020. It accelerated the decrease of emissions cap to 2.2% after 2020 which should lead to emissions reduction by 43% in comparison to 2005 by 2030 (in line with targets agreed in October 2014). The share of allowances that were transferred to the MSR in case of oversupply was doubled in years 2019-2023.	• To achieve emissions reduction in the non-EU ETS sectors by 10% by 2020 in comparison to 2005, Decision 406/2009/EC on effort sharing included specific emissions reduction targets for each EU member state. The specific targets ranged from +20% for Bulgaria to -20 for Denmark, Ireland, and Luxembourg (European Parliament and the Council of the European Union 2009a). • In May 2018 Effort Sharing Regulation distributing the 30% emissions reduction goal for 2030 (in comparison to 2005) entered into force. The national targets range from 0% Bulgaria to -40% for Sweden. The Regulation allows for the utilization of up to 280 million tonnes of CO_2 equivalent (cumulative for the whole period and all member states) from the removals in the land use, land-use change and forestry (LULUCF) sector to achieve the emissions reduction goals (European Parliament and the Council of the European Union 2018h). • While not covered by the Effort Sharing Regulation, climate action in the land use, land-use change and forestry (LULUCF) sector has an impact on climate mitigation. According to this Regulation 280 $MtCO_2e$ from the LULUCF can be used throughout the whole period and for all EU member states to account for emissions reduction in the non-EU ETS sector (European Parliament and the Council of the European Union 2018g, 2018h).

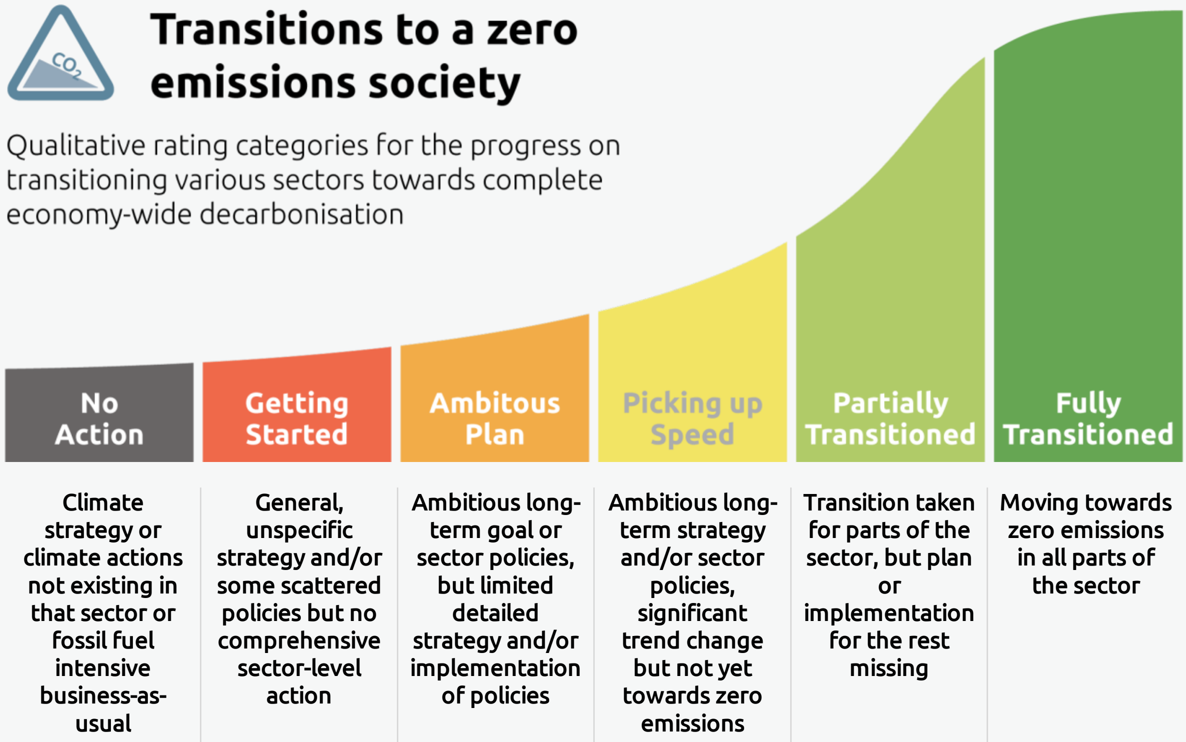
Changing activity	Energy efficiency	Renewables	Non-energy
• The governance regulation introduces the requirement for the member states to submit their national energy and climate plans every five years. In addition, every two years they should also submit reports summarizing their progress in the implementation of those plans. By 1 January 2020 member states should also present their long-term strategy with a time horizon of at least 30 years (European Parliament and the Council of the European Union 2018i).	• Directive 2012/27/EC operationalized the goal of reducing energy consumption in 2020 by 20% in comparison to the projections. As a result, the EU's energy demand should decrease to 1,483 Mtoe and 1,086 Mtoe of primary and final energy, respectively (European Parliament and the Council of the European Union 2012). • In 2018 the energy efficiency directive was amended to include more ambitious emissions reduction target of improving energy efficiency by 32.5% in 2030 which should result in primary energy consumption below 1,273 Mtoe and final energy consumption below 956 Mtoe (European Parliament and the Council of the European Union 2018c). • The Ecodesign Directive creates a framework for the adoption of minimum mandatory requirements for the energy efficiency of household appliances (European Parliament and the Council of the European Union 2009b) .	• Directive 2009/28/EC operationalized the goal of increasing the share of renewables in the energy sector to 20%, with individual, binding RES targets for each EU member states (European Parliament and the Council of the European Union 2009c). • In 2018 a compromise was reached concerning a recast of the renewable energy directive from 2009. The new directive operationalizes the goal of increasing the share of renewables in the energy sector to 32% in 2030. Depending on the future developments, this goal can be increased upwards in 2023. It also includes a goal of increasing the share of final energy consumed in the transport sector to 14% (European Parliament and the Council of the European Union 2018d).	• Regulation on LULUCF adopted in May 2018 introduces a "no-debit" rule requiring member states to ensure that GHG emissions from the sector are compensated by at least an equivalent removal of CO2 from the atmosphere (European Parliament and the Council of the European Union 2018g). • F-Gas Regulation binding since January 2015 introduces the goal of reducing the sale of F-gases in the EU by 80% between 2014 and 2030. It also bans their utilization wherever less harmful alternatives are available (European Parliament and the Council of the European Union 2014d).

2 Overview of the EU's climate policy actions and gaps

This chapter provides a comprehensive overview of existing and planned climate policies in the European Union and some of the member states. It is divided into five subsections with each describing a specific sector, starting with electricity, through transport. Buildings, industry and finishing with land use, land-use change and forestry (LULUCF). Each of the sectoral subsections is further divided into four parts. A first part of each of the subsections presents the most important short-term steps for limiting global warming to 1.5°C identified by the Climate Action Tracker for a specific sector (Kuramochi et al. 2018). A second part investigates the most important policies aiming at emissions reduction in a given sector. Subsequently, the benchmarks and policies are compared for each sector. This comparison is complemented with some recommendations for further emissions reduction in a specific sector.

Box 1 Qualitative policy rating for sectoral transition to zero-emissions society

The qualitative analysis of policy activity and ambition of this analysis for the EU results in a rating of each sector. The rating aims to reflect the sector's current transition state towards 1.5°C Paris Agreement compatibility. For this purpose, the rating accounts for existing sectoral long-term strategies and/or policies, their status of implementation, as well as the general state of transition of the sector under analysis.



The policy ambition analysis compares historical and projected developments under current policies to the global indicators without any further adjustments of the indicators to country-specific circumstances, such as for example the respective capabilities of countries. The policy ambition analysis mainly provides an indication to which degree current trends in each sector align with required steps on a global level and presents a standardised approach for all countries analysed in the CAT Scaling Up Climate Action series. The in-depth analysis in Section 2 addresses country specific circumstances and considerations for the European Union and specific sectors.

Key findings of policy activity and policy ambition analysis

Table 3 summarises the key findings of the policy activity and gap analysis for each of the focus areas and the respective sectoral benchmarks. The qualitative rating evaluates the current sectoral status in transitioning to 1.5°C Paris Agreement compatibility.

Table 3: Summary table for sectoral policy activity and gap analysis for the European Union.

Sector	1.5 °C-consistent benchmark	Overall evaluation based on policy activity and gap analysis	Policy rating
Electricity sector	Sustain the global average growth of renewables and other zero and low-carbon power until 2025 to reach 100% by 2050	• Based on the implementation of policies adopted before 2015, the share of electricity from renewables is projected to increase from 29% in 2015 to 43% in 2030 and 55% in 2050 (European Commission 2016e). • The projections indicate decreasing rate in the growth of low carbon sources of energy from 7% in the period 2010-2015 to 3.6% in the period 2045-2050. • While decreasing role of nuclear energy will slow down decrease of emissions, it will make grid more flexible and will make it easier to integrate higher share of renewables earlier. • There is an increasing political will in some EU member states (e.g. Spain, Germany, France, the Netherlands) to accelerate the development of renewables. • In 2017 the new installed capacity in renewable sources of energy amounted to 23.9 GW and represented 85% of all new installations in energy sector (WindEurope, 2018). • Achievement of the recently adopted target of 32% share of renewables requires increasing the share of renewable power in the EU to around 55% in 2030 (European Commission 2018i). This is almost twice as high as the share of RES-E in 2017 at 30% (Agora Energiewende and Sandbag 2018). • While the capacity increased, partly due to the decreasing unit costs, overall investment in renewables decreased in the EU in 2017 to the lowest level since 2006 (BNEF, 2018). • While some EU countries have significantly increased the share of renewables, Denmark is a global leader in integrating variable renewable energy, and many EU Member States are advanced compared to other countries (IEA 2018), most EU countries need to accelerate action to prepare the power sector for significantly larger share of renewables.	Partially Transitioned
	No new coal plants, reduce emissions from coal power by at least 30% by 2025	• There are 288 coal-fired power plants in the EU, with combined installed capacity of around 150 GW. Germany and Poland concentrate 50% of the installed capacity. • In July 2018 coal power generation units with a combined capacity of almost 10 GW were planned in the EU28, mostly in Poland (6.2 GW) and Germany (2 GW). Plants with a combined capacity of almost 7 GW are currently under construction: 3.4 GW in Poland, 1.1 GW in Germany and 660 MW in Greece and Czechia, each (Endcoal 2018). • Many member states have a coal-free electricity mix and nine member states - Austria, Denmark, France, Finland, Italy, Portugal, Sweden, the Netherlands and United Kingdom— accounting for 26% of EU coal capacity have announced phase out dates for coal ahead of 2030. The German Government is expected to decide on a phase-out date by end of 2018. • According to current projections share of electricity from coal is set to decrease from 26% in 2015 to 19.1% in 2025 and 6.2% in 2050 (European Commission, 2016g). • An increasing number of countries announcing dates of coal phase-out while some capacity increase is planned, especially in Poland. • For a Paris Agreement-compatible pathway coal would need to be phased-out by 2030. Therefore, early retirement of current capacity and cancellation of planned capacity required.	Picking Up Speed

Transport sector	Last fossil fuel car sold before 2035	• In the mid-2030s the EU is projected to lead globally in terms of the share of electric vehicles. Their share is expected to reach around 68% of newly sold cars in 2040 (BNEF, 2017). Ambitious policies introduced in some member states (e.g. Netherlands by 2030 (Dutch Government, 2017), the United Kingdom and France by 2040 (WEF, 2017). • Legislation introducing obligation to install charging station in all new and refurbished buildings with more than 10 parking spaces (European Parliament and the Council of the European Union 2018c). • Increasing share of electric cars in the new registrations, from 1.2% in 2015, 1.3% in 2016 to 1.7% in 2017 and projected 2.4% in 2018 (EV-Volumes, 2018). • Interinstitutional negotiations about the adoption of stricter emissions standards for passenger cars and vans for 2030 that would also include quotas for the share of low carbon vehicles. • Lack of European approach to the phase out of combustion cars or policies encouraging increasing the share of electric vehicles resulting in a piecemeal approach.	Ambitious Plan
	Aviation and shipping: Develop and agree on a 1.5°C compatible vision	• Depending on the level of demand, emissions from the EU aviation sector are projected to be between -11 and +101% of the 2015 levels in 2035. (EASA, EEA, and EUROCONTROL 2016). • Emissions from the intra-EU aviation are projected to increase by 55% in the same period (+42% by 2030 and +94% by 2050) (European Commission 2016d). • Adoption of the goal of capping aviation emissions at 2018-2019 levels in the framework of the CORSIA mechanism (2021-2027, post 2027, obligatory) • Steps taken to incorporate shipping under EU's own commitments • Targets for aviation and shipping remain incompatible with the 1.5°C limit • Aviation benefits from numerous fiscal advantages in comparison with low carbon means of transport, e.g. railways. These incentives include exemption from fuel taxation or value added tax (VAT) on tickets. In addition, some public authorities provide state aid to airports to encourage tourism (EEA, 2017a). • Over 70% of the ships are registered under the "flag of convenience" (EEA, 2017a), meaning that they can benefit from the lax environmental and fiscal regulations of countries competing for the registrations.	Ambitious Plan
Buildings sector	All new buildings fossil free and near zero energy by 2020	• Emissions from the residential sector are set to decrease by 25% and 33% by 2030 and 2050 respectively in comparison to 2005. Emissions from the tertiary sector (non-residential buildings) are projected to decrease by 33% and 43%, respectively. (European Commission, 2016f) • The existence of legislation facilitating an increase in energy efficiency in the building sector (Energy Performance of Buildings Directive (EPBD), Energy Efficiency Directive, Renewable Energy Directive) • Adoption of a requirement that all new buildings to be near-zero emissions buildings (NZEBs) by the end of 2020 (European Parliament and the Council of the European Union 2010b, 2018b) • Lack of clear definition of the NZEBs – the specification and implementation is left to the member states.	Picking Up Speed
	Increase building renovation rates from <1% to 5% by 2020	• Most estimates of renovation rates for the EU are between 0.5% and 2.5% of the building stock/year (D'Agostino et al. 2017). • The renovation rate at 1% is well below the 5% benchmark.	Ambitious Plan

Industry sector	All new installations in emissions-intensive sectors are low-carbon after 2020, maximise material efficiency	• Emissions from industrial processes are projected to decline by 10.4-10.9% between 2015 and 2035. Decline in emissions from manufacturing sector should be smaller: between 2.8 and 5.1% in the same period (EEA 2017c). • Industrial installations are Included in the EU Emissions Trading Scheme. • Financing of low carbon technologies in the framework of NER 300 funding programme and in the future in the framework of the Innovation Fund. • Emissions allowances granted for free up to a certain BAT benchmark. • Results of R&D not yet implemented broadly.	Getting Started
LULUCF	Reduce emissions from forestry and other land use to 95% below 2010 by 2030, stop net deforestation by 2025	• EU net sink of emissions from the LULUCF sector is set to decrease from over 300 $MtCO_2eq$ to between 230-240 $MtCO_2eq$ in the 2030s (European Environment Agency 2017d). • In all but three EU member states (Denmark, Ireland, Netherlands) emissions from the LULUCF sector are negative (EEA 2018b). • EU LULUCF Regulation adopted in 2018 introduces a "no debit" rule according to which emissions from land use are to be entirely compensated by an equivalent removal of CO_2 emissions in the sector (European Parliament and the Council of the European Union 2018g). • Between 2021-2030 up to 280 $MtCO_2$ for emissions reduction in the LULUCF sector can count towards the non-ETS sectors (European Parliament and the Council of the European Union 2018h).	Partionally Transitioned
Commercial Agriculture	Keep emissions in 2020 at or below current levels, establish and disseminate regional best practice, ramp up research	• Implementation of existing measures would lead to emissions from the agriculture decreasing by 1.6% between 2015 and 2035. Implementation of additional, planned measures would reduce emissions by 3% in the same period (EEA 2017c). • EU has already implemented comprehensive accounting rules for emissions from the agriculture sector and facilitated adoption of measures by the member states reducing emissions from agriculture and forestry. In 2017 679 such measures existed in all EU member states (IEEP 2017). • The reform of the EU Common Agricultural Policy (CAP) in 2015 led to the adoption of "green payment" which is granted if practices leading to carbon sequestration are implemented (European Commission 2015a).	Picking Up Speed

2.1 Electricity sector

The electricity sector accounted for almost 30% of total emissions in 2015 (EEA, 2017k). In the cost-efficient pathway set out in the EU Roadmap from 2011 to reduce the EU's overall emissions by 80% by 2050 (compared to 1990 levels), CO_2 emissions of power generation and distribution would have to be almost completely eliminated by 2050 (European Commission, 2011a). However, the more stringent Paris Agreement's temperature limit, combined with the increasing role to be played by the electricity to decarbonise the other sectors, especially transport and heating, but also industry, would require an even faster decarbonisation of the power generation. Coal phase out, followed by the phase out of the other fossil fuels, and combined with the development of renewable sources of energy, is the most effective and efficient way to reach this goal. To be compatible with the Paris Agreement emissions pathway the EU should phase out coal around 2030 (Climate Analytics 2017b).

The share of electricity from renewable sources has increased significantly in recent years: from 19.7% in 2010 to 27.5% in 2014 (Eurostat, 2017), to 30.0% in 2017 (Agora Energiewende and Sandbag, 2018). As a result, and despite the decreasing role of nuclear energy, the carbon intensity of the electricity available for final consumption decreased from 554gCO_2eq/kWh in 2010 to 427CO_2eq/kWh in 2016 (European Environment Agency 2018; Eurostat 2018m).

Table *4* summarises the EU's progress on the most important steps to decarbonise the electricity sector the electricity sector.

Table 4: Progress of the EU on the most important indicators in the power sector to limit temperature increase to 1.5°C.

Sector	1.5 °C-consistent benchmark	Projection(s) under current policies	Gap assessment (qualitative)	Policy rating
Electricity and heat sector	Sustain the global average growth of renewables and other zero and low carbon power until 2025 to reach 100% by 2050	• Based on the implementation of policies adopted before 2015, the share of electricity from renewables is projected to increase from 29% in 2015 to 43% in 2030 and 55% in 2050 (European Commission 2016e). • The projections indicate decreasing rate in the growth of low carbon sources of energy from 7% in the period 2010-2015 to 3.6% in the period 2045-2050. • While decreasing role of nuclear energy will slow down decrease of emissions, it will make grid more flexible and will make it easier to integrate higher share of renewables earlier.	+ There is an increasing political will in some EU member states (e.g. Spain, Germany, France, the Netherlands) to accelerate the development of renewables. + In 2017 the new installed capacity in renewable sources of energy amounted to 23.9 GW and represented 85% of all new installations in energy sector (WindEurope, 2018). - Achievement of the recently adopted target of 32% share of renewables requires increasing the share of renewable power in the EU to around 55% in 2030 (European Commission 2018i). This is almost twice as high as the share of RES-E in 2017 at 30% (Agora Energiewende and Sandbag 2018). - While the capacity increased, partly due to the decreasing unit costs, overall investment in renewables decreased in the EU in 2017 to the lowest level since 2006 (BNEF, 2018). - While some EU countries have significantly increased the share of renewables, Denmark is a global leader in integrating variable renewable energy, and many EU Member States are advanced compared to other countries (IEA 2018), most EU countries need to accelerate action to prepare the power sector for significantly larger share of renewables	Partially Transitioned
	No new coal plants commissioned, reduce emissions from coal power by at least 30% by 2025	• There are 288 coal-fired power plants in the EU, with combined installed capacity of around 150 GW. Germany and Poland concentrate 50% of the installed capacity. • In July 2018 coal power generation units with a combined capacity of almost 10 GW were planned in the EU28, mostly in Poland (6.2 GW) and Germany (2 GW). Plants with a combined capacity of almost 7 GW are currently under construction: 3.4 GW in Poland, 1.1 GW in Germany and 660 MW in Greece and Czechia, each (Endcoal 2018). • According to current projections share of electricity from coal is set to decrease from 26% in 2015 to 19.1% in 2025 and 6.2% in 2050 (European Commission, 2016g)	+ An increasing number of countries announcing dates of coal phase-out + Many member states have a coal-free electricity mix and nine member states - Austria, Denmark, France, Finland, Italy, Portugal, Sweden, the Netherlands and United Kingdom - accounting for 26% of EU coal capacity have announced phase out dates for coal ahead of 2030. The German Government is expected to decide on a phase-out date by end of 2018. + Spain has committed to close coal mines and prepare a just transition, with the government considering a coal phase out. - Some capacity increase planned, especially in Poland. - For a Paris Agreement compatible pathway coal would need to be phased-out by 2030. Therefore, early retirement of current capacity and cancellation of planned capacity required. - Some member states may still attempt to subsidise coal in the framework of the capacity markets which could allow member states to subsidise new fossil fuel power plants until 2035.	Picking Up Speed

2.1.1 Actionable benchmarks in electricity sector

The Climate Action Tracker identified two short-term actionable benchmarks for the electricity sector to limit warming to 1.5°C at a global level (Kuramochi et al., 2018):

- Sustain the growth rates of renewables and other zero and low-carbon power until 2025, and reach a 100% share of electricity generation by 2050.
- No new coal capacity to come online as of 2017, emissions from coal combustion need to be reduced by at least 30% by 2025. A more recent CAT publication supports this direction, and suggests reducing the use of coal in electricity by two-thirds between 2020–2030 and phase out coal globally by 2050 (Climate Action Tracker 2018a). This is in line with the IPCC Special Report on 1.5°C (IPCC 2018a). For the EU a complete coal phase-out is needed by around 2030 (Climate Analytics 2017b)

The following gap analysis compares historical and projected developments in the EU electricity to these global benchmarks without any further adjustment to allow for comparison between countries under analysis. Country specific circumstances will be addressed in the in-depth analysis on raising ambition in the following chapters. Please refer to the publication for more detailed explanation on each indicator.

2.1.2 Recent policy developments

An overview of the main climate policies influencing development of renewables and decarbonisation of the electricity sector is provided in Table 5. The obligation to introduce support mechanisms for renewable sources of energy has for the first time been included in directive 2001/77/EC and repeated with some modification in directive 2009/28/EC. The Emissions Trading Scheme (EU ETS), aiming at carbon pricing, complemented with national measures to phase-out fossil fuels, has an impact on the fuel mix and carbon intensity of electricity.

Table 5: Overview of implemented climate change policies affecting the selected benchmarks for electricity sector

OVERVIEW OF IMPLEMENTED CLIMATE CHANGE POLICIES FOR THE ELECTRICITY SECTOR IN THE EUROPEAN UNION	
EU ETS	**Non-EU ETS**
• The **EU ETS** introduced in 2005 aims at internalization of the external costs fossil fuels and decreasing the competitiveness of the most carbon intensive sources of energy. The most recent reform of this mechanisms has been adopted in March 2018 and establishes the basis for its functioning after 2020 (European Parliament and the Council of the European Union 2018a). • In addition to the EU ETS, some EU member states introduced **carbon pricing for electricity sector** (e.g. the UK, Sweden). • Out of 22 EU member states in which coal power plants still generate electricity, 10 have already a phase-out date before 2030 and in 3 (Spain, Germany and Slovakia) coal phase-out is under discussion.	• The Renewable Energy Directive adopted in 2009 introduced **binding targets** for the share of energy from renewable sources of energy in each EU member state by 2020. It has also reinstated the requirement to provide for **priority or guaranteed access** to the grid for electricity generated from renewable sources already introduced in 2001 (European Parliament and the Council of the European Union 2001, 2009d). • The Renewable Energy Directive II adopted in 2018 introduces the requirement to increase the share of energy from **renewable sources to 32% in 2030**. This directive also includes a clause that allows for an upward revision of this target in 2023.

The main instrument to reduce emissions from the electricity sector in the EU by carbon pricing is the Emissions Trading System (EU ETS), which requires operators of the power plants to purchase allowances for their emissions. Since its foundation in 2005 the system suffered from its ineffectiveness resulting from the low price of these allowances thus not incentivising decarbonisation of the power sector. Despite numerous reforms of the mechanisms, between 2013 and 2017 the price didn't exceed €8 per tCO_2 and even fell below €3 per tCO_2 in April 2013. After recent reforms became effect, the price exceeded €10 per tCO_2 for the first time in the early 2018 and reached €25 in September of that years before falling below €20 (EEX, 2018).

This low price of allowances decreased the impact of the EU ETS on the GHGs emissions from the electricity and industry sectors. The need to increase the effectiveness of this mechanism has become the focus of the EU ETS reform for the period after 2020. In November 2017, the European Parliament and the Council agreed to strengthen the mechanism by:

- Accelerating the decrease of the annual emissions cap from 1.74% in Phase 3 (2013-2020) to 2.2% in Phase 4 (2021-2030);
- Placing a share of the oversupply in the Market Stability Reserve (MSR). The default share of allowances to be placed in the MSR every year in which the oversupply exceeds 833 million was defined by the Commission at 12%, but during the interinstitutional negotiations it was doubled until 2023. Should the oversupply of allowances decrease to below 400 million, some of the allowances will be returned to the market.
- Cancelling all allowances in the MSR exceeding the number of allowances auctioned during the previous year.
- Member states can unilaterally cancel allowances in the course of additional national climate policies

Importantly, the cancellation mechanism, together with the option for unilateral cancellations will from 2019 on, stop the so called "waterbed effect": A decrease in demand for allowances in some countries (resulting e.g. from coal phase-out) would not reduce the impact of the EU ETS on emissions reduction in other countries any longer (Ecofys 2016). The MSR would ensure that some part of this oversupply of allowances is taken off the market, especially in the early 2020s when 24% of the oversupply of allowances will be taken off the market annually. Furthermore, the option of unilateral cancellation by the member states allows for the reduction in allowances in one country not leading to the increase for other member states (AgoraEnergiewende & Öko-Institut e.V 2018).

The inefficiency of the EU ETS led to a situation in which the development of renewable sources of energy had a much bigger contribution to decarbonisation of the electricity sector. Already in 2001 EU directive 2001/77/EC obliged all EU member states to introduce support mechanisms for renewable sources of energy with the aim of increasing the share of electricity in the *power* sector to on average 21% in 2010, with specific, *indicative*, targets for each member state (European Parliament and the Council of the European Union, 2001). In 2009 this directive was replaced by directive 2009/28/EC which introduced *obligatory* renewable energy targets for 2020 for each EU member state. Those targets should result in the share of *energy* from renewable sources increasing to 20% leading to a much higher share of RES-E. A failure to achieve these targets will require member states to make arrangements for "statistical transfers" from countries which overachieved their targets (European Parliament and the Council of the European Union, 2009b).

In 2018, the renewable energy directive was adopted with a new binding goal of 32%. Achieving this will require share of renewables in the power sector to approach 55% (European Commission 2018h). While – contrary to the goals for 2020 - this target is binding at the European level and not divided into national binding targets, the Governance Regulation empowers the Commission to take additional measures if the contribution of all member states will not be enough to reach this goal.

With significant differences between countries regarding their approach to nuclear energy, the European Commission does not have a clear-cut policy regarding this source of energy. The role of nuclear will be determined by national policies, especially in Germany where a detailed phase out of nuclear energy has been legislated, leading to the close of the last remaining nuclear power plants by the end of 2022 (Deutscher Bundestag, 2011). In its energy transition law France set a target to reduce the share of nuclear to 50% by 2025 but has not yet decided on a detailed schedule and discussing a potential delay (France24, 2017; Reuters, 2017b). Some other EU member states, like the United Kingdom, Finland, Hungary, Czech Republic or Poland are planning to invest or are already investing in new nuclear energy capacity.

The EU's climate and energy package for 2020 presented by the European Commission in 2008 included a proposal of a directive creating a legal framework for the investment in the CCS, especially in terms of the geological storage of CO_2. The directive introduced a number of limitations that should ensure the storage is permanent and the threat of a leak is minimised. At the same time the directive requires that when applying for license to build new large scale combustion plants the technical and economic feasibility of carbon capture a storage should be assessed (European Parliament and the Council of the European Union, 2009c). All 29 assessments prepared until 2016 found that the installation of CCS is not economically feasible but many of the permitted power plants set aside land for the CCS equipment and are designed in a way that would allow connecting CCS installations at a later stage (European Commission, 2017h).

The EU is supporting the development and implementation of the CCS projects in the framework of the NER300 program funded from the sale of 300 million allowances. This program was opened to all large-scale projects that are not yet commercial viable but sufficiently mature to be ready for demonstration with the main focus on CCS and RES. In the two calls for proposals (2011 and 2013) only one out of 39 projects awarded funding dealt with carbon and capture (European Commission, 2018i). The goal of the White Rose project supported with €300 million is to equip a 426 MW coal-fired power plant in North Yorkshire, UK, with a carbon capture and storage facility. Interestingly, in the future the plant may also switch to bioenergy which would allow it to contribute to the negative emissions (Power Technology, n.d.).

2.1.3 Comparison of recent developments and projections to benchmarks

2.1.3.1 **Actionable benchmark No.1:** Growth of renewables and other zero and low carbon power

The policies adopted before 2015 would lead the EU to increase the share of renewables in electricity sector to only 43% in 2030 (European Commission, 2016g). Implementation of the renewable *energy* target of 32% increase the share of *RES-E* to around 55% (IRENA, 2018).

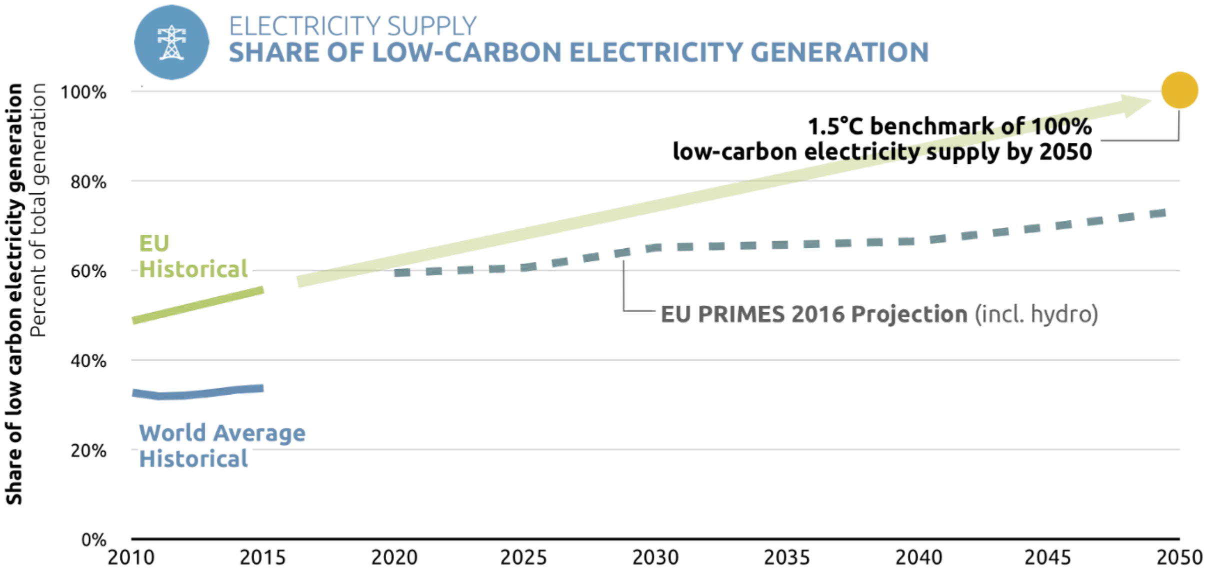


Figure 7: Historical and projected share of low carbon electricity generation in the European Union (European Commission 2016d)

Growth in renewable electricity generation

Introduction of support mechanisms resulting from the implementation of directive 2001/77/EC had a positive impact on renewables development in the power sector. Between 2005 and 2014 the share of renewables in the electricity sector increased by on average 1.32%, with the growth exceeding 2% in 2008, 2010 and 2013. In 2016 the increase in the share of renewables slowed down to 0.8% (Eurostat, 2017). Further deceleration in the growth of renewables took place in 2017 when their share in the power sector has only increased by 0.3%. While this slowdown in 2017 can to a significant degree be blamed on the lower electricity generation in hydro power plants (Agora Energiewende and Sandbag, 2018), the overall trend results from a decrease in investment security caused by sudden changes in support mechanisms or the introduction of additional taxes on renewables (e.g. in the Czech Republic, Spain, Italy) (CEPS, 2016) in the preceding years. Spain has now decided to abolish this additional tax.

The stagnation in renewables' development in the EU is also visible in value of investment. Investment in renewables in the power sector in the EU in 2017 reached $57.4 billion, the lowest level since 2006. This means a 58% decrease in comparison to the record year 2011 and less the half the investment in renewable energies in China. While this development can partly be explained by decreasing unit costs, it also results from decreasing investments in the two major contributors to the previous growth, namely the UK (-56% in comparison to 2016) and Germany (-26% in comparison to 2016) (BNEF, 2018). The decrease in the latter, contrary to the overall increase in the installed capacity, can be explained by the significant cost reduction of onshore wind energy with the prices falling to USD¢4.73 kWh in the last round of auctioning in 2017 (BMWi, 2017b). Investment in clean energy in Spain, France and Italy has been steadily increasing since 2015 but remained significantly below that in the UK or Germany.

While the development of renewables needs to accelerate significantly to be compatible with the Paris Agreement, despite the recently adopted more ambitious target, such an acceleration still needs to translate into real action. The recent growth in wind energy might only be temporary due to the developments in Germany, the biggest wind energy market in Europe. Starting from 2019 only installations that were granted financing in the framework of an auction will be realized. According to current plans around 2.8 GW are to be auctioned annually (BMWi, 2017a). A positive sign is the agreement of the German ruling coalition from November 2018 to conduct additional auctions in years 2019-2021 for wind and solar energy amounting to 4 GW for each technology (Arte 2018). In addition, the abolishment of the Solar Tax in Spain announced in October 2018 will significantly reduce administrative burden on small electricity producers and increase the competiveness of small-scale solar energy (GTM 2018).

The combined installed solar energy capacity is projected to almost double in the coming years from and reach between 11.5 and 15.3 GW in 2018 and between 10.8 and 16.9 GW in 2021 (SolarPower Europe, 2017). Between 2017 and 2021 solar energy is set to grow on average by 16% in France, 32% in the Netherlands and 66% in Poland (SolarPower Europe, 2017). Between 2017 and 2020 the projected installed capacity in wind energy is projected to increase by 25% and exceed 200 GW (WindEurope, 2017a). By 2030 cumulative EU installations should reach 323 GW and satisfy 30% of the EU's electricity demand (WindEurope, 2017b).

For solar energy, this growth is expected to be driven by decreasing costs and the resulting economic benefits of self-consumption further strengthened by the decreasing costs of storage that allows consuming own power. In addition, for both, wind and solar, countries that abolished feed-in tariffs for large installations are finally introducing tenders specifically dedicated to this sources of energy. While the investors get accustomed to the new support mechanism and the governments have a greater control over the RES-E capacity installed, they may increase the capacity to be auctioned and installed. Auctioning of 4 GW of renewables in Spain in 2017 (Global Data, 2017) that should result in higher investments in the coming years as the projects are realized, is an example of this process.

Growth of other zero and low-carbon technologies

In 2017 around a quarter of electricity in the European Union was generated in nuclear power plants (Agora Energiewende and Sandbag, 2018). It was a significant decrease since 2004, when nuclear power plants in the EU generated over 1000 TWh of electricity, equivalent to almost 31% of all the power. Since then power generation from nuclear power plants started to decrease steadily (EEA, 2016c). This decrease accelerated after the nuclear catastrophe in Fukushima, which led to an almost immediate, temporary switching off of seven nuclear reactors built bevor 1980 in Germany (The Guardian, 2011). In June 2011, the German government decided to permanently close the older nuclear power plants. The remaining nine plants are to be switched off by the end of 2022 (Haunss, Dietz, & Nullmeier, 2013). As a result, 8.4 GW, equivalent to 6.4% of the nuclear energy capacity installed in the EU, went offline in just one year (Eurostat, 2018j; Morris & Pehnt, 2016a).

The German nuclear phase out will have an impact on the role of nuclear energy also in the future. After two nuclear power plants with combined capacity of 2.7 GW were switched off in Germany in 2015 and 2017, the remaining 10 GW are to be switched by the end of 2022, with 8.5 GW at the beginning of the next decade (Morris & Pehnt, 2016b).

Of importance is also the discussion about the role of nuclear energy in France, where close to 50% of the EU's nuclear capacity is situated; this could have a significant impact on the role of nuclear power in decarbonisation. With the average age of nuclear power plants exceeding 30 years and 15 reactors older than 35 years (France24, 2017), the plants are approaching the end of their 40-year lifetime (Assemblée Nationale, 2003). In July 2015 France's National Assembly adopted an energy transition bill that aimed at reducing the share of nuclear energy in its power mix from 75% to 50% in 2025 (WNN, 2015). However, in late 2017 the French government indicated that achieving this goal may have to be postponed until 2030 or 2035 to avoid an increase in CO_2 emissions (Euractiv, 2017).

Discussion about nuclear phase-out has also taken place in Belgium, where 5% of the EU installed nuclear capacity is based (Eurostat, 2018k) and in 2015 nuclear power plants provided 37% of the electricity generated in this country (World Nuclear Association, 2017a). By 2025 all seven nuclear power plants in Belgium will have exceeded the 40-year lifetime. The oldest reactor, Doel 1, will be over 50 years old. While discussion about nuclear phase-out has already begun in 2003, few concrete steps have been taken to replace the potentially missing capacity and develop the grid for an increasing role of renewables (The Economist, 2016).

In 2017 there were four nuclear power plants under construction in the European Union with combined capacity of almost 4.4 GW. After numerous delays and cost overruns the reactor Olkiluoto 3 in Finland with the installed capacity of 1.7 GW is expected to begin commercial activity in May 2019 (Reuters, 2017a). A third-generation pressurised water reactor (PWR) with similar capacity should begin operating in Flamanville, France, by the end of 2018 (WNN, 2018). The other two reactors currently under construction are built in Slovakia. Mochovce 3 and 4 with the installed capacity of 471 MW each, are expected to start generating power in late 2018 and late 2019, respectively (World Nuclear Association, 2017b).

Six EU countries are planning to build in total 24 nuclear power plants with the combined capacity of 29 GW. More than half of that is planned to be built in the United Kingdom (World Nuclear Association, 2017c). These plans are at different stages of development, starting from the plant Hinkley Point C, for which an agreement between the British government and the French company EDF has already been signed, including a generous, guaranteed price for each megawatt hour generated (Watt, 2017), to undefined plans to build a nuclear power plant in Poland, with unclear financing and deadlines (Reuters, 2018b; RP, 2010). The liberalisation of the electricity markets and increasing competition from renewables make investments in large and expensive energy projects, like the construction of nuclear power plants, increasingly challenging. As a result, the share of nuclear is set to continue decreasing steadily: from 23% in 2020, 16% in 2030, 9% in 2040 to 6% in 2050 (European Commission, 2016g).

Large-scale application of CCS in the EU power sector is limited to date. In 2017 there were only two CCS facilities in the EU, both in the United Kingdom and both at early stages of development (Global CCS Institute, 2017). According to the official projections the role of CCS in the energy sector will be limited and reach only around 1 GW until the early 2040s. It will subsequently increase to 4 GW in 2045 and 19 GW in 2050 (European Commission, 2016g).

2.1.3.2 **Actionable benchmark No.2** - Reduce emissions from coal power plants

The fast development of renewables since the beginning of the 2010s, as well as the introduction of the EU ETS, has only had a limited impact on coal consumption in the EU. Between 2010 and 2016 the consumption of hard coal fell from 316 Mt to 260 Mt, a decrease by around 18%. The role of lignite was increasing between 2010 and 2012, before starting to decrease in 2013. In this period, it fell to almost 8% below the 2010 levels (Eurostat, 2018n). In 2017 two thirds of emissions in the EU's power sector were coming from coal-fired power plants. Contrary to hard coal, which share decreased in 2017 by 7%, power production from the most carbon intensive source of energy, lignite, increased in that year by 2% (Agora Energiewende and Sandbag, 2018).

The major reason for the slower reduction in the role of the most carbon fuel was the aforementioned low price of emissions allowances, combined with the low costs of electricity generation from fossil fuels. In addition, lignite extraction was granted a number of subsidies of different kinds, e.g. in Germany open-cast lignite mining has been exempted from the production charge of 10% or charges for water abstraction (Umweltbundesamt, 2014), in Poland the subsidies take the form of co-financing coal miners pensions or utilization of the European funds to financing reducing emissions of pollutant from coal-fired power plants (WISE, 2014).

There is an increasing disparity between EU member states in their approach towards the future role of coal in the power sector. By early 2018 ten countries have announced coal phase-out in the coming decade, whereas in further three EU member states closing all remaining coal power plants is currently under discussion (see the table below). The latter includes the largest coal consumer in Europe, Germany.

Table 6: National coal phase-out dates for EU countries with a coal phase-out planned or completed.

Country	Coal phase-out date	Coal phase-out status
Austria	2025	The companies operating the last two coal plants in Austria will phase-out coal by 2018 and 2025, respectively. Austria is a signatory of the Powering Past Coal Alliance.
Denmark	2030	Denmark signed on to the Powering Past Coal Alliance declaring to phase out coal by 2030.
Finland	2029	In April 2018, Finnish Environment Minister Kimmo Tiilikainen confirmed that the government will move up its plans for a 2030 ban on coal as an energy source to 2029. Finland is a signatory of the Powering Past Coal Alliance.
France	2021	France had committed to a coal phase-out by 2023 under the previous

		administration. President Macron has reconfirmed this commitment, bringing it forward to 2021. France is a signatory of the Powering Past Coal Alliance.
Ireland	2025	According to the Draft Irish Climate Plan, the only coal plant in Ireland, Moneypoint, will come to the end of its operating life in 2025. Decisions on the future of Moneypoint will be taken before 2020.
Italy	2025	In October 2017, the Italian government announced a coal phase-out by 2025 as part of the National Energy Strategy, signed on November. Italy is a signatory of the Powering Past Coal Alliance.
Netherlands	2030	Announced. In October 2017, the incoming Dutch government announced full shutdown of coal-fired power plants by 2030. Three of the remaining plants have only recently been completed, meaning that they will operate for less than half of their expected lifetime. Netherlands is a signatory of the Powering Past Coal Alliance.
Portugal	2030	Announced. The coal phase out by 2030 was announced in November 2016 and reaffirmed in October 2017 in the roadmap to 2050 carbon neutrality. Portugal is a signatory of the Powering Past Coal Alliance.
Sweden	2022	The last coal plant in Sweden will close by 2022 (Not a proactive government policy). Sweden is a signatory of the Powering Past Coal Alliance.
United Kingdom	2025	Announced. The UK was the first country in the world to announce a coal phase-out policy in 2015. The coal fleet is already halved from around 30 GW in 2010 and by 2016 the coal share had fallen to 9% of the electricity mix. The UK, together with Canada is the Initiator of the Powering Past Coal Alliance.
Germany	Under discussion	A special commission for "Growth, structural change and employment" should is to decide by the end of 2018 about a specific deadline for coal phase-out.
Slovakia	Under discussion	Phasing out coal by 2023 has been announced by the Slovakian Minister of Environment during the One Planet summit in December 2017. It is not clear if this announcement will be acted upon as the Prime Minister Fico was pro-coal, especially after Fico's resignation in March 2018
Spain	Under discussion	Spain's Minister for Ecological Transition, Teresa Ribera, hinted at coal phase-out by 2025, but this decision is to be combined with support for coal miners. In October 2018, Spanish government and miners unions struck a deal to invest €250 million in the coal mining regions in exchange for closing most of coal mines in the country by the end of 2018.
Belgium	No coal	The last coal plant closed in March 2016. Belgium is a signatory of the Powering Past Coal Alliance.
Cyprus	No coal	Completed.
Estonia	No coal	Completed.
Latvia	No coal	Completed. Signatory of the Powering Past Coal Alliance.
Lithuania	No coal	Completed.
Luxemburg	No coal	Completed. Signatory of the Powering Past Coal Alliance.

Source: Own elaboration based on information from the Beyond Coal Europe

In the remaining nine countries in which coal is still utilized for electricity generation and which didn't make any announcements about coal phase-out, this source of energy plays a diverse role. In Croatia and Hungary coal combustion is the source of less 20% of the electricity. Close to a third of electricity is generated from this source of electricity in Romania, Slovenia and Greece. The most important role is played by coal in Bulgaria with 46% share, Czech Republic (49%) and Poland (77%) (Agora Energiewende and Sandbag, 2018).

Coal phase-out would not only significantly reduce emissions but would also save European power companies billions of dollars as nearly all of the existing coal-fired power plants will be loss-making in Europe by 2030. According to Carbon Tracker, 54% of the European coal-fired power plants are currently cash flow negative and this could increase to 97 per cent by 2030 due to rising carbon prices and stricter air quality rules. Phasing out coal in line with the Paris Agreement could save the EU €22 billion with Germany (savings €12 billion) and Poland (savings €2.7 billion) as the main beneficiaries (The Carbon Tracker Initiative 2017). The so-called "Dutch Coal Mistake" illustrates this risk: Three brand new power plants in the

Netherlands became unprofitable in 2016 “under a wide range of plausible policy or market scenarios”, ruling out “any new-build coal power in western Europe” (IEEFA 2016).

In the future, the competitiveness of the coal-fired power plants will be significantly reduced by the need to accommodate EU’s new air pollution standards that come into effect in 2021. According to some estimates about 82% of EU, 80% of German and virtually all Polish coal power plants do not comply with a new EU regulation. The costs for upgrading these coal power plant to meet the new air pollution regulations are estimated at be between €8-14.5 billion for the EU - €2.4-4.3 billion for Poland and €0.7-1.2 billion for Germany. In addition, operating costs of these plants with more effective filters would also increase (DNV GL-Energy, 2016).

Even though the competitiveness of the coal-fired power plants in the EU’s power sector has significantly decreased over the last few years, their closure rate has been much lower than necessary to achieve the temperature goal of the Paris Agreement. Two major factors that led to the decrease in the role of coal were: the increase in the carbon tax in the UK and cheaper gas. Neither of these are sufficient for a speedy and sustained coal phase out on the continent. While the cost of renewables continues to decrease, a clear pan-European policy is needed to enable the replacement of existing and amortised coal fired power plants (Climate Analytics 2017a).

2.1.4 Conclusion

The power sector in the European Union has over the last decade experienced the fastest decarbonisation of all the other sectors. Increasing deployment of renewables has led to reduced generation costs and allowed for wind and solar energy to gain momentum on the other markets. But as the costs of the transformation decreased, sudden policy changes in some of the EU countries worsened the security of investment and slowed down or in some cases even completely halted the development of renewables.

At the same time, the price signal provided by the EU ETS was too weak to have a meaningful impact on the role of coal in the power sector. This applied especially to lignite, which role has decreased only slightly. While the reform of the EU ETS adopted in the early 2018 resulted in much higher prices of emissions allowances, a significant acceleration of decarbonisation of the power sector is needed to make the emissions pathways compatible with the Paris Agreement temperature and emissions goals. Phasing out coal in the coming decade, either by a regulated phase-out, decreasing the emissions cap faster or introducing floor carbon price, would be the most effective way to reduce emissions faster in the short term. This needs to be combined with an accelerated development and integration of renewable sources of energy in the power mix, enabled through stable and predictable legal and financial framework and support for innovation.

2.2 Transport sector

Emissions reduction in the transport sector that is responsible for 25.8% of the EU’s total GHG emissions (EEA, 2017g) is more challenging than that in the power sector. In 2011, the European Commission published its “Roadmap for moving to a competitive low carbon economy in 2050” in which it distributed the emissions reduction effort among different sectors of economy to reach the overall emissions reduction of 80% by 2050. According to the Commission’s analysis, emissions from the transport sector would have to be reduced by 60%, much smaller reduction than in all the other sectors, except for agriculture (European Commission, 2011a).

Indeed, contrary to the trends observed in other sectors, like the overall emissions decrease by almost 24% between 1990 and 2015 (EEA, 2017d), emissions from the transport sector in the EU have *increased* in the same period by 23.1% (EEA, 2018c). This increase in emissions occurred despite the increased efficiency of cars by almost 16% between 2010 and 2016 (EEA, 2017h) and is mainly due to the increase in activity: between 1995 and 2015 passenger transport in the EU increased by 21% (EEA, 2017i). The slow increase in the share of renewables in the transport fuel mix, additionally, covered only 7.1% of the energy consumed in the sector in 2016 (EEA, 2017l).

The increasing affordability of the e-mobility offers a great potential of reducing emissions in this sector. But it requires significant investments in the relevant infrastructure and decarbonisation of the electricity sector (EEA, 2017c). In both cases, the adequate political and financial framework that ensures an increasing uptake rate of alternative combustion vehicles, decreasing unit costs and better integration with the electricity sector needs to be implemented.

Table 7 summarises the EU's progress on the most important steps in order to decarbonize the transport sector to limit temperature increase to 1.5°C.

Table 7: EU's progress on the most important steps in the transport sector to limit temperature increase to 1.5°C

Sector	1.5 °C-consistent benchmark	Projection(s) under current policies	Gap assessment (qualitative)	Policy rating
Transport sector	Last fossil fuel car sold before 2035	• In the mid-2030s the EU is projected to lead globally in terms of the share of electric vehicles. Their share is expected to reach around 68% of newly sold cars in 2040 (BNEF, 2017).	+ Ambitious policies introduced in some member states (e.g. Netherlands by 2030 (Dutch Government, 2017), the United Kingdom and France by 2040 (WEF, 2017) + Legislation introducing obligation to install charging station in all new and refurbished buildings with more than 10 parking spaces (European Parliament and the Council of the European Union 2018c). + Increasing share of electric cars in the new registrations, from 1.2% in 2015, 1.3% in 2016 to 1.7% in 2017 and projected 2.4% in 2018 (EV-Volumes, 2018). + Interinstitutional negotiations about the adoption of stricter emissions standards for passenger cars and vans for 2030 that would also include quotas for the share of low carbon vehicles. - Lack of European approach to the phase out of combustion cars or policies encouraging increasing the share of electric vehicles resulting in a piecemeal approach.	Ambitious Plan
	Aviation and shipping: Develop and agree on a 1.5°C compatible vision	• Depending on the level of demand, emissions from the EU aviation sector are projected to be between -11 and +101% of the 2015 levels in 2035. (EASA et al. 2016) • Emissions from the intra-EU aviation are projected to increase by 55% in the same period (+42% by 2030 and +94% by 2050) (European Commission 2016d)	+ Adoption of the goal of capping aviation emissions at 2018-2019 levels in the framework of the CORSIA mechanism (2021-2027, post 2027, obligatory) + Steps taken to incorporate shipping under EU's own commitments - Targets for aviation and shipping remain incompatible with the 1.5°C limit - Aviation benefits from numerous fiscal advantages in comparison with low carbon means of transport, e.g. railways. These incentives include exemption from fuel taxation or value added tax (VAT) on tickets. In addition, some public authorities provide state aid to airports to encourage tourism (EEA, 2017a). - Over 70% of the ships are registered under the "flag of convenience" (EEA, 2017a), meaning that they can benefit from the lax environmental and fiscal regulations of countries competing for the registrations.	Ambitious Plan

2.2.1 Actionable benchmarks in transport sector

The Climate Action Tracker identified two short-term actionable benchmarks for the transport sector to limit warming to 1.5°C at a global level (Kuramochi et al., 2018):

- The last fossil car needs to be sold before 2035 to achieve car fleets consisting of 100% zero-emissions cars by 2050.
- A 1.5°C compatible vision for the aviation and shipping needs to be developed and agreed upon.

With the findings from the IPCC report on achieving net-zero CO_2 emissions around 2050 and the rapid update of electric vehicles of the previous years in mind, this analysis decides to strengthen the benchmark for the vehicle sales to a fully 100% zero-emissions car stock by 2050, meaning the last fossil car needs to be sold before 2035.

The following gap analysis compares historical and projected developments in the EU transport sector to these global benchmarks without any further adjustment to allow for comparison between countries. Country specific circumstances will be addressed in the in-depth analysis on scaling up climate action in the following chapters. Please refer to Kuramochi et al. (2018) for more detailed explanation on each indicator.

Additionally, the freight transport needs to decarbonise: Freight trucks need to be almost fully decarbonised by approximately 2050 (Climate Action Tracker 2018a).

2.2.2 Recent policy developments

The EU has implemented several climate strategies and policies in the transport sector to varying degrees. In addition, some member states adopted deadlines for phasing out the sale of combustion cars. Table 8 provides a comprehensive overview of the currently implemented and planned sectoral climate policies.

Table 8: Overview of implemented climate change policies in the transport sector in the EU (This overview does not include the range of policies implemented in respective EU member states in addition to EU policies and implementing the EU legislation), including fuel levies, and additional support schemes for electric mobility.

OVERVIEW OF IMPLEMENTED CLIMATE CHANGE POLICIES FOR THE TRANSPORT SECTOR IN THE EUROPEAN UNION	
Increasing efficiency	**Promoting e-mobility and renewables**
• Regulation 443/2009 introduced the target of **95 gCO_2/km as average emissions for the new car fleet after 2020** (European Parliament and the Council of the European Union 2009f). • Regulations 333/2014 reconfirmed the 95 gCO_2/km target but introducing a number of exceptions postponed its **full achievement to 2021** (European Parliament and the Council of the European Union 2014c). • Regulation 253/2014 introduced emissions targets for **the average fleet of light commercial vehicles: 175 gCO_2/km in 2017 and 147 gCO_2/km for 2020 in 2020** (European Parliament and the Council of the European Union 2014b). • The current negotiations between the Parliament and the Council should result in the adoption of a new regulation with emissions reduction targets for **new passenger and light duty vehicles for 2030 in the range of 35-40% below 2021 levels** (Council of the European Union 2018c; European Parliament 2018). • In May 2018, the European Commission presented a legislative proposal with emissions standards for heavy duty vehicles. According to it, the average	• Directive 2009/28/EC introduced the **goal of increasing the share of renewables in the transport sector to at least 10%** in 2020. This goal was modified with Directive 2015/1513 which aimed at reducing the role of 1st generation biofuels in reaching this goal (European Parliament and the Council of the European Union 2015b, 2009c). • The recast of the renewable energy directive increased the share of renewable energies used in the **transport sector to 14% in 2030,** while excluding the contributing from some kinds of bio liquids from achieving this goal (European Parliament and the Council of the European Union 2018d). • The currently negotiated regulation with the stricter emissions reduction target for new passenger and light duty vehicles also includes a quota for zero and low emissions vehicles in sales. Depending on the outcome of the negotiations this quota will be **between 15% - 20% in 2025 and up to 35% in 2030** (Council of the European Union 2018c; European Parliament 2018). • To accelerate development of charging infrastructure Directive 2014/94/EU obliged member states to initiate the **development of charging infrastructure for alternative vehicles** (electric, LNG and CNG) (European Parliament and the Council of the European Union 2014a). This requirement has been strengthened with the new Energy Performance

emissions from new lorries should be 15% lower in 2025 and 30% lower in 2030 than in 2019 (European Commission 2018j). After interinstitutional negotiations, this proposal is expected to be adopted in 2019.

Buildings Directive (EPBD) adopted in 2018 which required **installing charging station in each new residential building with more than 10 parking spaces**. The same requirement applies to residential buildings undergoing major renovation (European Parliament and the Council of the European Union 2018g).

- Some member states introduced or suggested introducing a ban on the sale of combustion cars, e.g. the Netherlands by 2030 (Dutch Government, 2017), the United Kingdom and France by 2040 (WEF, 2017).
- Proposal of the clean vehicles directive focuses on promoting low carbon vehicles in public procurement tenders. It introduces **strict CO_2 emissions thresholds for different categories of vehicles and minimum procurement targets for each of these categories** (European Commission, 2017a).

Emissions reduction goals

- In the European Union emissions from the transport sector are covered under the non-EU ETS legislation. Effort Sharing Decision from 2009 included the goal of reducing emissions from that sector in 2020 by 10% in comparison to 2005. The Effort Sharing Regulation adopted in 2018 increased this goal to 30% in 2030. Both documents included specific emissions reduction goals for each of the EU member states (European Parliament and the Council of the European Union 2018h, 2009a).

Aviation

- Aviation – as the only transport sector – has been included in the EU ETS. Due to the staunch opposition of the EU's main trade partners to the inclusion of extra-EU flights in the mechanism, such flights have been temporarily excluded – initially until 2013, 2016 and after the adoption of the CORSIA, until 2023. Emissions resulting from flights between member state of the European Economic Area (EU + Norway, Iceland and Lichtenstein) have to be accounted for in the framework of the EU ETS (European Parliament and the Council of the European Union 2008).

Maritime

- Directive 2014/94/EU encouraged member states to facilitate building charging stations in maritime and inland waterways (European Parliament and the Council of the European Union 2014a).
- Regulation 2015/757 sets up a framework to monitor, report and verify emissions from the shipping sector (European Parliament and the Council of the European Union 2015c)

Over the last two decades, the EU's transport policies have evolved from narrow focus on increasing fuel efficiency and moving toward biofuels in the road transport into a more diverse array of measures and policies aiming at reducing emissions from different means of transport and thus reaching the emissions reduction targets specified for the non-EU ETS sector. These policies were strengthened by additional policies of some EU member states. At the same time, however, certain infrastructural investments co-funded in the framework of the European structural funds, such as motorways and airports, undermined the long-term decarbonisation prospects.

The Renewable Energy Directive adopted in 2009 introduced a 10% target for energy from renewable sources in transport by 2020 (European Parliament and the Council of the European Union, 2009b). However, due to the high potential of emissions from the **first generation of biofuels** in the LULUCF sector in other countries, the role of certain biofuels and bio liquids in achieving this target was limited to 7% in 2015 and therefore the remaining targets had to be met by advanced biofuels and greater use of electricity in the transport sector (European Parliament and the Council of the European Union, 2015b). The recast of the renewable energy directive increases the renewable energy goal to 14% in 2030. The contribution from biofuels and bio liquids produced from food or feed crops is to be capped at 7% whereas the contribution from biofuels and bio liquids produced from palm oil is to be fully excluded (European Parliament and the Council of the European Union 2018d).

Simultaneously the EU introduced regulations aiming at **increasing the efficiency of combustion cars**. The EU regulation from 2009 (amended in 2014) introduced efficiency and CO_2 emissions standards for new passenger cars, with a plan to increase the stringency annually until 2020. As a result, it should reduce the average emissions level of a new car sold in the beginning of the 2020s to 95 grams CO_2/km (European Parliament and the Council of the European Union, 2009e, 2014c). While the fuel economy of the new cars continued to improve between 2010 and 2016, the trend has overturned in 2017 with the average CO_2 emissions increased by 0.4 g/km and reaching 118.5 g/km, a decrease by 22% in comparison to 2010 (EEA, 2018d). To reach the 2021 goal of 95 g/km, car producers have to improve the average efficiency of cars by almost 25%.

In 2011 (amended in 2014) the EU has also adopted CO_2 emissions targets for new vans for 2017 (175 gCO_2/km) and 2020 (147 gCO_2/km) (European Parliament and the Council of the European Union, 2011, 2014b). The 2017 target has already been reached in 2013 and by 2016 the average van sold in the EU emitted 163.7 gCO_2/km, which was 7% below the 2017 target. However, it was 10% above the 2020 goal. Achieving the 2020 goal would mean a 19% improvement in comparison to 2012 (European Commission, 2018k).

To this time, the European Parliament and Council of Ministers are negotiating the emissions standards for passenger cars and vans for 2025 and 2030. While the European Parliament is calling for the decrease in the average emissions of new vehicles by 20% in 2025 and 40% by 2030 in comparison to the 2021 level, the Council is suggesting a respective reduction of 15% and 35% and an even lower emissions reduction goal for vans: 30% (Council of the European Union 2018c; European Parliament 2018). The negotiations are expected to finish by the end of 2018 and the new goals for 2030 to be formally adopted by both institutions in the early 2019.

In May 2018, the Commission presented a legislative proposal introducing emissions standards for heavy-duty vehicles for the first time. According to the proposal, the average emissions from new trucks, trailers, buses and coaches should be 15% lower in 2025 than in 2019 (binding target). By 2030, the average emissions should be at least 30% below the 2019 levels (aspirational target) (European Commission 2018j). Both the European Parliament and the Council of Ministers are – at the time of writing – to still adopt their respective positions. The ENVI Committee of the European Parliament has already suggested raising the emissions reduction target to 20% in 2025 and 35% for 2030. In addition, it suggested a minimum share of low and zero-emissions Lorries at 5% in 2025 and 20% in 2030. By then, at least three quarters of urban buses should also be electric (ENVI 2018).

While increasing vehicle efficiency has been the most preferred option to achieve the EU's emissions standards, an increasingly popular way of average emission reduction of the cars of a certain manufacturer is the **sale of zero and low-emissions vehicles**. For this reason, the aforementioned proposal with stricter emissions standards for 2025 and 2030 has also included targets for the share of zero and low emissions vehicles in the sales of new vehicles. While the European Parliament suggested that a share of such vehicles should reach 20% in 2025 and 35% in 2030, the Council was in favour of lowering the shares and pushing the target periods back: 15% in the period 2025-2029 and 35% after 2030 (Council of the European Union 2018c; European Parliament 2018).

Their market uptake of electric vehicles has however been hindered by the lack of charging infrastructure, which discouraged potential buyers from purchasing cars with alternative combustion. At the same time, the slow uptake of electric and hydrogen vehicles render development of charging infrastructure unprofitable for private investors. To mitigate this issue and accelerate the development of low-carbon mobility, the European Commission adopted the "directive on the deployment of alternative fuels infrastructure" in 2014, in which each EU member state is obliged to have at least ten publicly available electric vehicles charging stations by the end of 2020. The directive has also set targets for developing charging infrastructure for liquefied natural gas (LNG) every 400 km and compressed natural gas (CNG) every 150 km along the TEN-T core networks by the end of 2025. There should also be a "sufficient number of publicly accessible refuelling points" for hydrogen vehicles by end-2025 (European Parliament and the Council of the European Union, 2014a).

Another measure to promote e-mobility infrastructure has been introduced in the recast of the Energy Performance Buildings Directive (EPBD) agreed upon by the European Parliament and the Council in December 2017. According to the EPBD, new residential buildings and those undergoing major renovations, with more than ten parking spaces, shall be equipped with an adequate pre-cabling or pre-tubing to enable the installation of **recharging points for electric vehicles** for every parking space (European Parliament and the Council of the European Union 2018g).

To stimulate the market for **clean energy efficient vehicles** the Commission presented a proposal in November 2018, which, among others, introduces **minimum targets for clean vehicle procurement** (e.g. buses, light duty vehicles) in 2025 and 2030. The level of the target was to be determined by the member state's GDP per capita and urban population density (European Commission, 2017f). According to the Commission's proposal, at least 29% of buses procured in Romania and 50% of buses procured in 13 richer EU member states would have to be "clean vehicles" that are defined by vehicles with zero emissions art tailpipe or vehicles using bio-methane (European Commission, 2017a). In its Opinion, the European ENVI Committee suggested introducing binding targets for some categories of vehicles already in 2020 and replacing "clean vehicles" with "ultra-low emissions vehicles" that have even stricter emissions standards: maximum 50 g/km for buses in 2020, 25 g/km in 2025 and 0 g/km in 2030. This would require that the electricity used to power the buses is "fully based on renewables" (ITRE Committee, 2018). The final shape of the directive and thus its impact will be the outcome of interinstitutional negotiations between the Council and the European Parliament.

The need to develop charging infrastructure has also been underlined the Commission's **strategy for low-emission mobility from 2016**. It also further encourages the member states to increase the use of digital technologies in transport sector, fairer taxation that would improve the competitiveness of railways, and introduction of more stringent tests for emissions from cars and vans (European Commission, 2016a). Building on these suggestions, the Commission presented a package of initiatives titled "Europe on the Move" in May 2017, which included a proposal on monitoring and reporting CO_2 emissions from heavy-duty vehicles, and a suggestion to foster e-mobility through the introduction of EU-wide technical specifications (European Commission, 2017b).

Decarbonisation of the road transport sector in the EU is further strengthened by the discussions about **banning the sale of cars with combustion engines** by some member states, e.g. the Netherlands by 2030 (Dutch Government, 2017), the United Kingdom and France by 2040 (WEF, 2017).

European legislation has also included some suggestions and requirements that would reduce emissions from the **maritime and aviation sectors**. However, due to the international character of both sectors, the EU's role is rather limited, especially for extra-EU routes. This became notable when the EU attempted to include aviation emissions in the EU ETS. Due to international pressure and threats of a "trade war" (Climate Home, 2012), the EU ETS requirements for flights to and from non-European countries were initially suspended until the end of 2013 (European Commission, 2012b), and then until the end of 2016 in expectation of the International Civil Aviation Organization (ICAO) adopting a measure that would regulate emissions from the global aviation sector (Aviation Week, 2014). Following ICAO's agreement to introduce an international offsetting scheme—CORSIA—which will cap emissions from international aviation at the average level in 2019–2020, the EU extended the derogation from fulfilling the EU ETS requirement until the end of 2023 (European Commission, 2017c).

Contrary to the extra-EU flights, the 900 aircraft companies operating flights between member state of the European Economic Area (EU + Norway, Iceland and Lichtenstein) have to cover the resulting emissions by a respective amount of emissions allowances. For this reason, the EU issues 211 million allowances (each equivalent to 1 tonne of CO_2) annually, which corresponds to 95% of the average annual CO_2 emissions in the years 2004-2006. In contrast to the other sectors within the EU ETS, this cap remains constant throughout Phase 3 of the EU ETS (2013-2020). Furthermore, European legislation provides the aviation sector with an additional advantage by granting 85% of these allowances to the aircraft operators for free and having only the remaining 15% of the allowances auctioned (European Commission, 2018b). Regulation adopted in late 2017 will slightly strengthen the application of the EU ETS towards aviation: starting in 2021, the emissions cap for aviation will be reduced annually by the same share as the other sector, namely by 2.2% (European Parliament and the Council of the European Union, 2017b).

Meanwhile, the European – as well as international – aviation industry benefits from significant subsidies taking the form of co-funding of the construction of airports (European Court of Auditors, 2014), non-taxation of aviation fuel and exemption of airline tickets for flights between different EU member states from the Value-Added Tax (VAT) (Transport&Environment, 2011). Such measures not only diverge or limit financial resources that could be spent on other purposes but also decrease the incentives to invest in numerous emissions reduction opportunities (EEA, 2017a).

Different from the case of aviation, in the case of the international maritime transport, the EU didn't make any attempts to regulate within the framework of the EU ETS. Instead, it has joined the efforts of some other countries to develop a common approach to the global emissions from this sector (European Commission, 2013b). These efforts led to the adoption of IMO strategy in April 2018, which includes the goals of reducing emissions from international shipping by 50% by 2050 compared to 2008 and a complete phase out "as soon as possible in this century" (ICCT, 2018).

Nonetheless, already in its White Paper from 2011 the EU suggested an emissions reduction target for EU maritime transport of 40% (if possible 50%) by 2050 compared to 1990 (European Commission, 2011b). However, the lack of effective monitoring, reporting and verification (MRV) system poses a major challenge in assessing the impact of mitigation efforts. Therefore, in parallel with the international negotiations process that should lead to the adoption of a common approach towards mitigation efforts, the EU has developed a stepwise plan for integrating international shipping emissions into its own climate commitments. As a first step, an MRV system from CO_2 emissions from large ships using ports in the EEA has been set up. According to the European Commission's impact assessment, this will reduce annual GHG emissions by only up to 2% by 2030 relative to the baseline scenario. However, the principal purpose of this step is to enable further reductions through the development of GHG reduction targets for the maritime transport sector, and, in the longer term, through the use of market-based measures (European Parliament and the Council of the European Union 2015c). In addition, further emissions reduction should be achieved by encouraging member states to facilitate building charging stations in maritime and inland waterways (European Parliament and the Council of the European Union, 2014a).

2.2.3 Comparison of recent developments and projections to benchmarks

2.2.3.1 **Actionable benchmark No.3:** Last fossil fuel car sold before 2035

In 2017, the number of sold electrically-chargeable vehicles reached 216,000, an 39% increase in comparison to the preceding year. This amounted to 1.4 % of all passenger cars sold in the EU in the same year (ACEA, 2018a). The share of electrically-chargeable vehicles increased further in the first quarter of 2018 and reached 1.7% of all cars sold. However, the share significantly differed from one country to another, with Sweden, Finland and the Netherlands leading with 7.1%, 4.3% and 3.3% share, respectively. Slovakia, Lithuania, Estonia and Poland registered the lowest share of electrically-chargeable vehicles with the share between 0.2% and 0.3%. In the biggest car market in the EU, Germany, electric vehicles constituted 2% of all new cars, slightly above the EU average (ACEA, 2018b).

While the share of electric vehicles in the EU is increasing, it still constitutes a relatively small share of all cars and is far behind China's share of 2.1% in 2017 (Clean Technica, 2018). Meeting the Paris Agreement-compatible emissions trajectory requires a complete phasing out of the sale of combustion vehicles before 2035 (Sterl et al., 2016), a goal that would require a much more decisive action on behalf of the European Union and its member states.

The spread of electric and other alternative, low-carbon vehicles (e.g. hydrogen, plug-in hybrid) depends on national policies: Only a small number of countries were responsible for the majority of the cars sold: in 2017 68% of all electrically chargeable cars in the EU were sold in only 5 countries that represent 37% of the EU population: Belgium, Germany, the Netherlands, Sweden and the UK (ACEA, 2018a; Eurostat, 2018m).

This disparity across the EU is expected to continue as some countries are taking bold steps in setting targets to decrease the role of combustion cars. In August 2016, the Dutch Parliament gave an approval to the proposal to ban the sale of new combustion cars after 2025 (Irish Time, 2016). Some members of the Swedish government are considering a similar step (Pedestrians Observations, 2016). In Germany, the biggest car market in Europe, the Federal Council (Bundesrat) passed a resolution to ban internal combustion engines from 2030 (Süddeutsche Zeitung, 2016).

Even if some of these announcements are merely declarations that lack the necessary instruments for implementation, they send a clear message to the automakers to invest in alternative, low-carbon modes of transport. A clear target on the European level would send a potent signal to countries where such targets have not been implemented to develop the necessary infrastructure.

Freight transport

With total of 2.4 trillion tonne-kilometres (or almost 4 800 tkm per person) of inland freight in the EU in 2016, three quarters of which by road (Eurostat 2018h), emissions reduction from the heavy duty vehicles and moving from road to rail play an important role in emissions reduction. The Climate Action Tracker has shown in a detailed EU case study that, with ambitious efficiency standards and advancements in other policy measures related to incentives to shift transport from road to rail, uptake of zero emissions vehicles, combined with the decarbonisation of electricity generation, heavy road transport can achieve a reduction of 30% below 2015 levels by 2030 and 90% by 2050. To achieve this, the EU must strengthen policies in all of these areas. This would lead to a reduction of 35% of emissions from freight transport compared to the emissions expected under the current EU NDC (Climate Action Tracker 2018b). The recent Commission's proposal—aiming at reducing the average CO_2 emissions from new trucks by at least 30% below 2019 levels by 2030 —is a first step in the right direction although it is not yet fully in line with what is needed for the Paris Agreement.

2.2.3.2 **Actionable benchmark No.4:** Develop a 1.5°C compatible vision in aviation and shipping

Aviation

Emissions from aviation have increased the fastest from all sectors in the EU: from 69 $MtCO_2eq$ in 1990 to 142 $MtCO_2eq$ in 2015 (EEA 2017b). In the late 1990s as well as in the mid-2000s the growth rate of emissions exceeded 6% and approached almost 8% (EEA, 2017e). Without radical action this trend is set to continue: the number of flights in Europe—and the associated CO_2 emissions—are forecast to grow by 45% between 2014 and 2035 in the base traffic scenario assuming low technology improvement. Depending on the level of demand and technology improvement, the emissions could either fall by 1.3% (low traffic, advanced technology improvement) or increase by 101% (high traffic, no technology improvement) in comparison to the 2014 levels (EASA, EEA, & EUROCONTROL, 2016). No action at the international level would mean that emissions from the aviation sector would more than quadruple by 2050 (ICAO, 2016). As a result, aviation could be responsible for 22% of global emissions in 2050 (EEA, 2017a).

However, while aviation is a more challenging sector in terms of decarbonisation than road transport there are nonetheless numerous solutions that could or in some cases have already been implemented. Between 2005 and 2014 the average amount of fuel burn per passenger decreased by 19% (EASA et al., 2016). Higher occupancy rate, e.g. by avoiding doubling connections between the same destinations, could further decrease emissions per passenger. Currently investigated changes to the planes aerodynamics and reduction in friction could reduce fuel consumption by up to 5%. New technology engines applicable for smaller and medium size planes (e.g. A320neo, 737MAX or C919) allow up 15% emissions reduction. Changing planes design and utilizing new alloys could reduce empty planes' weight by up to 45% and thus decrease their fuel consumption (ICAO, 2016). In the shorter term, operational improvements, such as reducing the landing delays or increasing the prevalence of the Continuous Descent Approach (CDA) would in some cases significantly reduce CO_2 emissions with the additional benefit of limiting noise pollution (EEA, 2017a). Finally, significant reduction in emissions can be achieved by replacing fossil fuels in the aviation sector by sustainable biofuels (IRENA, 2017a).

Reducing emissions from aviation could also be achieved by developing alternative modes of transport. Already between 2005 and 2014 the number of short-haul, intra-EU flights has been reduced due to the expansion of high-speed rail network. While this decrease has been overcompensated by opening new, more distant directions (EASA et al., 2016), without this option the increase in the emissions from the aviation would even be higher. An even bigger opportunity is offered by – whenever possible - replacing air transport of cargo by rail transport. With an average age of 19 years, cargo planes are almost twice as old as conventional ones and have thus correspondingly higher emissions. As a result, emissions intensity of airfreight is 27-times higher than that of rail transport (ECTA, 2011).

While numerous opportunities for emissions reduction in the aviation sector exist, the preferential treatment mentioned in the earlier section reduced their utilization rate. Until the agreement to introduce CORSIA was reached in October 2016, there was no comprehensive, global mechanisms that would cover the emissions from the sector and mobilize airline operators to reduce them. The European Commission made some attempts at mobilizing the aviation industry to take action by suggesting in its 2011 White Paper on transport a mid-century target to increase the share of low-carbon sustainable fuel in aviation to 40% (European Commission, 2011b) but its uptake to-date has been very slow (EASA et al., 2016). In the framework of the European Advanced Biofuels Flightpath initiated by the European Commission in 2011 a goal of producing 2 million tons of "sustainably produced paraffinic biofuels" annually by 2020 for the aviation sector was adopted (European Commission, 2011d). Also, the EU's decision to include aviation in the EU ETS – including flights from and to the EU – was an attempt to facilitate emissions reduction from the sector. Those measures, especially the latter, have contributed to the adoption of the global scheme to address the emissions from aviation, CORSIA.

However, while considered step in the right direction, the adoption of CORSIA with the goal of carbon neutral growth after 2020 is merely implementation of the same goal adopted already in 2010 (ICAO, 2010), long before the adoption of the Paris Agreement temperature target. This goal of climate neutral growth is not compatible with the 1.5°C temperature limit. It is further weakened by making participation voluntary to ICAO member states until 2027. Thus, the EU should continue its attempts to strengthen global climate action in the aviation sector and **come up with a more ambitious vision for the aviation sector**.

Maritime shipping

GHG emissions from shipping represent around 4% of the EU's total emissions (European Commission, 2013b) – this is significantly above the global share of around 2.6% (icct, 2017). Differently from the international level, emissions from ships bunkering in the EU have been decreasing since the economic crisis of 2008/2009, even though this decrease couldn't compensate the significant increase in shipping emissions between 1990 and 2007. As a result, in 2015 emissions from the EU international shipping were 23% higher than in 1990 and amounted to 135 MtCO_2 (EEA, 2018b).

Recent improvements in efficiency, encouraged by the International Maritime Organisation (IMO) standards for ship, was the major factor contributing to emissions decrease despite increasing activity. While the increase in fuel prices is expected to lead to further efficiency improvements, the current rate of improvement will not be sufficient to limit warming to 1.5°C.

The future development of emissions is strongly dependent on the economic development and trade relations. According to some estimates the current decreasing trend is set to change and the emissions from EU-related shipping are expected to increase by 86% until 2050 compared to 1990 (51% compared to 2010) (European Commission, 2013a). This is a slower growth in comparison with the global rise in emissions which are projected to increase by between 31% in the scenario of moderate trade growth and 137% in the scenario of high trade growth between 2016 and 2050 if no emissions reduction measures are introduced (DNV GL, 2017).

The issue of emissions reduction in the shipping sector is complicated by the fact that in addition to reducing the GHG emissions, by 2020 the shipping industry have also agreed to reduce the emissions of other pollutants, especially NOx and sulphur (IMO, 2008). Achieving the latter goals by implementing scrubbers or Exhaust Gas Recirculation could increase CO_2 emissions (DNV GL, 2017). While switching to liquefied natural gas (LNG) could reduce the NOx and sulphur pollution and decrease GHG emissions by about 27% (Energy World, 2018), it would not be enough to meet either the Paris Agreement temperature goal or IMO's emissions reduction goal of halving maritime emissions by 2050.

At the same time, numerous other options for emissions reduction in the maritime sector exist. Those can be divided into replacing fossil fuels by low carbon alternatives and increasing energy efficiency. In terms of alternative fuels, replacing fossil fuels by biofuels or liquefied biogas (LBG) could reduce emissions by between 50-90%, provided the sustainability criteria are fulfilled (DNV GL, 2017). On shorter distances electrification of the ferries is already being implemented between different ports of the Nordic countries (Electrec, 2018). In the longer-term hydrogen offers an opportunity to provide an attractive alternative, provided it is generated from low-carbon electricity, the costs of the fuel cells decrease and their efficiency increase (De-Troya, Alvarez, Fernandez-Garrido, & Carral, 2016). Some examples of hydrogen-powered ships already exist (Norwegian Maritime Authority, 2017). Finally, solar and wind energy may play a complementary role, depending on the weather conditions (EEA, 2017a). While at the port, the ships can also plug into the onshore power grid ("cold ironing"), which allows them to completely shut down vessels' diesel generators (Theodoros, 2012).

In addition to fuels switch, emissions can also be reduced by modifying the ships' form which would result in fuel savings between 12-17%. Additional reduction in fuel consumption and thus resulting emissions can be achieved by machinery improvements and waste heat recovery. (DNV GL, 2017). Air lubrication that reduces the resistance between the ship's hull and seawater could reduce emissions by 10-15% (Marine Insight, 2017). Adapting the ship's course to the weather conditions such as wave height, currents and wind (weather routing), as well as reducing the speed (slow steaming), would lead to further fuel and emissions reduction (EEA, 2017a) but especially in the latter case could lead to additional costs resulting from ships underutilization.

Emissions from the shipping industry will also be influenced by the levels of consumption of fossil fuels in other areas resulting from the fact that a large share of the transported freight are fossil fuels, especially coal, LNG and oil. Therefore, decarbonisation of the other sectors of economy will also have a positive impact on reducing emissions from freight transport.

While in many cases emissions reduction in the maritime would require additional upfront investment, it would also lead to savings resulting from decreasing fuel costs. According to some estimates, introducing zero costs abatement measures for the European maritime transport would reduce CO_2 emissions in 2030 by between 15-23% in comparison to 2012. The abatement scenario utilizing all emissions reduction options would lead to emissions reduction by 28% in comparison to 2012 and by 34% in comparison to a scenario without any measures, while at the same time more than doubling the tonnage of the freight transported. In the latter case, however, it would also increase the costs of cargo transport by 26% (TNO, 2014).

Adequate carbon pricing with the perspective of an increasing carbon price in the mid- and long-term, would encourage shipping companies to introduce such investments or invest in more energy efficient vessels. Additional research and development scheme possibly funded by the EU – similarly to the European Advanced Biofuels Flightpath Project for the aviation sector - could facilitate decarbonisation of the sector, while upholding its competitiveness. The EU financed project "The Global MTTC Network" aiming at building capacity for emissions reduction in maritime shipping industry in the Least Developed Countries and Small Islands Developing States is already a step in the right direction (IMO, 2018). But it should be strengthened by more concerted action, as suggested by the European Parliament during the negotiations of the EU ETS reform post 2020, when it suggested creating a maritime climate fund to offset maritime transport CO_2 emissions, improve energy efficiency and encourage investment in technologies cutting CO_2 emissions from the sector (European Parliament, 2017a).

While emissions from maritime transport *within* the EU are covered by the EU's climate targets, and the European Commission's White Paper on transport suggests that these emissions should be reduced by at least 40% below 2005 levels by 2050 (European Commission, 2011b) the practical instruments that would facilitate achievement of this goal were lacking as the EU has largely been relying on a global approach led by the IMO for reducing emissions.

Even if more ambitious than in the case of aviation, the objective of "peaking GHG emissions from international shipping as soon as possible and to reduce the total annual GHG emissions by at least 50% by 2050 compared to 2008, whilst pursuing efforts towards decarbonising the sector as soon as possible in this century" is not fully compatible with the 1.5°C temperature goal. It is also below the emissions reduction target lobbied for by the EU which called for reducing emissions by between 70 and 100% compared to 2008 (European Commission, 2018h). Therefore, as in the case of aviation, the EU should facilitate efforts to reduce emissions from the intra-EU maritime industry, especially reflecting the broader array of measures that can be – and already are - implemented on shorter routes.

2.2.4 Conclusion

The transport sector currently constitutes the second largest source of emissions in the EU. If the worrying trend of emissions increasing continues, especially in the aviation sector, in the coming decade it could exceed the emissions from the power sector. The longevity of the transport stock, especially in the maritime and aviation sectors, will lead to carbon lock-in for the decades to come.

The EU has taken some action to change this trend and accelerate transformation towards low carbon means of transport. The currently discussed stricter emissions standards for passenger light duty cars for 2025 and 2030 combined with quotas for zero and low carbon vehicles as well as the discussion about introducing standards for heavy duty vehicles are steps in the right direction. At the same time, more action is needed to facilitate the development of charging infrastructure, currently one of the major issues for the spread of e-mobility. Introduction of the minimum targets for clean vehicle procurement (e.g. buses, light duty vehicles) in the recast of the Directive on the promotion of clean and energy-efficient road transport vehicles will decrease the costs of e-mobility through the economies of scale.

The pressure on behalf of the European institutions to adopt a global mechanism leading to CO_2 emissions reduction in the aviation and maritime sectors has contributed to reaching agreements in both sectors, with the goal for the maritime sector of halving the sectors emissions by 2050 and fully decarbonisation before 2100 significantly more ambitious than the IMO's CORSIA, which capped the net emissions at the 2020 levels with the emissions above required to be offset. The adoption of these goals does not relieve the EU from aiming at more ambitious sectoral emissions reduction goals and working towards the improvement of the existing global targets as soon as a window of opportunity opens again. In the meantime, intra-European aviation and maritime sectors should be required to implement all "no-regret" options for emissions reduction and supported in the implementation of the measures that go beyond the sectoral emissions reduction goals.

Despite this progress made by the EU in different modes of transport, its action needs to strengthen and accelerate to keep the increase of global temperature to below 1.5°C. Priority should be given to updating the current outdated 2050 goal of reducing emissions in the transport sector by 60% and aiming at decarbonising the transport sector by 2050 consistent with the Paris Agreement temperature goal. Since the adoption of the old goal in 2011 the global temperature limit has been strengthened and the array of options to reduce emissions in this sector has broadened.

The main practical repercussion of the more ambitious climate goal is that improving the efficiency of the combustion cars will not be enough to meet the goal of carbon neutrality. An EU wide approach to gradually decrease the share of such vehicles, starting with the most polluting ones, culminating in a complete phase-out the sale of combustion cars by at the latest 2035 and phase-in of low carbon alternatives including for trucks would be more effective than the piecemeal approach currently introduced by different member states as it would send a strong message to car manufacturers that the age of the combustion is nearing an end. The massive investment in the infrastructure necessary for low carbon mobility – starting from charging stations and ending with the fast speed trains – and the development of new branches of low-carbon industries, can only be done efficiently and at a speed required by the Paris Agreement if the direction of the European transport policy is clear and such investments will have a guarantee of bringing not only environmental but also economic benefits to the private sector. In relation to aviation and maritime transport, the adoption of the respective goals by the ICAO and IMO doesn't relieve the EU from aiming for more ambitious sectoral emissions reduction goals and lobbying for the improvement of the existing global targets as soon as a window of opportunity opens again. In the meantime, intra-European aviation and maritime sectors should be required to implement all the "no-regret" options for emissions reduction and supported in the implementation of the measures that go beyond the sectoral emissions reduction goals.

2.3 Buildings sector

The buildings sector accounts for 40% of energy consumption and 36% of CO_2 emissions in the European Union (European Commission, 2018d). In 2016 the residential sector alone was responsible for 25.4% of the final energy consumed mainly in the form of natural gas and electricity covering jointly over 60% of the energy needs. Only 16% of the final energy in the households was coming from renewables, with strong variety between different member states: starting with 1.7% in Ireland and 4.4% in the UK and ending with 45.9% in Slovenia and 40.2% in Romania (Eurostat, 2018d). The comparably high utilization of renewables in the household sector in these two countries is mainly due to an important role played by solar thermal and biomass for heating and hot water (EurObserv'ER, 2018).

Emissions from the sector remained relatively constant since 1990, which is the result of two countervailing trends: decreasing energy consumption by square meter by 30% and increasing size of the dwellings (European Union, 2017). While no data are available for the earlier years, only between 2000 and 2014 the total floor area of dwellings increased by 22% (European Commission, 2018f).

European legislation has played an important role in facilitating an increase in energy efficiency. According to some estimates, the EU building codes resulted in annual decrease in energy consumption by 1.2% overall and 0.5% in the new buildings (European Environment Agency, 2016). It remains to be seen what will be the impact of the recast of the Energy Performance of Buildings Directive adopted in 2018 (see section 2.3.2 for more details).

Table 9 summarises the EU's progress on the most important steps to decarbonize the buildings sector to limit temperature to 1.5°C.

Table 9: EU's progress on the most important steps in the buildings sector to limit temperature increase to 1.5°C

Sector	1.5 °C-consistent benchmark	Projection(s) under current policies	Gap assessment (qualitative)	Policy rating
Buildings sector	All new buildings fossil free and near zero energy by 2020	• Emissions from the residential sector are set to decrease by 25% and 33% by 2030 and 2050 respectively in comparison to 2005. Emissions from the tertiary sector (non-residential buildings) are projected to decrease by 33% and 43%, respectively. (European Commission, 2016f).	+The existence of legislation facilitating an increase in energy efficiency in the building sector (Energy Performance of Buildings Directive (EPBD), Energy Efficiency Directive, Renewable Energy Directive) + Adoption of a requirement that all new buildings to be near-zero emissions buildings (NZEBs) by the end of 2020 (European Parliament and the Council of the European Union 2010b, 2018b) - Lack of clear definition of the NZEBs – the specification and implementation is left to the member states.	Picking Up Speed
	Increase building renovation rates from <1% to 5% by 2020	• Most estimates of renovation rates for the EU are between 0.5% and 2.5% of the building stock/year (D'Agostino, Zangheri, and Castellazzi 2017).	- The renovation rate at 1% is well below the 5% benchmark	Ambitious Plan

2.3.1 Actionable benchmarks in buildings sector

The Climate Action Tracker identified two short-term actionable benchmarks for the buildings sector to limit warming to 1.5°C at a global level (Kuramochi et al., 2018):

- All new buildings ought to be fossil-free and near zero energy by 2020.
- The annual retrofit rates of existing building stock need to increase from less than 1% in 2015 to 5% by 2020.

The following gap analysis compares historical and projected developments in the EU buildings sector to these global benchmarks without any further adjustment to allow for comparison between countries under analysis. Country specific circumstances will be addressed in the in-depth analysis on raising ambition in the following chapters. Please refer to Kuramochi et al. for more detailed explanation on each indicator.

2.3.2 Recent policy developments

The EU has implemented several climate strategies and policies in the buildings sector, which have been implemented to a variable degree. Table 10 provides a comprehensive overview of the currently implemented and planned sectoral climate policies.

Table 10: Overview of implemented climate change policies in the buildings sector in the EU

OVERVIEW OF IMPLEMENTED CLIMATE CHANGE POLICIES FOR THE BUILDINGS SECTOR IN THE EUROPEAN UNION		
Emissions standards	**Renovation rate**	**Appliances**
• The Energy Performance of Buildings Directive (EPBD) introduced the obligation that by the end of 2018 all new public buildings and by the end of 2020 all new buildings are Near Zero Carbon Buildings (NZEBs) (European Parliament and the Council of the European Union, 2010c). The amendment of this directive adopted in 2018 expanded this goal to existing buildings in 2050 (European Parliament and the Council of the European Union 2018b). • The definition of the NZEBs was left to the member states. However Commission's Recommendation 2016/1318 provided some guidelines for the promotion of nearly zero-energy buildings and best practices to ensure that, by 2020, all new buildings are nearly zero-energy buildings (European Commission 2016c)	• The Energy Efficiency Directive adopted in 2012 introduced a goal of renovating at least 3% of the total floor of the building space owned and occupied by the central government annually (European Parliament and the Council of the European Union 2012). • The goal of increasing the renovation rate has been moved to the recast of the EPBD directive adopted in 2018. While no specific goal has been mentioned, the directive refers to 3% annual renovation rate as necessary to "accomplish the Union's energy efficiency ambitions in a cost-effective manner" (European Parliament and the Council of the European Union 2018b)	• The Eco-design Directive adopted in 2009 established a framework that allowed the European Commission to set energy efficiency requirements for energy related products (European Parliament and the Council of the European Union 2009b). This is the basis for issuing numerous regulations with eco-design requirements for different groups of products (European Commission 2018c). • The Energy Labelling Regulation from 2017 initiated upscaling of the products labelling which should last until 2030 (European Parliament and the Council of the European Union 2017).

The EU legislation dealing with energy efficiency in the building sector underwent a significant evolution since the adoption of the first directive dealing with this subject in 1993 which focused mainly on energy certification and audits of the dwellings but didn't include any specific targets (Council of the European Communities, 1993). The Energy Performance of Buildings Directive adopted in 2010 was much more specific and included a requirement that by the end of 2018 all new public buildings and by the end of 2020 all new buildings are "nearly zero-energy buildings". Its main weakness was that the definition of such buildings was left to the member states, with the directive specifying only that such buildings should consume zero or very low amount of energy, and this energy should be coming "to a very significant extent" from renewable, preferably local sources. In an attempt to further reduce the disparity between states a harmonised methodology for accounting was suggested. In addition to referencing the need for renovation of buildings albeit without specifying targets, the directive also stresses on the need for adequate reporting on heating and cooling systems and encourages the introduction of intelligent metering. Moreover, the directive offers assistance in setting up national and regional financial support programs. (European Parliament and the Council of the European Union, 2010c). According to the Commission's estimates, the EPBD Directive contributed to additional emissions reduction of 63 $MtCO_2$ in 2013. (European Commission, 2016h).

The Energy Efficiency Directive adopted two years later complemented the EPBD by stating that starting in 2014 at least 3% of the total floor of the building space owned and occupied by the central government is renovated each year, starting with the buildings with the poorest energy performance (European Parliament and the Council of the European Union, 2012c).

The recast of the EPBD adopted in 2018 obliged EU member states to establish a long-term renovations strategy that would lead to "highly energy efficient and decarbonised building stock". The directive listed a number of elements that such a strategy should include, among others, an overview of policies and actions targeting the most inefficient segments and ways in which the obstacles hindering renovation will be addressed. These roadmaps should also include indicative milestones for 2030 and 2040. The recast has also included a requirement that all new and renovated building should be equipped in devices allowing for separate regulation of temperature in each room or designated area (European Parliament and the Council of the European Union 2018b).

Beyond environmental and economic benefits, investing in building renovation leads to a reduction in energy poverty and improvements in health and well-being. Renovation of housing can lead to a reduction in housing deprivation (defined as a measure of poor amenities, calculated by referring to those households with a leaking roof, no bath/ shower and no indoor toilet, or a dwelling considered too dark. In addition, building renovation can reduce energy poverty by cutting energy bills. Moreover, this also improves indoor air conditions, decreases the incidence of respiratory disease, thus improving productivity (European Parliament, 2016b; Government of Scotland, 2017).

Appliances

While the Energy Efficiency Directive and EPBD focused on reducing emissions from heating and cooling, the Ecodesign and Energy Labelling directives aim at reducing emissions from the appliances used in the households (European Parliament and the Council of the European Union, 2009a, 2010a). Both directives complement each other: whereas the Ecodesign directive aims to encourage the industry to **produce** more energy efficient products, proper labelling allows the consumer to **select** the most energy efficient appliances.

Article 15 of the Ecodesign Directive empowers the Commission to introduce implementing measures with minimum mandatory requirements for products of which at least 200.000 are sold annually in the European Union. Such measures with respective benchmarks have already been adopted for numerous groups of products, such as ventilation, water pumps or dishwashers (European Commission, 2018e). The directives are projected to reduce emissions by 315 $MtCO_2eq$ in 2020. Moreover, the working plan for 2016–2019 includes measures that, combined, would lead to primary energy savings equivalent of over 100 TWh in 2030 (European Commission, 2016e). Impact assessments of these directives find that the measures are effective not only in reduction of emissions, but also in cost saving for end users. The latter is illustrated in a study by ANEC and BEUC, which finds that consumers save over 330 euros yearly by buying energy efficient products. According to their estimates these savings would increase to 450 euros if all new appliances fell in the best class of the energy label directive (ANEC & BEUC, 2016).

A constant increase in the efficiency of different products led to almost all products being classified between A and A++++, and the remaining labels ranging from B to G not utilized anymore. In August 2017, European Commission published Energy Labelling Regulation which repealed the initial Energy Labelling Directive from 2010 and initiated rescaling the labels which should finish by August 2030 (European Parliament and the Council of the European Union, 2017a).

2.3.3 Comparison of recent developments and projections to benchmarks

2.3.3.1 **Actionable benchmark No.5:** All new buildings fossil free and near zero energy by 2020

The Energy Performance of Buildings Directive (EPBD) directive adopted in 2010 required all new public buildings to be nearly zero-energy after 2018. This requirement was extended to all new buildings after the end of 2020 (European Parliament and the Council of the European Union, 2010c). The amendment of the directive adopted in 2018 left this requirement unchanged.

While the directive did not provide a clear definition of a near-zero energy building (NZEB), this requirement has already had an impact on the national regulation concerning the energy efficiency of new buildings. Denmark for instance introduced a limit on the maximum required primary energy consumption in new buildings which will decrease from 52.5 kWh/m^{2}y + 1650 kWh before 1990 to 20 kWh/m^{2}y in 2021 and afterwards. In Slovakia, this limit will be almost three times higher and amount to 54 kWh/m^{2}y, but nonetheless less than half of the most stringent limit before 2020 (109-216 kWh/m^{2}y). Austria and Romania belong to the countries with the least stringent absolute limits of 160 and 93-217 kWh/m^{2}y respectively. However, such a comparison is made difficult by the fact that in some countries and regions (e.g. Belgium-Flanders, Czech Republic and Germany) the limits are defined as a percentage of efficiency of a reference building, which is not yet known (BPIE, 2015).

The discrepancy in terms of stringency of the energy consumption limits has an impact on the number of new builds that may qualify as NZEBs. The numbers from 2014 – latest available in the EU Buildings Database – range from 10.000 NZEBs in Spain to 342.670 in France. In the latter case, they have to fulfil the relatively stringent limit of 50 kWh/m^{2}y (European Commission, 2018f). In 2016 the Commission published its Recommendations concerning the promotion of the NZEBs, which also referred to the issue of their definition. According to this Commission's document, the starting point of setting the efficiency requirements for new and renovated buildings should be cost-optimality understood as the lowest cost during the estimated lifecycle of the building. The Recommendations assume that for 2020 the cost-optimal levels will correspond to the NZEB levels (European Commission, 2016d).

In its periodical Report on the National Plans for NZEBs from 2016 JRC has also pointed out, that progress has been made in terms of defining such buildings since the publication of the 2013 Commission progress report on the implementation of the EPBD (JRC, 2016). In its Recommendation, the Commission expresses hope that by 2021 the minimum energy performance (determined by cost-optimality) will be close or the same as the NZEB standards, the Energy Efficiency Directive strengthens the discrepancy between the two standards (cost optimality versus NZEB) by pointing out that the 3% annual renovation rate of the public buildings can be replaced by deep renovation of a smaller share of buildings.

To improve information about the buildings' efficiency, the EPBD has also introduced the requirements concerning certification of buildings' energy performance. Such an energy performance certificate should not only reflect the energy consumption – and thus costs for the building owners – but also recommendations about the way the energy performance of the building can be improved in connection with a major renovation either of the building envelope or its technical equipment (European Parliament and the Council of the European Union, 2010c). This requirement was strengthened by the amendment of the directive adopted in 2018 which required that the energy performance of a building is expressed in kWh/m^{2}y, thus making it easier to compare it with the other buildings and the minimum energy performance requirements (European Parliament and the Council of the European Union, 2018b). The main idea of the building certification is to increase the demand for buildings with excellent energy efficiency performance and a high proportion of energy from renewable sources and thus increase their market value. This will encourage building owners or investors to renovate their building (ADENE, 2015). Increasing transparency in terms of dwellings' energy consumption offers the opportunity to complement the EU's energy efficiency requirements at the construction stage with a pull effect on behalf of buyers willing to save on the energy costs. The importance of the latter is increasing as the costs of NZEBs are only slightly above the costs of the regular houses (Passive House +, 2018).

Finally, the EPBD has also obliged member states to submit national plans presenting how they were going to increase the number of NZEBs. Such plans should describe measures and policies that the countries are adopting to increase the numbers of NZEBs. While no specific measures were suggested, this requirement put the issue of national support for energy efficiency on the national agenda in member states in which that had not been the case. This has already resulted in the introduction of a plethora of support measures for low-carbon buildings in many of the plans submitted (e.g. Government of Bulgaria, 2013; Government of Hungary, 2015; Government of Italy, 2013).

But at the same time some countries are still promoting and even subsidizing fossil fuel installations, especially for heating purposes, mostly to increase their efficiency. E.g. Poland is subsiding replacement of old central heating installations using coal with more efficient ones (WFOIiGW 2018), whereas in Germany an oil installation used for heating can benefit from 10% subsidy if it replaces an older one (KfW 2018). Understanding that this may lead to carbon lock-in has led the latter country to adopt in its Climate Action Plan 2050 a goal of making the building stock “virtually climate-neutral”, meaning “buildings with a very low energy demand which is met by renewables, and which avoid direct greenhouse gas emissions.” In the short term the plan introduces a commitment to phase out funding for replacing heating technology based exclusively on fossil fuels by 2020 (German Ministry of Environment 2016). Dutch government is aiming at replacing gas as a source of heating and cooking by clean, low-carbon alternatives (EnergyPost 2017). In the framework of the UK’s Clean Growth Strategy British government is planning to completely phase-out gas cookers and boilers by 2050 (HM Government 2017). Denmark has already banned the installation of oil or natural gas based heating boilers in new buildings, as well as oil based boilers in existing buildings and is funding conversion from fossil to renewable energy heating (IEA 2012; World 2013).

The requirement that all new buildings are NZEB starting in 2021 comes very close to achieving the Actionable Benchmark. However, despite a significant in comparison with the situation before the adoption of the EPBD, the current definitions do not assume carbon neutrality. This needs to change to make this sector compatible with the Paris Agreement temperature goal. Furthermore, the availability of information about the share of new and renovated buildings that qualify as NZEB is scarce and makes it difficult to monitor the situation.

2.3.3.2 **Actionable benchmark No.6:** Increase building renovation rates from <1 to 5% by 2020

With 90% of the European dwellings built before 1990 (European Parliament, 2016a) and the average age of the existing building stock in the EU at 55 years (JRC, 2016), deep renovation offers significant potential for low cost or even cost neutral climate change mitigation. This potential has already been recognized by the European institutions which included a requirement in the Energy Efficiency Directive of renovating at least 3% annually of the total floor area of publicly owned buildings starting in 2014. The renovated buildings should meet the minimum energy performance standards outlined in the EPBD. Alternatively, member states could choose deep renovation of a smaller share of the buildings or promotion of behavioural changes, which could result in at least an equivalent reduction in energy consumption. The measures that the member states would implement to achieve this goal were to be published in the National Energy Efficiency Action Plans submitted by every member state by the end of April 2014 and every three years thereafter (European Parliament and the Council of the European Union, 2012a). Only seven member states decided to fulfil the first requirement of 3% renovation rate. One of these countries, Spain, reserved the right to complement this requirement by an alternative approach of promoting behavioural changes (Spanish Ministry of Industry Energy and Tourism, 2013). For the majority of the countries that decided to introduce behavioural changes or deep renovation to achieve energy savings equivalent to those resulting from an annual 3% renovation rate, the measures are described in very general terms and their impacts is impossible to quantify (European Commission, 2018c).

The Energy Efficiency Directive has also required EU countries to design long-term national building renovation strategies to be included in their National Energy Efficiency Action Plans. This requirement has subsequently been moved to the revised EPBD, which stresses the role of financial mechanisms, energy performance contracts and public private partnerships in increasing the renovation rates. Member states are also encouraged to take advantage of “trigger points”, explained as moments in the life cycle of a building, which makes an investment in energy efficiency especially cost-effective (European Parliament and the Council of the European Union 2018b).

It remains to be seen whether the EU legislation will improve the current situation in which the renovation rate is too slow and too shallow amounting to only between 1-2% annually (European Parliament, 2016a). The quantification of the renovation rate in the EU is made difficult by the different depths of that renovation. For instance, in 2012 France had a renovation rate of 13.3% while Germany had a much lower renovation rate of 0.87%. However, comparisons between these two numbers is difficult exactly because of the different depths of the renovation and thus the reduction in the CO_2 emissions. This issue has to some degree been solved by the methodology developed in the framework of the ZEBRA2020 project, which uses an equivalent major renovation rate which accounts for these differences and attempts to use a representative renovation rate as a basis for comparison amongst countries. When the difference is accounted for, the equivalent major renovation rate for France is 2% while that of Germany is 1.49%. Out of the 13 EU countries for which the numbers are available, renovation rate in six of them doesn't exceed 1%, with the lowest renovation rate in Spain (0.08%) and Poland (0.12%) (ZEBRA2020, 2017).

The significant differences in the renovation rate – as well as the depth of the renovation – has had an impact on the trends in energy consumption per square meter. Between 2000 and 2014 the average energy consumption per square meter of residential space decreased in the EU by 25% with the largest decrease exceeding 30% in the UK, Germany, Austria, Netherlands, Ireland and Romania. Despite this improvement, building stock in the latter country belonged in 2014 to the most inefficient in the EU with energy consumption of 298 kWh/m^2. Largely due to the weather conditions, average energy consumption was the lowest in Malta (48 kWh/m^2), Cyprus and Portugal (70 kWh/m^2 both) (EU Building Database, 2018).

Focussing on low and medium renovation diverts resources away from prospective deep renovation projects. This has two repercussions. First, it diverts *funding* away from deep renovation projects. The difficulty in accessing finance has already been highlighted as a significant barrier, and this barrier is exacerbated. Further, a building which undergoes a certain level of renovation is, in effect "*locked in*". These buildings are unlikely to be renovated further for a significant period further compromising the ability to meet the 1.5°C- compatible limit.

At the same time improvement in efficiency of the building stock is facing numerous barriers. Lacking awareness of the financial benefits and technical possibilities is one of the major challenges. For rented buildings, the owners may not be willing to make an investment that would result in lower energy for tenants, especially in cases where the additional costs cannot be recovered through higher rents. For home owners, the high upfront investment poses a major barrier, especially in the Eastern European countries where the running energy costs make it difficult to accumulate enough savings for such an investment (European Commission, 2016b; The World Bank, 2014). In addition, subsidies and tax exemptions introduced in some of the member states to reduce the issue of energy poverty (EEA, 2017b) decrease the competitiveness of low carbon alternatives. Overcoming these barriers to implementation will be key to achieving a 1.5°C-consistent emissions pathway for the buildings sector.

2.3.4 Conclusion

The buildings sector is of great importance to achieving the temperature goal of the Paris Agreement for two reasons: Firstly, with 36% of emissions and 40% of energy consumed in the EU, it is the single largest source of emissions, and secondly due to the durability of the buildings as most of the dwellings built now will still be there when the goal of carbon neutrality will have to be reached. Therefore, not only should the new buildings be characterized by low energy consumption fully generated from renewable sources of energy, but also the deep renovation rate need to be increased significantly.

With the revision of relevant legislation (EPBD, Energy Efficiency Directive, Ecodesign Directive and Energy Labelling Regulation) the European Union has created a legal framework that constitutes a step in the right direction. But there are serious weaknesses in the legislation that threaten the achievement of the goal enshrined in the Paris Agreement. The first such weakness is the disparity between the minimum energy performance requirements compared to the Near Zero Emissions Buildings standards and the narrow understanding of cost-optimality, which excludes economic, environmental and social benefits of deep renovation.

This disparity is further exacerbated by fact that each member state is to develop its own standards according to the respective guidelines, is counterproductive and may lead to carbon lock-in resulting from too shallow renovation. This is especially the case for public buildings, 3% of which will need to be renovated annually according to the minimum standards mentioned in the Energy Efficiency Directive. Furthermore, some buildings that fulfil these standards may not be renovated at all due to the narrow understanding of cost-optimality, which excludes the economic, environmental and social benefits of deep renovation.

This discrepancy between the minimum energy performance requirements and the NZEBs standards contributes to another problem: outdated and incomplete information about the situation of the building infrastructure in the EU, including the renovation rate and the number of NZEBs. In mid-2018 the EU Building Database only provides numbers for 2014 thus making it difficult to assess the impact of the European legislation on the energy efficiency and renovation rate of the building stock in the EU. As a result, it also difficult for the member states to assess the effectiveness of different kinds of policy measures and thus select those that work best.

2.4 Industry sector

Between 1990 and 2015 EU's emissions from the industry sector have decreased both, in absolute terms (-38%) and as the share of the overall, emissions (from 25% to 21%) (Eurostat, 2018g). This decline in emissions is largely due to improved efficiency, decreased carbon intensity of energy, and structural changes to the economy with a greater share of services.

Around a quarter of the industry emissions are coming from three energy intensive sectors: chemicals, steel, cement. Emissions reduction in the latter is challenging due to the large share of process emissions which thus cannot be reduced by replacing fossil fuels by renewables. For steel, replacing coal with hydrogen generated from renewable sources - as discussed in Sweden (SSAB 2018) - is one of the promising solutions towards zero emissions steel. Over the last decade the decrease in emissions was mostly due to decreased activity in these two sectors: between 2007 and 2015 steel production in the EU decreased by 21% and cement by 38% (Cembureau, 2018; World Steel Association, 2017).

Emissions in the industry sector can be reduced by two complementary measures: carbon pricing and research and development of alternative, low and zero carbon technologies that can contribute to decarbonisation in the long term. Both measures are implemented in the EU with a modest rate of success, with the EU ETS granting numerous exception to the energy intensive industries to avoid carbon leakage, and the major research and deployment program, ULCOS, failing to facilitate decarbonisation in the steel sector.

Table 11: EU's progress on the most important steps in the industry sector to limit temperature increase to 1.5°C

Sector	1.5 °C-consistent benchmark	Projection(s) under current policies	Gap assessment (qualitative)	Policy rating
Industry sector	All new installations in emissions-intensive sectors are low-carbon after 2020, maximise material efficiency	• Emissions from industrial processes are projected to decline by 10.4-10.9% between 2015 and 2035. Decline in emissions from manufacturing sector should be smaller: between 2.8 and 5.1% in the same period (EEA 2017c)	+ Industrial installations are included in the EU Emissions Trading Scheme (EU ETS). + Financing of low carbon technologies in the framework of NER 300 funding programme and in the future in the framework of the Innovation Fund - Emissions allowances granted for free up to a certain BAT benchmark - Results of R&D not yet implemented broadly.	Getting Started

2.4.1 Actionable benchmarks in industry sector

The Climate Action Tracker identified one short-term actionable benchmark for the industry sector to limit warming to 1.5°C at a global level (Kuramochi et al., 2018):

- All new installations in emissions-intensive sectors need to be low carbon after 2020 such as low-carbon steelmaking technologies, including carbon capture and storage (CCS) and material efficiency needs to be maximized.

The following gap analysis compares historical and projected developments in the EU industry sector to this global benchmark without any further adjustment to allow for comparison between countries under analysis. Country specific circumstances will be addressed in the in-depth analysis on raising ambition in the following chapters. Please refer to the publication for more detailed explanation on each indicator.

2.4.2 Recent policy developments

EU's climate policies in the industry sector have been influenced by, on one hand, an attempt to facilitate emissions reduction and develop low carbon alternatives to the established technologies, while on the other by the real or perceived risk of carbon leakage especially in the case of energy intensive sectors, such as steel, cement and chemicals. Since high energy and carbon costs could decrease the competitiveness of the products manufactured in the EU, the associations representing the energy intensive industries attempted to weaken the measures that would lead to carbon pricing (Alliance for a #FairETS, 2017; CEFIC, 2017; EUROFER, 2016). At the same time, some studies confirmed, that a number of different factors play an even more important role in investment decisions and thus the issue of carbon leakage didn't play a major – if any – role in siting energy intensive industries (C.I.R.E.D., 2013; DECC, 2014; Neuhoff et al., 2014a).

As a result, the European climate policy in the industry sector is a balance act between the need to reduce emissions and the protection of the competitiveness of the European industry – especially the energy intensive sectors. This resulted in providing sectors covered by the EU ETS with free allowances up to a certain benchmark and funding development and deployment of low carbon technologies in the sector from public sources.

In addition, European Commission is influencing emissions from the manufacturing industry by promoting circular economy. Its Circular Economy Package presented in 2018 listed a number of measures that would decrease plastics production by either increasing their durability or making them easier to recycle (European Commission, 2018a).

Table 12: Overview of implemented climate change policies in the industry sector in the EU.

OVERVIEW OF IMPLEMENTED CLIMATE CHANGE POLICIES FOR THE INDUSTRY SECTOR IN THE EUROPEAN UNION			
Changing activity	**Energy efficiency**	**Development of low carbon alternatives (process and products)**	**Incentives to reduce fluorinated gases**
• EU Circular Economy Package introduced a number of measures to reduce waste generation, with implications for emissions from manufacturing sector (European Commission, 2018a)	• The industrial plants have from the beginning been included in the EU ETS mechanism but granted emissions allowances for free. While this is still the case in Phase 3 (2013-2020) and Phase 4 (2021 2030), the number and subsectors granted allowances for free will be substantially reduced (European Parliament and the Council of the European Union 2018a). • Directive 2010/75/EU requires member states to take into consideration the Best Available Technologies (BAT) for the respective technology when issuing permits for the construction of new industrial plants (European Parliament and the Council of the European Union, 2010d)	• NER 300 programme made funding for large scale, low carbon technologies (including CCS that could be utilized in industrial plants). However most of the funding went to renewable energy projects (European Commission, 2018i) • Innovation Fund was established with the reform of the EU ETS for the period post 2020 and will be funded from the sale of 400 million allowances (current value around €8 billion) (European Parliament and the Council of the European Union 2018a)	• Directive 2006/40/EC (so called "MAC Directive") bans the utilization of refrigerants with GWP higher than 150 in mobile air-conditioning systems utilized mainly in passenger cars (European Parliament and the Council of the European Union 2006). • Regulation 517/2014 introduced the goal of reducing emissions of fluorinated greenhouse gases ("F-gases") in 2030 by around 80% in comparison to 2014 (European Parliament and the Council of the European Union 2014d) • In September 2018, the EU ratified the Kigali Amendment to the Montreal Protocol that requires the EU to start reducing HFC consumption in 2019. It still need to be ratified by individual EU member states (European Commission 2018e). By 2036 the EU should consume 85% less HFC than on average in years 2011-2013 (+15% HCFC) (UNEP 2016).

Industry GHGs emissions in the EU are regulated both, in the framework of the EU ETS (large installations, mainly chemical, cement, steel and iron plants) and the non-EU ETS (product use, smaller plants). To avoid the risk of carbon leakage, installations in some selected sectors or subsectors were given allowances for free up to a certain benchmark. Whether or not a given sector or subsectors is considered as threatened by carbon leakage was determined by two factors:

- There is a significant risk that carbon pricing would lead to costs increase by at least 5%, and
- the total value of imports and export of given products to countries beyond the countries covered by the EU ETS, exceeds 10% (European Commission, 2009).

Those sectors were granted free allowances up to the level corresponding to the benchmark of 10% most greenhouse gas efficient installations in 2007 and 2008 (European Commission, 2011c). A point of criticism was that as long as the annual production volume of an installation didn't fall below 50%, the investors were nonetheless receiving full allowances allocations – the rest of which could be sold. This allowed some investors to underutilize some installations to reach this threshold in the other installations of the same company (Neuhoff et al., 2014a). According to some estimates, the provision of free allowances led to windfall profits for energy intensive companies between 2008 and 2014 of €24 billion (CarbonMarketWatch, 2016).

The reform of EU ETS adopted in 2018 presupposes reduction of the number of allowances that companies will receive for free in Phase 4 (post 2020). This will result from the following measures:

- Starting in 2026 the number of allowances for sectors and subsectors for which there will only be low risk or no risk of carbon leakage will be significantly reduced. There should be no free allocations for these sectors in 2030.
- The benchmarks used to determine the number of free allowances will be reviewed to reflect technological progress in the respective sectors.
- The amount of free allowances will be closer aligned to the actual production levels.

Free allocation of allowances will still be granted to district heating and high efficiency cogeneration installations (European Parliament and the Council of the European Union, 2018a).

The EU has also taken action to reduce its emissions of the fluorinated gases (F-Gases), which are responsible for almost 2.8% of EU's GHG emissions (EEA 2018b). Already in 2006 it adopted a directive phasing out utilization of refrigerants with the Global Warming Potential GWP) higher than 150 in mobile air-conditioning systems used mainly in passenger cars (which gave it the name "MAC Directive") (European Parliament and the Council of the European Union 2006). In 2014 Regulation 517/2014 introduced the goal of reducing emissions of fluorinated greenhouse gases in 2030 by 80% in comparison to 2014 and banned their utilization in products where less harmful alternatives are "widely available". It has also introduced additional requirements that should reduce F-gases emissions by training and certification (European Parliament and the Council of the European Union 2014d). The EU was also playing an active role in international negotiations that led to the adoption of the Kigali Amendment to the Montreal Protocol. The document ratified by the EU in September 2018 (with ratification by EU member states still pending) requires the EU to start reducing HFC consumption in 2019 (European Commission 2018e). By 2036 the EU should consume 85% less HFC than on average in years 2011-2013 (+15% HCFC) (UNEP 2016).

2.4.3 Comparison of recent developments and projections to benchmarks

2.4.3.1 **Actionable benchmark No.7:** All new installations in emissions-intensive sectors are low-carbon after 2020, maximise material efficiency

Industrial installations, especially in the cement and steel sectors, are characterized by their longevity: e.g. the majority of the European blast furnaces are older than 35 years, with some of them built in the 1960s (OECD, 2013). As a result, while incremental changes are possible and in many cases already implemented to reduce energy costs (OECD, 2015), major technological changes would require significant investments to change the technological processes. This has two repercussions for 1.5°C compatible emissions pathway for emissions-intensive sectors: firstly, all new installations built after 2020 need to be low carbon, and secondly, the deployment of low carbon technologies in the sectors that may be affected by carbon leakage should be co-financed by public sources.

In Phase 3 of the EU ETS, the proceeds from the sale of 300 million allowances were to be invested in projects contributing to emissions reduction. Due to the low prices of emissions certificates the sale of these allowances generated only €2.1 billion. Among the 38 projects funded by these resources, only one was dealing with carbon capture storage (European Commission, 2018i). The reform of the EU ETS adopted in 2018 provides groundwork for the creation of Innovation Fund fed from the sale of 400 million allowances. At the current price of almost 20€ per allowance that would result in €8 billion investment, some of which should flow into substituting carbon intensive technologies by low-carbon alternatives (European Parliament and the Council of the European Union, 2018a).

While this funding could provide the low-carbon technologies in the area of industry with the necessary boost to enter the market and steadily replace the high-carbon modes of production, it must be ensured that these resources are utilized in an effective way. Already in 2004 the European Commission began funding the Ultra-Low CO_2 Steelmaking project (ULCOS) aiming at investigating process routes that could reduce specific emissions by at least 50% (Birat, 2005). After four such production pathways were developed, the implementation of the results was stalled due to the discontinuity of funding and the lack of long-term business case for low carbon steel resulting from the low prices of emissions allowances (Neuhoff et al., 2014b) – most of which were provided to the industry for free.

While the ways in which low carbon technologies are supported in the challenging sectors, especially steel and cement, can be improved, it also necessary to move towards circular economy by encouraging reducing, reusing, replacing and recycling (Climate Action Tracker, 2017). Especially for the EU, where steel demand is expected to increase only slightly until the middle of the century (Boston Consulting Group & Steel Institute VDEh, 2013), scrap recycling utilizing low carbon electricity presents itself as an opportunity at decarbonisation. Emissions from the cement sector could be partly reduced by replacing clinker – which production generates process emissions and thus cannot be reduced by increasing the share of renewables – by low carbon alternatives that are being developed by some companies and research institutes (Celitement, 2018; CO2Upcycling, 2018; Technology Review, 2015).

2.4.4 Conclusion

The specific character of the emissions in different industry sectors – especially steel and cement - requires going beyond carbon pricing. Long-term *perspective* of steadily increasing costs of carbon is needed to facilitate investment in new, low carbon technologies and products to ensure such an investment will be profitable, following the example of Sweden aiming at decarbonising its steel production as part of their objective to become carbon neutral by 2045 (Government Offices of Sweden 2018). Investments in low-carbon technologies could be further incentivised with an effective utilization of public funding, especially in the case of high costs and risky technologies, especially where no economically viable alternatives exist. The Innovation Fund may provide the right incentives provided that the significant resources at its disposal are distributed in the most effective way and contribute to the marketization of technologies with the largest cost reduction potential.

Reduction of emissions also need to go beyond the development of new modes of production. Transition towards circular economy offers the potential to significantly reduce upstream emissions. In most cases – especially steel - recycling would allow switching to electricity, which would have to be largely decarbonized in the coming decade. While carbon pricing could play a role in decreasing consumption of new products and facilitating reusing and recycling, behavioural changes are necessary to make a step change in this respect.

2.5 Agriculture and forestry

The EU land-use sector is already a net sink for greenhouse gases, with emissions from croplands, settlements and wetlands more than compensated for by removals in grasslands and forests. In 2016 these removals from the LULUCF sector accounted to almost 7% of the EU's GHG emissions. However, the size of the sink is projected to decline over the next decade from 309 MtCO$_2$eq to 233 MtCO$_2$eq (European Environment Agency 2017d).

Agricultural emissions made up about 11% of the EU's greenhouse gas emissions in 2014 (EEA, 2017k), about half of these emissions coming from agricultural soils, a third coming from enteric fermentation in cattle, sheep and goals, and most of the remainder being associated with manure management (Eurostat, 2015). Between 1990 and 2012 a fall in livestock numbers and a reduction in the use of nitrogen fertilisers caused the EU's agricultural emissions to decrease by almost one quarter (23.8%) (Eurostat 2012). These changes were driven largely by economic transformation in newer EU member states, increased efficiency in the livestock sector, and changing agricultural practices. However, the pace of decline has reversed in recent years. In total, between 1990 and 2015 emissions from the agriculture sector decreased by 20.1% (European Environment Agency 2017d).

Table 13: EU's progress on the most important steps in the LULUCF and commercial agriculture sectors to limit temperature increase to 1.5°C.

Sector	1.5 °C-consistent benchmark	Projection(s) under current policies	Gap assessment (qualitative)	Policy rating
LULUCF	Reduce emissions from forestry and other land use to 95% below 2010 by 2030, stop net deforestation by 2025	• EU net sink of emissions from the LULUCF sector is set to decrease from over 300 MtCO$_2$eq to between 230-240 MtCO$_2$eq in the 2030s (European Environment Agency 2017d).	+ In all but three EU member states (Denmark, Ireland, Netherlands) emissions from the LULUCF sector are negative (EEA 2018b) + EU LULUCF Regulation adopted in 2018 introduces a "no debit" rule according to which emissions from land use are to be entirely compensated by an equivalent removal of CO$_2$ emissions in the sector (European Parliament and the Council of the European Union 2018g) - Between 2021-2030 up to 280 MtCO$_2$ for emissions reduction in the LULUCF sector can count towards the non-ETS sectors (European Parliament and the Council of the European Union 2018h)	Partionally Transitioned
Commercial Agriculture	Keep emissions in 2020 at or below current levels, establish and disseminate regional best practice, ramp up research	• Implementation of existing measures would lead to emissions from the agriculture decreasing by 1.6% between 2015 and 2035. Implementation of additional, planned measures would reduce emissions by 3% in the same period (EEA 2017c)	+ EU has already implemented comprehensive accounting rules for emissions from the agriculture sector and facilitated adoption of measures by the member states reducing emissions from agriculture and forestry. In 2017 679 such measures existed in all EU member states (IEEP 2017). + The reform of the EU Common Agricultural Policy (CAP) in 2015 led to the adoption of "green payment" which is granted if practices leading to carbon sequestration are implemented (European Commission 2015a) • + The CAP encourages research into improving agricultural production efficiency and building a sustainable agricultural industry, with support from the Horizon 2020 research and innovation framework	Picking Up Speed

2.5.1 Actionable benchmarks in agriculture and forestry

The Climate Action Tracker identified two short-term actionable benchmarks for the agriculture and forestry sector to limit warming to 1.5°C at a global level (Kuramochi et al., 2018):

- Emissions from forestry and other land use needs to be reduced to 95% below 2010 by 2030 and a stop of net deforestation to be achieved by 2025.
- Emissions from commercial agriculture in 2020 need to be kept at or below current levels with the simultaneous establishment and dissemination of regional best practice and a ramp up of research.

In addition, the Climate Action Tracker has identified important steps towards reducing emissions in the agriculture sector both on the demand and on the supply side: Reducing food waste, shifting to healthy diets, and implementing best farming practices, such as efficient fertiliser have a substantial mitigation potential and large benefits for public health (Climate Action Tracker 2018c, 2018a) .

The following gap analysis compares historical and projected developments in the EU LULUCF and commercial agriculture sectors to these global benchmarks without any further adjustment to allow for comparison between countries under analysis. Country specific circumstances will be addressed in the in-depth analysis on raising ambition in the following chapters. Please refer to the publication for more detailed explanation on each indicator.

2.5.2 Recent policy developments

The EU's climate strategies and policies in the agriculture and forestry sectors have been implemented to a variable degree.

Table 14 provides a comprehensive overview of the currently implemented and planned sectoral climate policies with the potential to affect GHG emissions directly.

Table 14: Overview of implemented climate change policies in the agriculture and forestry sector in the European Union.

OVERVIEW OF IMPLEMENTED CLIMATE CHANGE POLICIES FOR THE AGRICULTURE AND FORESTRY SECTORS IN THE EUROPEAN UNION	
Forestry	**Agriculture**
• Regulation 2018/841 introduces the no debit rule according to which emissions from one land use category should be compensated with removals from another one. This rule is weakened by the possibility of transfers between member states and accumulation in the period 2021-2030 (European Parliament and the Council of the European Union 2018g)	• Regulation 1306/2013 introduced green direct payments. Their payment to the farmers is conditional on fulfilling a number of criteria, including carbon sequestration (European Parliament and the Council of the European Union 2013). • Nitrates Directive (91/676/EEC) aims at reducing surplus nitrate levels in water bodies throughout the EU (The Council of the European Communities 1991).
Emissions reduction goals	
• In the European Union emissions from the agriculture sector are covered under the non-EU ETS legislation. Effort Sharing Decision from 2009 included the goal of reducing emissions from that sector in 2020 by 10% in comparison to 2005. The Effort Sharing Regulation adopted in 2018 increased this goal to 30% in 2030. Both documents included specific emissions reduction goals for each of the EU member states. This Regulation also allows for utilization of up to 280 $MtCO_2eq$ of removals from the LULUCF sector in the non-EU ETS sector (European Parliament and the Council of the European Union 2018h, 2009a).	

2.5.3 Comparison of recent developments and projections to benchmarks

2.5.3.1 **Actionable benchmark No.8:** Reduce emissions from forestry and other land use to 95% below 2010 by 2030, stop net deforestation by the 2020s

At the national level, EU Members States are committed under the Kyoto Protocol to ensure that all emissions from land-use, land-use change and forestry are compensated by an equivalent absorption of CO_2 through activities in the forest and land-use sectors. This commitment has been extended beyond 2020 with the adoption of the EU LULUCF Regulation and applies to each EU member state – including three countries in which emissions from the LULUCF are higher than the equivalent absorption: Denmark, Ireland and the Netherlands (EEA 2018b; European Parliament and the Council of the European Union 2018g).

In parallel the EU adopted another regulation, that allows the utilization of up to 280 $MtCO_2eq$ (in total in the period 2021-2030) from the LULUCF sector to account for emissions in the in other sectors (European Parliament and the Council of the European Union 2018h). While this would still allow the EU to stay within the Actionable Benchmark, it would allow for weakening climate action in the other sectors, especially the transport, agriculture and buildings sectors, where higher emissions could be compensated through, for example, land management and reforestation.

2.5.3.2 **Actionable benchmark No.9:** Keep emissions in 2020 at or below current levels, establish and disseminate regional best practice, ramp up research

Climate action in the agricultural sector is covered by two main policy instruments: The Effort Sharing Regulation (ESR) and the Common Agricultural Policy (CAP). The scenarios used to develop this policy assumed relatively little abatement effort in the agricultural sector, with a maximum reduction of 20% below 2005 levels by 2030 (European Commission, 2016k), resulting in 2030 emissions at the same level as in 2015 (between -1.6 and -3%). The projections assume that more ambitious agricultural mitigation are much costlier and significantly affect agricultural production. However, some potentially cost-effective technology solutions—such as changes in feed mix for addressing enteric fermentation—have not been included (European Commission, 2015a).

The CAP includes some provisions for climate change and the environment, with a quarter of its budget for 2014–2020 related to climate (European Commission, 2008), and focuses on encouraging compliance with EU environmental laws and promoting a shift towards climate-smart agriculture. For example, in 2015 the CAP introduced the "Green Direct Payment"—a grant provided for implementing certain practices with proven benefits for biodiversity, water, soil, and carbon sequestration. In addition, the CAP encourages research into improving agricultural production efficiency and building a sustainable agricultural industry, with support from the Horizon 2020 research and innovation framework.

In addition, policies to reduce pollution from agriculture also have an impact on greenhouse gas emissions, such as the Nitrates Directive that aims to reduce surplus nitrate levels in water bodies throughout the EU by limiting nitrogen fertiliser application on farms and requiring certain management practices (The Council of the European Communities 1991).

2.5.4 Conclusion

In its climate action in the forestry and agriculture sector, the EU can rely on a long experience, especially with the Common Agricultural Policy (CAP) being one of the EU's initial areas of integration. While it has led to significant overproduction and high corresponding GHG emissions, the recent reforms, e.g. the introduction of the Green Payments, is a clear example of mainstreaming climate policy to other sectors. At the moment of writing the impact of the most recent reform of the EU's CAP is still being evaluated (European Commission 2017a) The EU and its member states have to address emissions from the agriculture sector systematically in their climate strategies, tapping into the mitigation options on the demand and supply side with large benefits for public health.

EU's goal of "no debit" emissions in the LULUCF sectors – with the largest contribution of emissions/sequestration coming from the forestry – is a step in the right direction. However, instead of allowing for part of the emissions sequestrated to be used to account for slower action in the other sectors, EU's policy should reflect the limited potential of that sector for carbon sequestration and the need to sequestrate significant amount of emissions in the coming decades due to a significant delay in climate action(IPCC 2018a).

3 Selection of focus areas for analysis on scaling up climate action

The report prioritises three areas for in-depth analysis on scaling up climate action in the European Union: the electricity supply sector, the road transport sector, and the residential buildings sector which together cover xx% of greenhouse gas emissions in the EU. The selection of focus areas in no way indicates that less mitigation action needs to happen in all other remaining sectors. Relevant literature in the field and most recent emission scenarios clearly indicate that all sectors need to maximise their efforts for Paris Agreement compatibility (Kuramochi et al. 2018). The selection of focus areas for scaling up climate action is based on following criteria combined with expert judgement by the authors.

i. **GHG emissions:** The relevance of the (sub-)sector in terms of historical and projected future GHG emissions
ii. **Existing gap**: The existing gap between currently existing and planned policies and 1.5°C compatible benchmark(s)
iii. **Potential for scaling up climate action:** The potential for enhancing climate action given local and global sectoral development (e.g. decreasing prices for RE technologies, pending investment in infrastructure)
iv. **Priority in the national discourse:** Priority of the respective (sub-)sector in the national discourse or window of opportunity to enhance climate action due to recent social, political, or economic developments
v. **Overlaps with other sectors:** The (sub-)sector's overlap with other sectors relevant for long-term decarbonisation (e.g. CO_2-neutral electricity sector in parallel to electrification trends in the transport or buildings sector)
vi. **Co-benefits potential and sustainable development goals:** Potential to realise co-benefits of scaling up climate action in a given country context (e.g. local job development through ambitious renewables deployment or reduction in urban air pollution due modal shifts away from combustion engines), especially linking to the country's sustainable development goals

The following sections provide explanation for each sector selection, also considered the technical feasibility of the research for the sectors, for example data availability might be a limiting factor.

3.1 Electricity sector

The focus on the European electricity sector justified by the significant share of emissions coming from the sector, combined with a strong trend towards decarbonisation in recent years. Electrification of the other sectors will further increase the impact of the sector's decarbonisation on EU's emissions.

- **GHG emissions:** in 2017 over 23% of the overall CO_2 emissions in the EU were coming from the electricity sector. In absolute terms emissions from this sector increased slightly from 1018 $MtCO_2$ in 2016 to 1019 $MtCO_2$ in 2017 (Agora Energiewende and Sandbag, 2017, 2018). The trend of electrification of the other sectors, which has already contributed to an increase in power consumption by 0.7%, may further increase CO_2 emissions from the electricity sector unless electricity decarbonisation is accelerated.
- **Existing gap:** The continuation of the rate of renewables' development, whose share in the electricity generation grew between 2007 and 2016 by on average 1.35% annually (Eurostat, 2017), would only lead to a share of power from renewables at around 75% in 2050. This doesn't take into consideration a slow-down in 2017, when the share of renewables has only increased by 0.4%. As a result, meeting the 1.5-compatible benchmark of 100% renewables in 2050 will be increasingly challenging. A slowdown in renewables development will also make it more challenging to decrease coal combustion by at least 30% by 2025 and completely phasing out coal by the end of the next decade (Climate Analytics, 2017c).
- **Potential for increasing ambition:** A significant decrease in the costs of renewables, potential for job creation and high acceptance for renewables development

(Renewable Energy Agency, 2016) offer the opportunity to increase the level of ambition and accelerate the rate of renewables development. Increasing opposition to coal driven by the contribution of the power plants to the air pollution and destruction caused by the open-pit mining for lignite makes coal phase-out, accompanied by structural support for the affected regions, easier to implement.

- **Overlaps with other sectors**: The flexibility of electricity makes it possible to replace other forms of energy in other sectors. The electrification of transport is progressing and according to the earlier projections could increase power demand in the EU by between 6 and 9.5% in 2050 (Öko-Institut, 2016). Some countries are also introducing lower tariffs for electricity to encourage electricity utilization for heating purposes instead of coal or wood, as a way to deal with smog (Reuters, 2018a). Finally, in the long-term low-carbon electricity can facilitate decarbonisation of more challenging sectors, such as steel (Climate Action Tracker, 2017; Neuhoff et al., 2015).
- **Co-benefits potential:** increasing the share of renewables in the power sector and phasing out coal will lead to significant benefits by reducing air pollution (EEA, 2017j) as well as the costs of natural gas and coal imports. Due to the distributed character of renewables it will also lead to job creation especially in rural areas often affected by high levels of unemployment.

3.2 Passenger road and rail transport

Differently from the other sectors, emissions from the road transport sector in the EU have been increased steadily over the recent years, thus increasing the gap to Paris Agreement compatible emissions pathway. At the same time, the recent trends offer new opportunities at emissions reduction. The calculations in the subsequent section show what impact a more active utilization of this potential could have on the EU's overall emissions.

- **GHG emissions:** The transport sector is the second largest source of emissions responsible for 22% of the overall EU emissions in 2015 – and it is the only sector where emissions are increasing - increase from 14.5% in 1990. Almost three quarter of these emissions are coming from the **road transport** (EEA, 2017g)
- **Existing gap:** Increasing emissions from the transport sector take the EU further away from the 1.5°C-compatible emissions pathway and require rapid acceleration in the sale of the zero-emissions cars, reduce unnecessary transport, increase the utilization of public transport and moving from road-to-rail or other modes of transport such as bicycles, walking (modal shift).
- **Potential for increasing ambition:** Decreasing costs of batteries (Lazard, 2017) open new opportunities for decarbonisation of the power sector. At the same time, increasing the frequency and quality of zero-carbon public transport, especially in the cities, can have a positive impact on the quality of life and those increase the acceptance for measures leading to an accelerated decarbonisation.
- **Overlaps with other sectors**: Reducing emissions from the transport sector by replacing combustion engines by electric vehicles will require decarbonisation of the power sector.
- **Co-benefits potential:** Replacement of combustion cars by low/zero-carbon alternatives would also significantly reduce air pollution. Reduction in road traffic, especially trucks and motorbikes, would also reduce noise pollution. The public space utilized for parking could be utilized in a much more effective way to the benefit of the local communities.

3.3 Residential Buildings

The longevity of the building sector makes is essential to achieving long-term decarbonisation. In addition to lower energy consumption and energy, adoption of energy efficiency measures and generation of energy on-site from renewable sources would result in significant savings and increasing quality of life

- **GHG emissions:** Buildings are responsible for 40% of energy consumption and 36% of CO_2 emissions. Between 1990 and 2015 emissions from the *residential* building sector decreased only slightly from 9.3% to 9.1%.
- **Existing gap:** Introducing standards requiring near zero energy buildings and increasing the annual retrofit rate to 5% is essential to not only reduce emissions in the short term, but also to avoid carbon-lock in the longer term as many of the buildings planed or built at the moment will still exist in 2050, when emissions from the building sector need to reach zero.
- **Potential for increasing ambition:** Some countries have already introduced near zero emissions standards for the building sector and banned installation of fossil fuel heating. The improvement in materials, especially the introduction of insulating glass, allows to significantly reduce heat losses.
- **Overlaps with other sectors**: Electrification of the transport sector allows to utilize the oversupply of power produced by the so called “active houses” for the transport sector.
- **Co-benefits potential:** Increasing the efficiency of the buildings sector will significantly reduce energy poverty. Elimination of fossil fuels will reduce the issue of air pollution, especially from the low stack sources.

4 Scenario analysis of scaling up climate action in European Union

This section presents scenario analysis supporting scaling up climate action in the European Union for three focus sectors: electricity supply, passenger transport, and the residential buildings sector. We quantify the emissions reduction achieved through enhanced climate action and corresponding co-benefits based on the selection of three different scenario categories as elaborated below. This scenario analysis allows to identify the overlaps, or the gaps, between sectoral transformations under the reference scenario projections, sectoral transitions required to be compatible with the Paris Agreement's temperature target. Additionally, we investigate the sectoral transformations demonstrated by international frontrunners and existing EU-specific scenarios.

1 EU SCENARIOS

2 BEST IN CLASS SCENARIOS

3 1.5°C PARIS AGREEMENT COMPATIBLE SCENARIOS

1.5°C Paris Agreement compatible scenarios

The category of '1.5°C Paris Agreement compatible scenarios' comprises sectoral indicator values, which are in line with a 1.5°C compatible sectoral emissions trajectory. The analysis in this scenario category enhances the general understanding about required sectoral transformations in the EU context to be in line with the Paris Agreement's temperature goal.

Applying best-in-class level(s)

The scenario category 'applying sectoral best-in-class level(s)' identifies indicator values from international and regional frontrunner(s) on national climate action in the respective (sub-) sector. The absolute indicator level(s) or growth rate(s) are applied to the developments in the respective sector. The analysis in this scenario category reveals the sectoral implications if sectoral transitions achieved by international frontrunners are replicated at an EU scale.

EU scenarios

The scenario category 'EU scenarios' comprises sectoral indicator levels obtained from analyses conducted particularly by European research institutions and universities. Such analyses mainly include long-term, least-cost modelling studies for the whole EU energy sector or at sectoral level. The analysis in this scenario category aims to illustrate the sectoral decarbonisation pathways proposed by recent studies focusing on the EU.

4.1 Electricity supply sector

The Paris Agreement compatible sectoral trajectories almost fully decarbonise the electricity sector by 2050. The most ambitious end of the range of best-in-class and EU-specific scenarios also lead to the near complete decarbonisation of the EU electricity sector by mid-century, reducing emissions by 97-99% below 1990 levels. In general, this scenario analysis indicates that scaling up climate action in the electricity supply sector of the European Union can achieve significant emissions reductions beyond reference scenario projections by 2050 for all scenario categories.

For the scenario quantification with the PROSPECTS EU scenario evaluation tool, total renewable share in electricity generation (RES) is selected as a representative indicator. Figure 8 and Table 15 present the value ranges for the RES indicator for each of the three scenario categories.

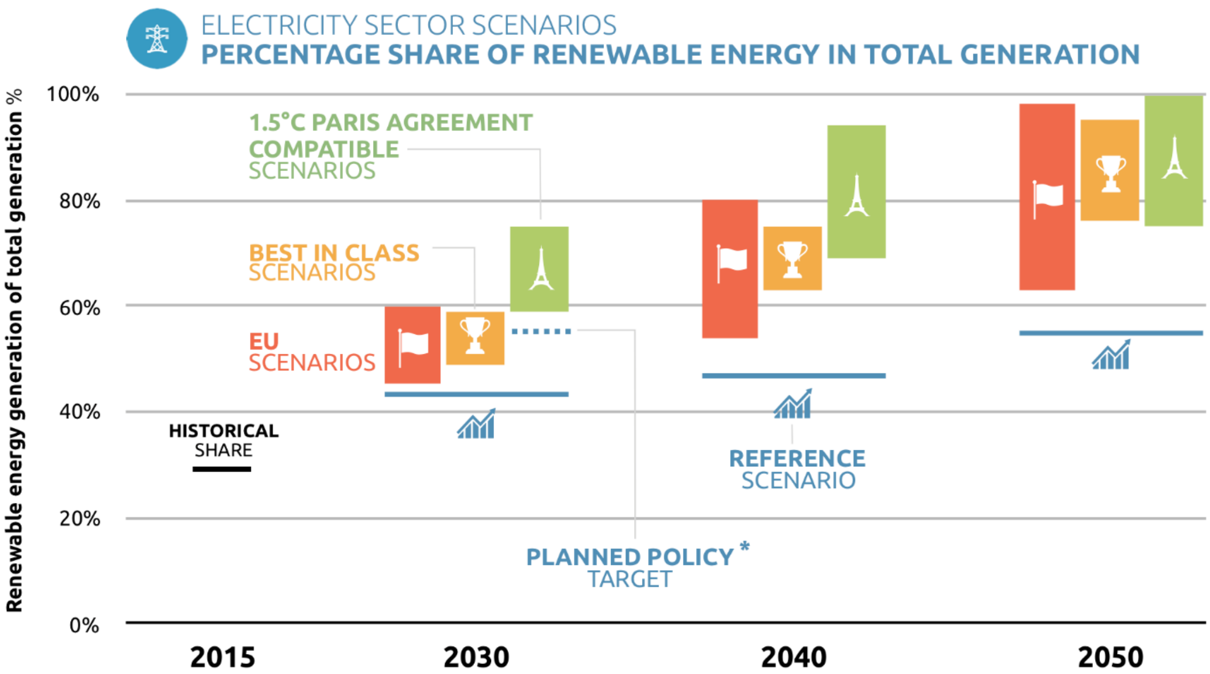


*Figure 8: RES indicator range for three different scenario categories compared to historical share and the new EU-RE target (*planned policy: based on the new EU target of 32% share of renewables in final energy consumption by 2030 corresponding to 55% share of renewables in total electricity production* (European Commission 2018i)*).*

Table 15: Outcome overview of scaling up climate action in electricity sector for European Union.

Reference Scenario Projection (RSP)	EU scenarios	Best-in-class scenarios	1.5°C Paris Agreement compatible scenarios
29% by 2015	**-**	**-**	**-**
43% by 2030	**45-60% by 2030**	**49-59% by 2030**	**59%-75% by 2030**
47% by 2040	**54-80% by 2040**	**63-75% by 2040**	**69%-94% by 2040**
55% by 2050	**63-98% by 2050**	**76-95% by 2050**	**75%-100% by 2050**
Based on PROSPECTS EU tool developed by Climate Action Tracker (2018) applying PRIMES REF Scenario projections for fuel mix.	*Based on 'Default Scenario' by Gerbaulet (2017) and 'Climate Market Scenario' by Odenberger et al. (2015) and 'high cost VRES-E' scenario by Knopf et al. (2015).*	*Based on s-curve VRES approach (CWF EU CTI Model) by Hagemann et al. (NewClimate, 2017) and values identified in the literature* (Fekete et al. 2015a).	*Based on electricity mix projections from the 'ADV ER Scenario' by Greenpeace et al. (2015) and 'B2DS Scenario' from ETP 2017.*

Required policy measures for sectoral transformation	Remaining challenges threatening implementation
⇨ Introduce policies that would accelerate development of renewables ⇨ Introduce measures increasing the flexibility of the electricity grid (demand management, storage, Power-To-Gas ⇨ Coal phase out in all relevant Member states by 2030, and additional measures flanking coal phase-out to avoid negative social repercussions	⇨ Development of renewables too slow to decarbonise electricity generation by the middle of the century ⇨ Underdeveloped electricity grid unable to cope with increasing share of variable renewables ⇨ Too slow decrease of coal in the power sector

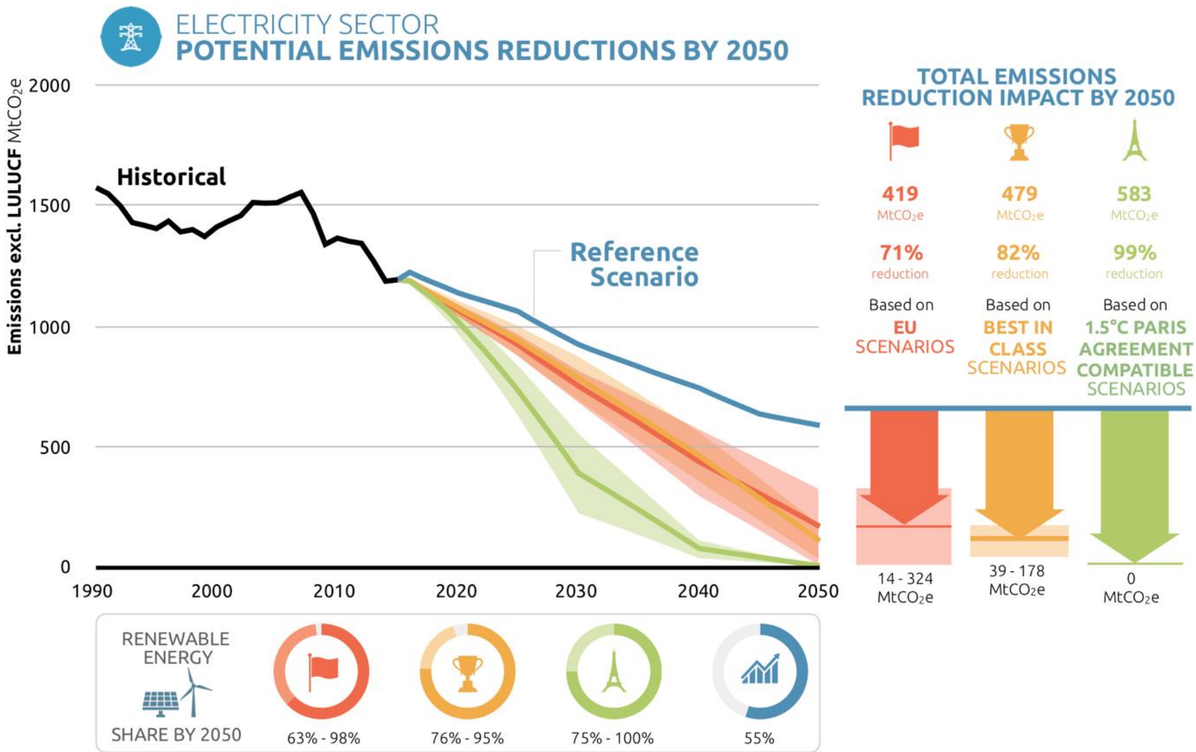


Figure 9: Overview of sectoral emission pathways under reference scenario projections and different levels of accelerated climate action in the European electricity supply. All sectoral projections towards 2050 done with the CAT PROSPECTS EU scenario evaluation tool. The electricity-related emissions from end-use sectors are included.

The projected share of renewables in electricity in 2030 (43%) and 2050 (55%) (reference scenario) is below all of the three scenario categories. The new RE target adopted by the EU (32% share of renewables in final energy consumption) corresponds to the share of 55% in electricity by 2030 (European Commission 2018i) is also below Paris Agreement scenarios and the most ambitious end of best-in-class scenarios. It corresponds to the middle of the range derived from EU scenarios. Adopting best-in-class levels would lead to the share of renewables between 6 and 16% higher than the reference scenario projections and between 1% and 11% higher than planned policy in 2030. By 2050, the share of renewable electricity under best-in-class levels exceeds reference scenario projections by 21-40%-points. Compatibility with the Paris Agreement would require levels of renewable electricity by 16-32%-points higher than reference scenario projections and 11-27%-points higher than planned policy in 2030, while exceeding reference scenario projections by at least 2%-points in 2050. The EU scenarios represent a renewable share which is between 2 and 17%-points higher than the reference scenario in 2030 and exceeds the reference scenario by 8-43%-points.

4.1.1 Context for scaling up climate action in the electricity sector in the EU

Saving costs through increasing share in renewables generation

- Since almost 86% of the currently existing coal power plants in EU were built in the last century (Platts 2018) and around 82% of them do not fulfil the EU's new emissions standards for air pollutants, their continuous operation would require costly investments (DNV GL-Energy 2017). Eventually, even without an ambitious climate change policy, those plants would have to be replaced within the coming decades. The most recent analysis shows that already in 2018 solar and wind energy offered a more cost-effective alternative than the construction of new coal power plants (Fraunhofer ISE 2018).
- Replacing fossil fuels by renewables would lead to significant savings. According to a study by the IRENA, increasing the share of renewables in the gross final energy mix to 34% in 2030 would result in net, accumulated, cost savings of up to $165 billion between 2020 and 2030 between 2020 and 2030 in comparison to the reference

scenario. These savings result from the lower LCOE of renewables in comparison of fossil fuels and do not include external savings (IRENA 2018a).

- Significant savings resulting from increasing the share of renewables have been confirmed by the EU's complimentary modelling prepared before the adoption of the renewable energy and energy efficiency goals. They show that increasing the share of renewables to 30% in 2030 would be €3.5 billion cheaper annually than reaching 27% share of renewables according to the costs of renewables used in the Commission's 2016 Impact Assessment. While the investments in new electricity generation capacity would increase in parallel with the increasing level of ambition, this higher cost would to a large degree be compensated by lower fuel costs (European Commission 2018i)

Coal phase-out on its way in many EU member states

- By mid-2018, 10 out of 28 EU member states accounting for 26% of EU coal capacity have set phase-out goals by 2030. The first ones to phase out coal are France (2021) and Sweden (2022). The United Kingdom, Ireland, Italy, and Austria are planning to phase out coal from the electricity sector by 2025. Denmark, the Netherlands, Finland and Portugal set phase-out dates by 2030 (BeyondCoal 2018). In Germany, the largest emitter of CO_2 from coal in the EU, a newly-created commission is addressing this issue and will propose the date for coal phase-out. The Spanish government is also discussing the need to phase out coal.
- Some countries are still planning to increase their reliance on coal. Poland is currently building an additional unit with the capacity of up to 450 MW in Turów and completing the construction of a hard-coal power plant in Opole with the capacity of 1.8 GW. The state owned electricity utilities are also planning to build two coal-fired power plants in Jaworzno (910 MW) and Ostrołęka (1 GW) (CIRE 2018). Especially the profitability of the latter one has been put in doubt (BiznesAlert 2018). The finalisation of the only two coal-fired power plants still under construction in Germany, Datteln 4 and Stade, has been delayed with none of them coming into operation before 2020 (NDR 2017; WDR 2018). Much smaller coal power plants are currently under construction in Czech Republic and Greece (Platts 2018).
- A growing number of companies are hesitant to invest in new coal power plants and the modernisation of the older ones due to the pressure from their stakeholders, increasingly stringency of the environmental legislation, decreasing costs of renewables and threat of high costs of emissions allowances in the future.
- A major issue in some EU member states, especially Germany, is the role of lignite. Between 2013 and 2017 consumption of this most carbon intensive source of energy has decreased by only 11% - in comparison to 23% decrease in hard coal consumption in the same period. In Germany, responsible for almost 45% of the overall lignite demand within the EU, consumption decreased by only 6% over the last five years (Eurostat 2018n). The low fuel costs of this source of energy resulting from the lack of internalisation of external costs, state subsidies and the threat of structural unemployment in case of coal-phase out is slowing down the transformation.

Integration of variable sources of energy

- Replacing fossil fuels by mostly wind and solar energy in the electricity sector poses the challenge of balancing electricity supply and demand. According to IRENA, increasing the share of renewables in the energy sector to 33% would lead to 50% share of renewables in the electricity sector, with 29% coming from variable renewables (IRENA 2018a).
- Due to the variety of renewables – including dispatchable sources such as hydro energy and biomass, and to a lesser degree CSP – the EU is well positioned to deal with this issue, with northern European countries putting more emphasis on wind, both onshore and offshore, and southern European countries taking advantage of the higher levels of solar radiation. Development of interconnections is essential to take advantage of the

complementarity of resources between different EU member states. In October 2014 the Council adopted a goal to increase the interconnection between the EU member states to at least 10% of their respective installed electricity generation capacity by 2020 (Council of the European Union 2014). The EU's governance regulation increases this goal to at least 15% by 2030 (Council of the European Union 2018b).

- Sector coupling, demand management, power-to-gas, distributed generation and storage, offer significant opportunities for integration of large share of intermittent sources of energy. According to the Smart Energy Europe Scenario investigating options for 100% renewables-based energy generation in the EU, utilisation of only one of these options – replacing natural gas by methane generated using renewable electricity - would allow for the share of intermittent source of energy in the electricity sector to reach 83% (Connolly, Lund, and Mathiesen 2016).

Job benefits

- In 2016 there were over 1.4 million people working in the renewable energy sector in the European Union, including 309,000 in wind energy sector and 95,900 in PV (EurObserv'ER 2018). A 100% renewables-based scenario would increase this number to 10 million (Connolly et al. 2016). Due to the distributed character of renewables, many of those jobs could be created in rural areas with few other employment opportunities.
- The European Union is one of the major importers of fossil fuels. In 2017 it spent over €260 billion on the import of fossil fuels, including €16.3 billion on the import of hard coal and €53 billion on the import of natural gas (Eurostat 2018f). Decarbonisation of the electricity sector combined with the electrification of the transport and heating sectors would significantly improve EU's trading balance (EPRS 2016).
- Currently 53,000 people work in coal-fired power plants and further 185,000 in operating coal mines. While the jobs in the power plants are more dispersed across the EU, lignite mining (normally combusted on the spot) is focused in a handful of regions in Germany, Poland, Czech Republic and Greece, while hard coal mining is focused in a few regions in Poland, Czech Republic, Romania and Bulgaria (JRC 2018b). The heavy concentration of these jobs in a few regions may lead to negative consequences in the form of structural unemployment. For this reason in December 2017 the Commission established the Platform for Coal Regions in Transition to assist EU Member States and regions in structural and technological transition in coal regions (European Commission 2017b).
- Accelerating the development of renewable in the electricity sectors to levels compatible with the Paris Agreement would lead to lead to over 295,000 more direct jobs in renewable energy in 2020 compared to the reference scenario, and almost 400,000 more direct RE-jobs in 2025 and about 375,000 in 2030, outweighing job losses in fossil-based technologies by far. In 2025, the estimated job creation in renewable energy is six times higher than the reduction in fossil-based direct jobs for the same year compared to the reference scenario. In 2030, almost 80% of direct jobs in electricity generation are in RE (excluding large hydro), compared to 55% in the reference scenario.

4.1.2 Scenario analysis for scaling up climate action in the electricity sector

4.1.2.1 Identification of indicator levels

Table 16 represents RES indicator levels identified for three different scenario categories. The RES indicator values have been directly used as input to the PROSPECTS EU scenario evaluation tool to quantify the emissions trajectories for the EU's electricity supply sector across all scenarios.

Table 16: Identification of indicator levels for analysis on scaling up climate action in the EU's electricity supply sector

	Reference Scenario Projection (RSP)	EU scenarios	Best-in-class scenarios	1.5°C PA compatible scenarios
Share of renewables in total electricity production[2]	29% by 2015	-	-	-
	43% by 2030	45-60% by 2030	49-59% by 2030	59%-75% by 2030
	47% by 2040	54-80% by 2040	63-75% by 2040	69%-94% by 2040
	55% by 2050	63-98% by 2050	76-95% by 2050	75%-100% by 2050
References	*Based on PROSPECTS EU tool developed by Climate Action Tracker (2018) applying PRIMES REF Scenario projections for fuel mix*	*Based on 'Default Scenario' by Gerbaulet (2017) and 'Climate Market Scenario' by Odenberger et al. (2015) and 'high cost VRES-E' scenario by Knopf et al. (2015*	*Based on s-curve VRES approach (CWF EU CTI Model) by Hagemann et al. (NewClimate, 2017) and values identified in the literature* (Fekete et al. 2015a)	*Based on electricity mix projections from the 'ADV ER Scenario' by Greenpeace et al. (2015) and 'B2DS Scenario' from ETP 2017*

1.5°C Paris Agreement compatible scenarios

The review of relevant literature identifies a range of 59% to 75% by 2030, 69% to 94% by 2040, and 75% to 100% by 2050 for the renewable energy share (RES) in total electricity generation of the European Union to be in line with the 1.5°C Paris Agreement's temperature target. The benchmark values have been derived from the following literature:

Upper bound of RES indicator range:

- The upper bound of RES indicator is based on the 'Advanced Energy Revolution (ADV E[R])' scenario by the Greenpeace International, Global Wind Energy Council and Solar Power Europe (Greenpeace 2015). This scenario has been developed using a primarily "bottom-up" approach (technology-driven) using the Mesap/PlaNet simulation model. This model does not use a cost optimization approach for the calculation of energy technology expansion rather it requires a consistent exogenous definition of feasible developments in order to meet the targets. The ADV E[R] scenario represents an ambitious pathway towards a fully decarbonised global energy system by mid-century. By 2050, 100% of the electricity produced worldwide comes from renewable energy sources. A rather fast introduction of new efficient technologies and applying other mitigation measures such as fundamental changes of consumption patterns leads to a complete decarbonisation of the global energy system by mid-century.
- Strong efficiency improvements and dynamic expansion of renewable energy in all sectors are the main strategies to meet the overall target of CO_2 emission reductions. CCS technologies are not implemented, and nuclear and lignite power plants are phased out quickly, followed by hard coal power plants. The global quantities of biomass power generators and large hydro power remain limited in the Energy [R]evolution scenarios, for reasons of ecological sustainability.

[2] For the specification of three scenario categories for the purpose of quantification with PROSPECTS EU scenario evaluation tool, renewable share in total electricity production is selected as the representative indicator, while other indicators are kept at the same level of Reference Scenario

- Wind power and solar power (both photovoltaics and concentrating solar power (CSP)) are expected to be the main pillars of future power supply, complemented by smaller contributions from geothermal (hydrothermal and Enhanced Geothermal Systems (EGS)), ocean energy and the further expansion of small and medium sized hydro power.
- The modelling results indicate a RES share of 75% by 2030, 94% by 2040, and 100% by 2050 for OECD Europe. This is also in line with the higher ambition end of the share of electricity generated by renewables and other zero and low carbon sources as envisaged by the recent 1.5°C scenarios (IPCC 2018).
- The IPCC SR1.5 Summary for Policy Makers focusses on assessing 1.5°C compatible mitigation pathways that limit global warming to 1.5°C, or below throughout the 21st century with no or limited (0.1°C) overshoot. These pathways envisage a renewable share in total electricity generation of 42-60% by 2030, 64-78% by 2040 and 68-91% by 2050 for the OECD region (OECD90+EU). In addition to these pathways a wide range of scenarios have been developed globally and regionally analysing a transition to 100% renewable energy generation, such as the scenario used here.

Lower bound of RES indicator range:

- The lower bound of RES indicator value is based on the "Beyond 2°C scenario (B2DS)" by the IEA Energy Technology Perspectives (ETP) 2017 (International Energy Agency (IEA) 2017)[3]. The B2DS provides a close analogue to a 1.5°C compatible pathway for the EU power sector by 2050 (see Box below). The B2DS results indicate a RES share of 59% by 2030, 69% by 2040, and 75% by 2050 for the European Union. The share of hydro does not vary considerably over time, while its share reaches to 13% of total electricity production by in 2050. The share of biomass power remains limited, reaching 12% of total electricity production by 2050, while the renewable energy mix is dominated by solar and wind energy. The share of other low-carbon energy sources such as nuclear reaches 25% by 2050.
- Thus, the share of renewables in power generation based on the ETP B2D scenario is comparable with the lower ambition end of the share of electricity generated by renewable sources from the recent 1.5°C scenarios. At the same time, an increase in nuclear energy to 25% is highly unlikely for the EU given the rising costs of nuclear energy (UCS 2018), especially if compared with the rapidly decreasing costs of dispatchable renewables and storage (Lazard 2018). Far from building new nuclear power plants, several member states are planning to phase out nuclear energy or decrease its role as described in Section 2.1.3.1. While the UK, Poland, Hungary, and Czechia are planning to invest in this source of energy, their plans are far from realisation. In its long-term vision, the European Commission assumes a much lower—but nonetheless optimistic—share of nuclear at 15% by the middle of the century. Realistically, a higher share of dispatchable renewable energy would be expected instead and at a lower cost.

Box 2 IEA B2DS and 1.5°C compatibility

Whilst the IEA estimated that the B2DS pathway has a peak global warming of 1.75°C above pre-industrial with a 50% likelihood, both our own analysis and that of the IPCC confirm that it provides useful information on 1.5°C compatible pathways up to at least 2050.

We evaluated the IEA B2DS pathway applying the same climate model approach to warming levels as was used in the IPCC SR1.5 and earlier IPCC AR5, enabling a comparison of "like with like" with the IPCC 1.5°C compatible scenario set.

As IEA provides only energy-related CO_2 emissions land-use and non-CO_2 GHG emissions need to be estimated. In it is own estimation of the peak warming level the IEA assumed that non-CO_2 GHG would add about 0.35°C to the CO_2 only warming. For a full climate-model simulation one needs to assume

[3] The ETP model is the primary analytical tool used in ETP 2017, which enables a technology-rich, bottom-up analysis of the global energy system. For a discussion of 1.5°C-compatibility see Box 'IEA B2DS and 1.5°C compatibility'.

pathways for non-CO_2 emissions and air pollutants. Rogelj et al (2015; 2018) showed that the key difference between 1.5°C compatible pathways and "likely below 2°C" scenarios is in CO_2 emissions, because the potential to reduce non-CO_2 emissions is seen as essentially the same as "likely below 2°C" scenarios. As non-CO_2 scenario information is available most extensively for "likely below 2°C" scenarios in the public database of IPCC SSP-RCP2.6 scenarios. Consequently, to evaluate the IEA B2Ds scenario we used the average of RCP2.6 scenarios (SSP2 representing middle-of-the-road socio-economic and technical developments) to characterize non-CO_2 emissions. In addition, we assumed CO_2 emissions from the land sector also follow the average of these scenarios, reaching largest amounts of annual removals of about -2 $GtCO_2$/yr around 2060, which we note is within the sustainable potential estimated by IPCC SR1.5 at around -3.6 $GtCO_2$/yr by 2050.

For energy related CO_2 emissions the IEA adopted a pre-defined assumption that there would not global negative CO_2 from the energy sector (IEA 2017), which is a feature of nearly all 1.5°C compatible pathways after 2050-2060. It is important to note that IEA B2DS energy sector CO_2 emissions reach net zero around 2060, supported by negative emissions through deployment of bioenergy with CCS, but are not allowed by assumption to lead to globally negative emissions. We extended the B2DS post 2060 with negative CO_2 from the energy sector comparable with 1.5°C compatible pathways.

To evaluate the global warming consequences of the B2DS scenario through 2100 we used the carbon-cycle/climate model MAGICC (Meinshausen, Raper, and Wigley 2011) in the same configuration used for IPCC's Fifth Assessment Report (IPCC 2014) and in the IPCC SR1.5.

The results of this evaluate show that after accounting for non-CO_2 GHGs as described above B2DS reaches a peak warming of 1.6°C above pre-industrial by 2060 and stays around that level afterwards. In contrast to 1.5°C compatible pathways in the IPCC SR1.5, warming does not drop to below 1.5°C after the peak.

Extending the B2DS energy related CO_2 emissions beyond 2060 to include negative CO_2 emissions comparable to those in 1.5°C compatible pathways leads to peak warming dropping below 1.5°C after the peak at 1.6°C.

It is clear that the IEA's predefined assumption of no net negative CO_2 from the energy sector leads to warming not reducing after the peak at 1.6°C and that if this is relaxed the B2DS is consistent with the IPCC compatible 1.5°C pathways.

The IPCC SR1.5 has also considered the utility of B2Ds for providing information on 1.5°C consistent pathways. In Chapter 2 of IPCC Special Report on 1.5°C, the B2DS scenario is shown to be consistent with 1.5°C pathways in terms of emissions up to 2060 (see section 2.4.3 and Figures 2.18, 2.19 and 2.20). While emissions intensity by 2050 in the power and industry sectors in the B2DS pathway are above those typical for 1.5°C pathways, B2DS emissions intensity is lower in the transport and buildings sectors. IPCC SR1.5 concludes that "… although its temperature rise in 2100 is below 1.75°C rather than below 1.5°C, this [B2DS] scenario can give information related to 1.5°C consistent overshoot pathway up to 2050." The IPCC did not conduct a like-for-like comparison of the full global warming consequences of the B2DS scenario, which as shown above results in a 1.6°C peak warming.

With these considerations, it is clear that both the energy-related CO_2 emissions in the B2DS scenario up to 2060, and its peak warming at 1.6°C around 2060 are comparable to low-overshoot 1.5°C scenarios. The B2DS scenario until 2060 is confirmed to be a suitable analogue to 1.5°C compatible pathways

Applying best-in-class levels

Applying best-in-class levels of international frontrunners in raising the renewable energy share in total electricity generation resulted in a RES indicator range of 49-59% by 2030, 63-75% by 2040, and 76-95% by 2050. The upper and lower bound of RES indicator level has been derived as described below:

- **Upper bound of RES indicator range**: The modelling logic for the uptake of variable renewables (VRES), i.e. solar and wind, is based on the definition of a s-curve shaped 'good practice' trajectory, defining the upper bound of potential uptake of variable renewables as well as a 'no policy' curve for the least ambitious case. The 'good practice' curve is fitted based on the historical growth in the share of VRES in total electricity generation in Denmark between 2009 and 2015, which went from 19.2% in 2009 to 39.2% in 2015. The saturation level has been defined by Denmark's long-term target of 100% renewable electricity generation by 2050. To determine the current policy curve of an EU member state, the impact of policies and drivers are modelled by shifting the logistic growth curve between the "no policy" and "good practice" options using two factors, namely a factor defining the ceiling and a factor driving the pace of growth. The methodological approach is elaborated in (Hagemann et al. 2017). However, the s-curve based approach to apply best-in-class levels faces a few limitations:

  - The approach focusses on variable renewables only while not modelling the uptake of other low-carbon electricity generation technologies and dealing with phase out schedule of fossil-based generation. The approach allows the user to set values by 2050 for biomass, nuclear, and hydro generation informed by the lifetime of currently existing capacity and/or use external projections for non-VRE sources until 2050.
  - The methodology is based on an elaborated policy analysis for five major EU Member States in terms of total annual electricity generation (Germany, France, Spain, Poland, United Kingdom) as well as Romania which was chosen as a representative South-Eastern European country. For all other EU Member States projections were directly taken from the PRIMES energy model.

- **Lower bound of RES indicator range**: A linear increase of 1.35 %-points per year in the EU's share of renewable-based electricity generation is assumed as the lower bound. The annual increase in %-points is informed by average growth rates of renewable energy in the United Kingdom and in Germany after the implementation of ambitious renewables support policies as identified by (Fekete et al. 2015a). The results for the European Union with a share of renewable-based electricity generation of 30% in 2015 (incl. hydro) are 49% by 2030, 63% by 2040, and 76% by 2050. This linear approach faces the limitation that no dynamic uptake in the renewable energy can be incorporated, especially when reaching the natural threshold of 100% in total generation. Furthermore, the breakdown into renewable energy technologies as well as the share of non-renewable energy sources need to be derived based on external scenario projections until 2050.

EU scenarios

Indicator values for the so-called 'EU Scenarios' have been inspired based on recently published modelling studies by European research institutions and universities. The RES indicator ranges derived from those studies are 45-60% by 2030, 54-80% by 2040, and 63-98% by 2050. The range of indicator values have been derived based on the studies described below and in the annex:

- **Upper bound of RES indicator range**: The upper bound of the RES indicator range is derived based on the 'Default scenario' by (Gerbaulet 2017). Quantification by (Gerbaulet 2017) has been conducted by applying the least cost optimization over the time horizon until 2050 using the dynamic investment and dispatch model of the European electricity system 'dynELMOD'. The 'Default Scenario' anticipates an overall moderate electricity demand increase as well as an almost complete decarbonisation of the electricity sector in Europe until 2050. It assumes perfect foresight over the entire horizon (2015–2050), while the central decision maker faces a yearly CO_2 constraint, which reduces carbon dioxide emissions by 2050 to only 2% of the current level. Due to high investment costs, no new nuclear power plants are built, and therefore nuclear power generation is reduced over time as older plants reach the end of their technical lifetime. Renewable become the dominant electricity source in Europe. In the absence of carbon capture technology due to high costs, lignite and coal are phased out as no new coal capacities emerge.

- **Lower bound of indicator range**: The lower bound of indicator values are based on a combination of the 'high cost vRES-E' scenario by (Knopf et al. 2015) and the 'Climate Market Scenario' by (Odenberger et al. 2015). The analysis conducted by (Knopf at al 2015) provides a model-based sensitivity study of the long-term decarbonisation of the EU's electricity system by applying the LIMES-EU model. The pathway implies an emission reduction of about 95% compared to 1990 for the EU's electricity system with a 52% reduction to be achieved by 2030. The intermediate annual emission limits are decreasing linearly between 2010 and 2050, resulting in a 52% reduction by 2030 compared to 1990. Renewables constitute 45% of total electricity production in 2030, while the share of other low-carbon energy sources such as nuclear reaches 17% in 2030. CCS is applied for the combustion of lignite, hard coal and natural gas. In the default scenario, the same vRES-E investment costs have been used as in the Impact Assessment. The scenario 'high cost vRES-E 'assumes that investment costs of vRES-E technologies (wind and solar) will develop less favourably and therefore constitutes the least ambitious scenario concerning the projected share of RES. Modelling results indicate a RES indicator level of 45% by 2030 for the 'high cost vRES-E' scenario. The analysis by (Odenberger et al. 2015) has been conducted through a least-cost optimization approach over the entire time horizon until 2050 by applying the long-term dynamic optimization model of the European electricity system 'ELIN (Electricity Investment) model'. The 'Climate Market Scenario' assesses the consequences of a stringent climate-mitigation target in the EU, but concentrated exclusively on reducing CO_2 emissions, and not, specifically, on increasing the share of renewables and efficiency. CO_2 emissions from electricity generation are to be reduced by 50% by 2030 and 93% by 2050, as compared to the levels in year 1990. Modelling results indicate a RES share of 38% by 2030 (because the RES share in 2030 goes below the reference scenario projections, is not included in our scenario analysis) and 63% by 2050. The share of hydro does not vary considerably over time, while the 2050 share reaches to 10%. The share of biomass rises to 18% by 2050. The share of other low carbon energy sources such as nuclear reaches 27% in 2050. As mentioned earlier, the decreasing competitiveness of the nuclear energy in comparison to renewables makes the realisation of this scenario less probable than scenarios with a much higher share of renewables.

To derive the upper and lower bound of RES indicator range as elaborated above, we considered several EU-specific studies and scenarios developed by various European research institutions and universities. The RES-E share from those scenarios stay within the indicator range specified above; therefore, not further considered here. Please see the annex for a brief overview on all the studies and scenarios we considered for this assessment.

4.1.2.2 Quantification of emission levels with PROSPECTS

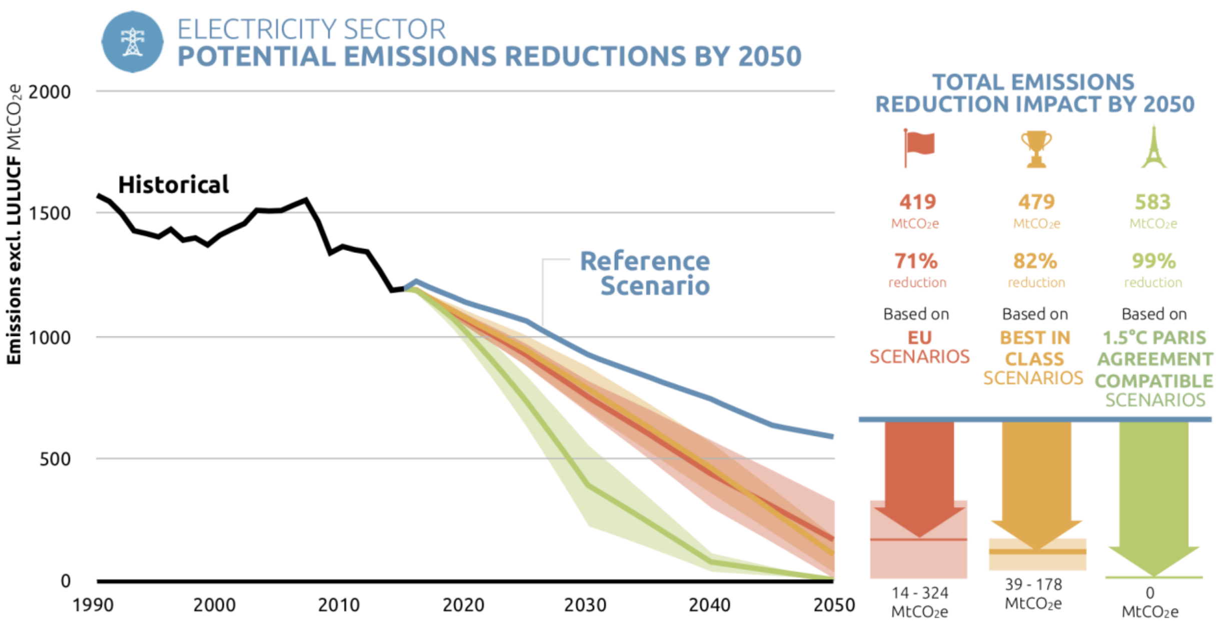


Figure 10: Overview of sectoral emission pathways under reference scenario and different levels of accelerated climate action in the European electricity supply. All sectoral projections towards 2050 done with the CAT PROSPECTS EU scenario evaluation tool. The electricity-related emissions from end-use sectors are included.

Figure 10 shows the emissions trajectories from electricity generation until 2050 for different scenario categories. Under the reference scenario projections, the emissions in 2050 are by 63% lower than 1990 levels. All resulting pathways based on enhanced climate action in the EU's electricity sector lead to emissions substantially lower than reference scenario projections by 2050. The pathways vary in the level of emissions reached by 2050 and the pace of reduction:

- The **'1.5°C Paris Agreement compatible'** pathways imply an immediate and drastic reduction of today emissions from electricity generation and lead to a full decarbonisation of electricity sector by mid-century. This is mainly driven by a quick ramp-up of renewable electricity generation and decreasing coal power. The annual average rate of emissions reduction varies from -4% p.a. to -5% p.a. until 2030 for the lower and upper end of ambition, respectively and followed by -5% p.a. pace of reduction until 2050. Both '1.5°C Paris Agreement compatible' scenarios almost fully decarbonise the electricity sector by 2050. For comparison, the recent 1.5°C compatible pathways from the SR1.5 scenario database (IPCC SR15, 2018) identify a reduction rate of -1% p.a. to -6% p.a. for CO_2 emissions from electricity supply for the OECD region over 2010-2030 and a rate of -3% p.a. to -17% p.a. over 2030-2050.
- The **'Applying best-in-class levels'** implies an immediate and drastic reduction of emissions under the higher ambition trajectory, which leads to a near complete decarbonisation of the EU's electricity supply sector by mid-century, reducing emissions by 98% from 1990 levels. The lower end of ambition leads to higher emissions, which are 89% below 1990 levels.
- The **'EU scenarios'** pathway reveals a broad range across the upper and lower ambition trajectory. The upper ambition end implies an immediate and quick reduction of emissions mainly driven by an ambitious ramp up of renewable power, while the lower end of ambition positions slightly below the reference scenario projections until 2030. The upper ambition end implies a fast reduction of emissions, while leading to an almost complete decarbonisation of the EU's electricity sector by 2050. The lower end of ambition leads to an emission reduction of 79% rel. to 1990 levels.

4.1.2.3 Quantification of employment impacts in the electricity sector for the different scenarios

An estimation quantifying the impact on direct employment in electricity generation reveals that ambitious climate policy can yield substantial employment benefits for the EU. We estimated direct jobs in the electricity sector in the EU differentiating by technology[4] and job type[5] for all scenarios for the years 2020 to 2030. We apply an employment factor-based approach suggested by (Rutovitz, Dominish, and Downes 2015) (see Appendix 2 for a detailed description of the methodology, underlying assumptions and limitations). In all 'Scaling Up Climate Action' scenarios, the total number of direct jobs in the electricity sector from 2020 throughout 2030 is higher than the estimated total jobs in the reference scenario (see Table 23 in the Appendix). We find that on average there are between about 350,000 (ambitious end) and 200,000 (lower bound) more direct jobs in the '1.5°C Paris Agreement compatible' scenario set than in the reference scenario over the period 2020 to 2030. The average net employment impact in the 'Best-in-Class' scenario set is between about 180,000 (ambitious end) and 106,000 (lower bound), and in the EU scenario set we estimate between about 190,000 (ambitious end) and 142,000 (lower bound) more direct jobs than in the reference scenario. Figure 11 shows the estimated total direct jobs in the electricity sector averaged over the period 2020 to 2030, and highlights the respective net employment impact compared to the reference scenario for each analysed scenario. For comparison, in 2017, around 410,000 people were employed in 'air transport' in the EU (Eurostat 2018c). The

[4] The technologies considered comprise electricity generation from coal, natural gas, oil & diesel, nuclear, large-scale hydro, small-scale hydro, geothermal, biomass, wind onshore, wind offshore, solar photovoltaics (PV), solar thermal (mostly CSP), ocean/marine and waste.

[5] We estimate jobs in local manufacturing, construction & installation, operation & maintenance, fuel supply and nuclear decommissioning.

estimated net employment impact in all 'Scaling up Climate Action' scenarios is therefore substantial.

Our estimates can be seen as rather conservative as we only consider direct jobs (see methodological Annex for more details) and do not account for indirect jobs and induced jobs. Indirect jobs include jobs along the supply chain, such as the production of input material, e.g. producing concrete for the foundation of wind turbines. The literature suggests that indirect employment is of a similar order of magnitude as direct employment (see e.g. Ortega et al. (2015) for indirect employment in solar and wind). Induced employment impacts are e.g. economic impacts 'trickling down' to other parts of the economy due to wages spent that have been earned in created direct jobs. Moreover, jobs in energy efficiency, replacement of facilities and heat supply-related jobs have not been taken into consideration in our analysis. Accounting for replacement of capacities would likely lead to higher employment effects for solar and wind as compared to coal, as solar and wind have a lower expected lifetime and therefore need more frequent replacement.

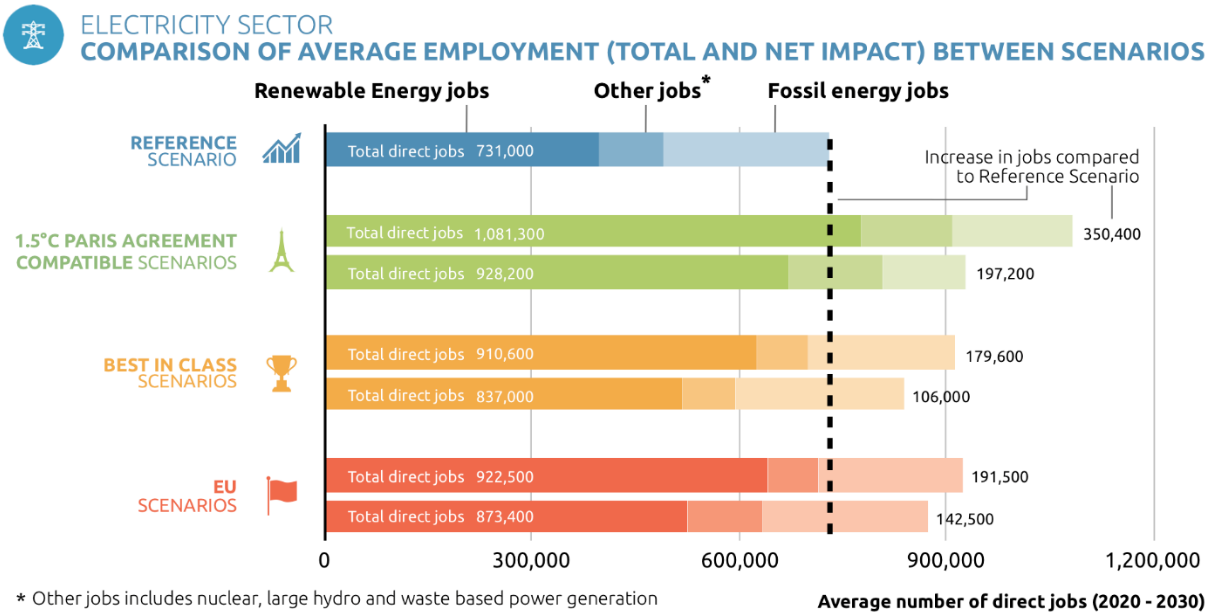


Figure 11: Average direct employment impact between 2020 and 2030 in the EU for different electricity generation scenarios. Shown is the estimated total direct jobs in the electricity sector averaged over the period 2020 to 2030, in the scenarios analysed in this study. The respective net direct employment impact compared to the reference scenario is also shown for each analysed scenario.

The most ambitious climate policy scenario in terms of carbon emission reduction also yields the highest employment benefits over time. In the most ambitious scenario – the '1.5°C Paris Agreement compatible' upper bound pathway – we estimate that there would be substantially more direct jobs in electricity generation than in the reference scenario with job impacts in the order of magnitude of around 310,000 more direct jobs in 2020, about 370,000 thousand in 2025 and about 270,000 in 2030. The annual average employment impact is estimated to be almost 350,000 direct jobs more than in the reference scenario over the period 2020-2030. For electricity generation from renewable energy (excluding large-scale hydro), we estimate the difference in direct jobs to be over 295,000 (in 2020), almost 400,000 (in 2025) and about 375,000 (in 2030) more direct jobs in the most ambitious '1.5°C Paris Agreement compatible' scenario than in the reference scenario, outweighing job losses in fossil-based technologies by far. In 2025, the estimated job creation in renewable energy is six times higher than the reduction in fossil-based jobs for the same year compared to the reference scenario. In 2030, almost 80% of direct jobs in electricity generation are in RE, compared to 55% in the current development scenario.

Wind and solar energy play an important role in, both, successful decarbonisation and job creation. The construction and installation of RE-facilities, most importantly solar and wind, is an important driver for job creation in the EU. Figure 12 (below) shows that, while operation and maintenance is the dominant job type in the reference scenario, many new jobs are created through the construction and installation of new renewable energy capacities as well as the local manufacturing of the installed technology parts, as manufacturing as well as construction and installation of renewable energy facilities is generally more job intensive. While the number of local jobs depends on the share of local manufacturing and biofuel supply, a sensitivity analysis on this shows that the job impact would still remain substantial for lower local shares.[6] At the same time, this also illustrates that policies supporting local expertise and skills for manufacturing and the development of a local manufacturing value chain could support the generation of local high quality jobs in the renewable energy sector, while the distributed character of renewables could enhance the impact on the creation of local jobs, especially in rural areas.

The job estimates presented do not include potential jobs from manufacturing for export of technology parts, which could add to the number of jobs created by a strong local renewable energy manufacturing industry. Moreover, jobs related to grid and flexibility measures that are needed for renewable energy development are also not considered. Our estimates are therefore rather conservative to this regard.

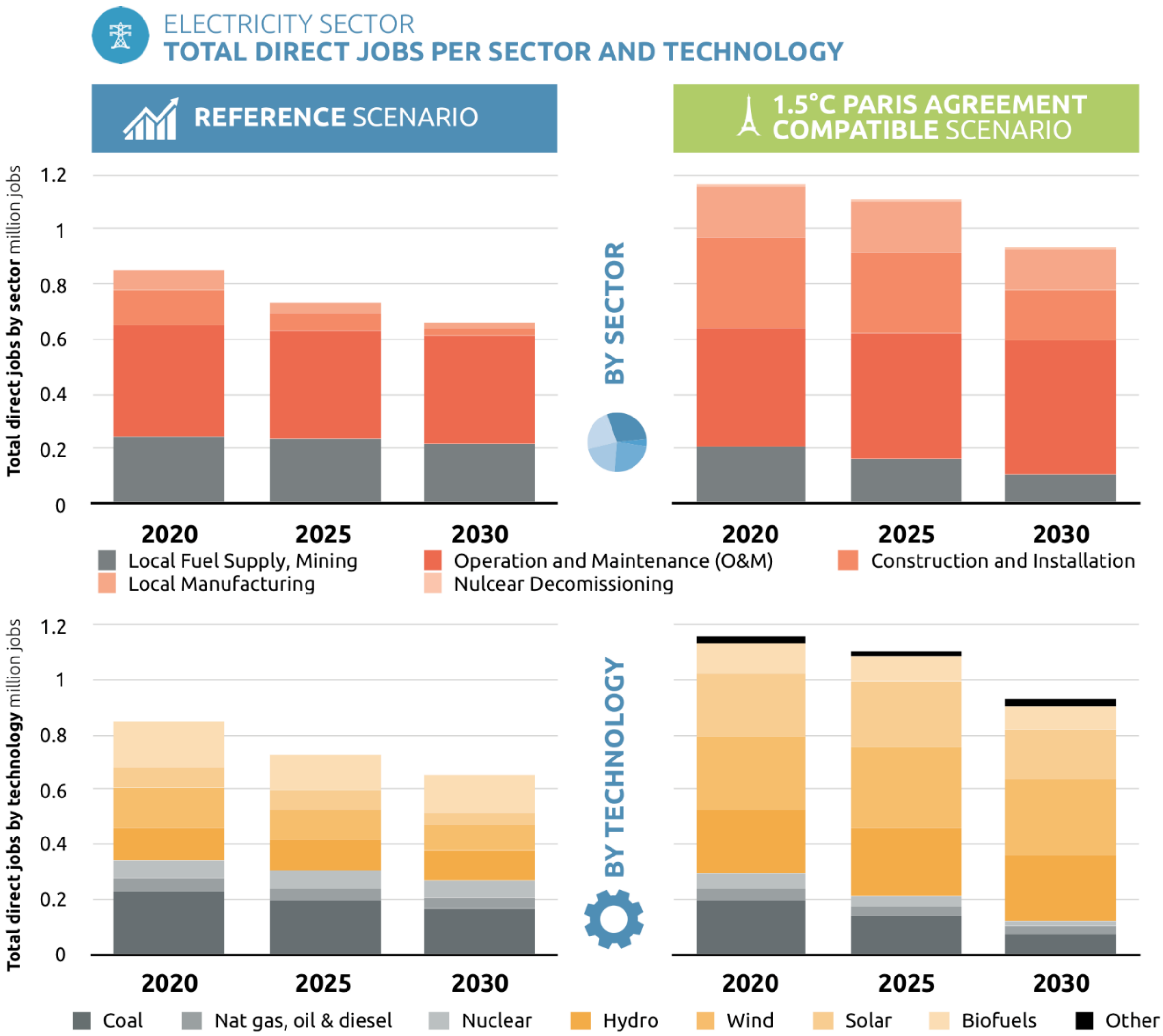


Figure 12 Estimated total direct jobs per employment sector and total direct jobs per generation technology for the reference scenario (graphs on left) and the 1.5°C Paris Agreement compatible scenario (graphs on right) for the EU electricity supply sector. Note: 'other' here refers to jobs in electricity generation from the technologies geothermal, marine and waste.

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6 For our main analysis, we assume that all construction and installation is carried out by people employed within the EU. For manufacturing, we assume that for solar PV, only one quarter of the installed parts are manufactured within the EU, while for all other technologies we assume that 100% are manufactured within the EU thereby creating jobs in local manufacturing (see appendix for a detailed description of the methodology and assumptions). To test the sensitivity of our results, we conducted a sensitivity analysis reducing the share of local manufacturing to 80% for all renewable energy technologies (solar remained at 25%) and the share of biofuel that is locally supplied also to 80%. The results are shown in Table 2422 in the appendix. While this reduces the number of local jobs, the net employment benefit in all Scaling Up Climate Action Scenarios still remains substantial, amounting to over 320,000 more direct jobs on average (2020 to 2030) in the most ambitious scenario compared to the reference scenario.

The benefits in job creation due to climate policy also depend on the choice of technologies to achieve decarbonisation. While all 'Scaling up Climate Action'- Scenarios analysed would achieve carbon emissions reductions compared to the Reference scenario, scenarios with a stronger reliance on natural gas or nuclear create fewer jobs than scenarios that are more ambitious in terms of building up new renewable energy capacities, especially in solar and wind energy. In the lower bound 'EU scenarios' pathway the number of direct jobs in electricity generation in 2020 is almost at the same level as in the reference scenario, as in this scenario carbon emission reductions are mostly achieved by switching from coal to natural gas and later to biofuels, while it is less ambitious in terms of building up solar PV and wind capacities. This leads to less jobs in local manufacturing as well as construction and installation in the lower bound 'EU scenarios' pathway than in the reference scenario for 2020.

The impact of technology choice can also be observed when comparing the two 1.5°C Paris Agreement compatible pathways. While the lower bound of the 1.5°C Paris Agreement compatible pathways is also comparably ambitious with regard to reducing carbon emissions, it predominantly achieves its emission reductions by phasing out coal and natural gas while increasing electricity generation from nuclear energy, while the upper bound pathway relies more on building up now capacities in wind, solar and hydro. While jobs in operation and maintenance are at a similar level in both 1.5°C Paris Agreement compatible pathways, the added capacities in renewable energy lead to substantially higher job numbers in local manufacturing as well as construction and installation in the upper bound pathways. Thus, in terms of employment impact, the upper bound scenario creates roughly 170,000 more jobs in 2025 and almost 100,000 more jobs in 2030 than the lower bound scenario. This illustrates that the choice of how to achieve carbon emission reduction can have a substantial effect on the co-benefits in terms of job creation.[7] The impact in terms of investment needs for different pathways was not analysed, but would need to be taken into account for decision making.

4.2 Residential buildings sector

The Paris Agreement compatible sectoral trajectories almost fully decarbonise the EU's residential buildings sector by 2050. Energy savings achieved through deep retrofit of existing buildings in parallel to construction of low-energy new buildings, energy efficiency improvement of lighting and appliances as well as strong electrification (e.g. heat pumps) or other shift to renewable energy of space/water heating[8] can fully decarbonise the EU's residential buildings sector by mid-century. This relies critically on decarbonising the electricity supply sector (see Section 4.1).

Table 17 gives an overview of the scenario analysis results for scaling up climate action in the residential buildings sector of the EU. Figure 13 visualizes the emissions trajectories across various scenarios resulted from quantification with the PROSPECT EU scenario evaluation tool.

Table 17: Outcome overview of scaling up climate action analysis in the residential buildings sector for European Union

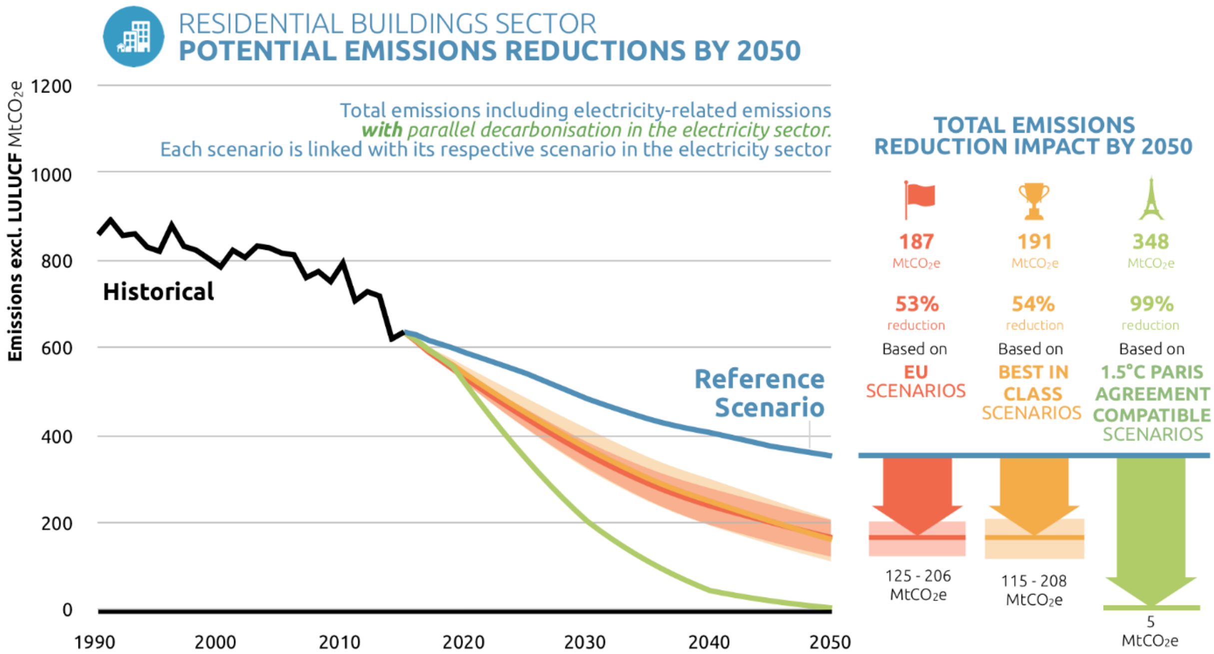
Indicator	Indicator values for scenario categories		
	EU scenarios	Applying best-in-class level(s)	1.5°C compatible scenarios
Renovation rate	• **2.5%** per year renovation rate by 2020, **2.7%** per year from 2022-2050 • **2.6%** per year renovation rate from 2016-1050	• **1.5-2.1%** per year renovation rate from 2020-2050 • Rate under current policies from 2016-2020	• **5%** per year renovation rate from 2020-2050 • Rate under current policies from 2016-2020
	Based on renovation rates from various scenarios developed for the European buildings sector in BPIE (2011)	*Based on best-in-class practice identified in Kriegler et al.* (2018a)	*Based on benchmark for OECD region specified in Kuramochi et al. (2018)*

[7] See Box in Section 4.1.2.1 for a discussion of the scenario underlying the lower bound Paris Agreement compatible pathway.

[8] The PROSPECTS EU scenario evaluation tool, applied for the quantification here, explicitly considers the electrification of water/space heating as a means of decarbonisation. However, this can also be achieved via direct shift to renewable energy, e.g. solar thermal.

Relative improvement of energy efficiency in renovated/new buildings	**48-71%** improvement compared to 2015	**45-88.5%** improvement compared to 2015	**100%** improvement compared to 2015
	Based on efficiency improvements from various scenarios developed for the European buildings sector in BPIE (2011)	*Based on best-in-class benchmarks for retrofits and new buildings identified in Kriegler et al.* (Kriegler et al. 2018a), *Fekete et al. (2015) and Erhorn and Erhorn-Kluttig, (2015)*	*Based on benchmarks for retrofits and new buildings identified in Kuramochi et al.* (Kuramochi et al. 2018)
Energy intensity improvement of cooking/ lighting/ appliances (electricity + direct energy)	Average efficiency improvement of **1.6-1.8%** per year applied from 2016-2050	Average efficiency improvement of **1.5-1.8%** per year applied from 2016-2050	Average efficiency improvement of **2%** per year applied from 2016-2050
	Based on EU buildings sector energy efficiency improvements indicated by Astroem et al. (2010) and efficiency improvement trend of the lighting and appliances in the European residential sector based on Odysseee (2015)	*Based on best-in-class practice identified in Fekete et al. (2015) and Kriegler et al. (2018)*	*Based on benchmarks identified in Kriegler et al.* (Kriegler et al. 2018a)
Decarbonisation of water heating/space heating	Not specified benchmark. Electrification rate under Reference Scenario is applied	Not specified benchmark. Electrification rate under Reference Scenario is applied	**100%** electrification rate in water/space heating by **2050**
	n/a	*n/a*	*Based on plans by EU MS to remove natural-gas based heat boilers in the buildings sector and replacing those with zero emissions electric/hybrid heat pumps or other renewable energy based heating, for instance in Netherlands as a good example*

Required policy measures for sectoral transformation	Remaining challenges threatening implementation
⇨ Increase awareness about the economic and non-economic benefits of increasing energy efficiency in the housing sector ⇨ Introduce measures reducing the scale of the upfront investment (e.g. lower interest rates, repaying the costs of efficiency measures from the savings on the heating costs ⇨ Introduce NZEBs standards for new buildings to avoid carbon lock-in ⇨ Ensure decarbonisation of space heating - no fossil-fuel based heating should be installed from 2030 on.	⇨ High costs of upfront investment ⇨ Low awareness about the benefits of efficiency improvement ⇨ The issue of split incentive when the investment in increasing efficiency and the benefits of lower energy bills are borne by different parties



	EU scenarios	Best in class scenarios	1.5°C Paris Agreement compatible scenarios	
BUILDING RENOVATION RATE	2.5 - 2.7%	1.5 - 2.1%	5%	percentage of existing building stock renovated per year to 2050
ENERGY EFFICIENCY IMPROVEMENTS OF BUILDINGS	48 - 71%	45 - 89%	100%	improvement of energy efficiency of any renovated and/or new buildings relative to 2015
ENERGY EFFICIENCY IMPROVEMENTS OF APPLIANCES	1.6 - 1.8%	1.5 - 1.8%	2%	improvement per year of energy efficiency of cooking, lighting and appliances

Figure 13: Overview of sectoral emission pathways under reference scenario projections and different levels of accelerated climate action in residential buildings sector in the European Union. All sectoral projections towards 2050 done in the CAT PROSPECTS European Union scenario evaluation tool.

The current renovation rate in the EU is around 1% - five times below the Paris Agreement compatible renovation rate. It is also significantly below the renovation rate if the best-class scenarios are applied.

4.2.1 Context for scaling up climate action in the residential buildings sector

There is a significant potential for emissions reduction in the residential buildings sector

- With a quarter of the overall final energy consumed in the residential sector, only 16% of which is coming from renewables (Eurostat 2018g), there is a significant potential to reduce CO_2 emissions by on one hand reducing energy consumption and on the other replacing fossil fuels by renewables.
- The emissions reduction potential is increased by the inert character of the buildings sector. With the current average age of the buildings at around 55 years (JRC 2016) it can be expected that the buildings currently under construction will still be there around 2070 and – depending on their durability – beyond. To comply with the goal of carbon neutrality, these buildings have to fulfil the strictest efficiency standards and rely exclusively on renewable sources of energy.
- Nearly zero energy buildings (NZEBs) have already been constructed across Europe. While – depending on the country – the exact requirements that need to be fulfilled by such a building differ, if the energy consumed is coming exclusively from renewable sources of energy they already fulfil the goal of carbon neutrality. In addition, combination of the newest technologies with some simple measures, like using more

natural lighting, allows construction of an active house, namely one, which produces more energy than it consumes (Active House Alliance 2015).

Significant benefits beyond climate mitigation

- Almost 52% of the final energy in the residential sector in the EU consumed in the form of fossil fuels, especially natural gas (Eurostat 2018i). Almost 54% of these fuels are coming from imports, with the share of imported natural gas exceeding 70% (Eurostat 2018e). Improved insulation and replacement of the fossil fuels by low carbon alternatives would significantly decrease EU's energy dependency. According to European Commission's estimates, an increase in energy savings by 1% decreases natural gas imports by 2.6% (European Commission 2014).
- In addition to the CO_2 emissions, a large share of the air pollution is also coming from the combustion of fossil fuels in households. While separate data for the household sector are not available, together with the commercial and institutional sectors it is responsible for 57% of the PM_{10}, and 74% of the benzo[a]pyrene (BaP) emissions, thus contributing to a large share of the over 500.000 premature deaths attributed to bad air quality in the EU every year (European Environment Agency 2017a). While energy efficiency in the buildings sector, combined with replacement of fossil fuels by renewables would significantly improve the situation, it must be pointed out that replacing fossil fuels by biomass combustion without a significant improvement in the combustion process, would not improve the situation (DEFRA 2017).
- Between 50 million and 125 millions of people in the EU are at risk of energy poverty (European Parliament 2016), with inefficient buildings and increasing energy costs as the leading factors. On average in 2016 over 11% of the Europeans could not afford to keep their households adequately warm and 10.5% had arrears on utility bills (European Commission 2018d). After an initial high upfront investment, the running costs of heating and cooling would decrease significantly thus improving the quality of life for millions of Europeans.
- By moving from exclusively energy consumption towards energy generation and storage, buildings could become a stabilising factor for the power sector increasingly reliant on intermittent sources of energy. Integration of smart buildings and smart grid creates the opportunity to store oversupply of energy either in the form of electricity or heat. This would allow to decrease energy consumption in times of peak demand or decreased electricity generation (Wurtz and Delinchant 2016).

Important barriers still exist:

- Whereas deep renovation would bring significant, long-term savings in fuel costs, the initial high upfront investment is one of the major barriers limiting the renovation rate. This issue can be mitigated by the mainstreaming and utilization of various instruments, such as dedicated, preferential credit lines, risk sharing facilities or on bill repayment schemes (EFFIG 2014).
- Instead of perceiving deep renovation as a combination of a number of interdependent measures, some home owners and investors implement different energy saving measures separately and independently of each other (Heiskanen, Matschoss, and Kuusi 2014). This decreases the benefits of a holistic approach to buildings renovation in terms of lower overall investment costs and higher energy savings and correspondingly lower CO_2 emissions (Degan et al. 2015).
- With almost a third of the EU population living in rented apartments (Eurostat 2018k) the benefits of higher efficiency and thus lower energy bills are not always enjoyed by the home owners, who would bear the initial investment costs. This reduces the incentive to make such an investment in the first place. Some solutions to this problem already exist, e.g. appropriating some of the energy costs savings to repay the costs of the initial investment (JRC 2014)

- Insufficient awareness about the long-term benefits of investing in deep renovation or bearing the initially higher costs of a NZEB discourage many from such an investment (ZenN 2013). To mitigate this issue, the EPBD adopted in 2010 required member states to establish a system of certification of the energy performance of buildings that would include a list of recommendations for possible improvement of the building's energy performance (European Parliament and the Council of the European Union 2010a).

4.2.2 Scenario analysis for scaling up climate action in the residential buildings sector

4.2.2.1 Identification of indicator levels

Table 18 provides an overview of indicator levels identified for scenario modelling in the residential buildings sector. The upper part of the table presents the relevant benchmarks as specified in the literature. The lower part shows how those benchmark levels have been adapted into selected indicator levels for providing input to the PROSPECTS EU scenario evaluation tool.

Table 18: Overview of different benchmarks specified in the literature and translation into indicator levels for analysis of scaling up climate action in the residential buildings sector with PROSPECTS EU scenario evaluation tool

	EU scenarios	Applying best-in-class level(s)	1.5°C compatible scenarios
Renovation rate	• **2.6%-2.7%** per year renovation rates from **2022** onward *Based on the renovation scenarios for the European buildings sector by BPIE (2011)*	• **1.5-2.1%** renovation rate from **2020** onward with **45%** energy efficiency improvement per retrofit *Based on best-in-class practice identified in Kriegler et al.* (Kriegler et al. 2018a)	• **5%** renovation rate from **2020** onward with **75%-80%** energy efficiency improvement per retrofit *Based on benchmark for OECD region specified in Kuramochi et al.* (Kuramochi et al. 2018)
New buildings stock	• **48%-71%** average improvement in the energy performance of new/retrofitted buildings by 2050 *Based on quantified renovation scenarios for the European buildings sector by BPIE (2011)*	• **20 kWh/m²/year** of new buildings stock from **2020** onward *Based on Erhorn and Erhorn-Kluttig, (2015) applying the case of Denmark with most ambitious definition of nZEB among EU MS*	• **0 kWh/m²/year** of new buildings stock from **2020** onward *Based on benchmarks for new buildings identified in Kuramochi et al.* (Kuramochi et al. 2018)
Appliances	• Average efficiency improvement of **1.6%-1.8%** per year (all appliances) *Based on EU buildings sector energy efficiency improvements indicated by Astroem et al. (2010) and efficiency improvement trend of the lighting and appliances in the European residential sector based on Odysseee (2015)*	• Average efficiency improvement of **1.5-1.8%** per year (all appliances) *Based on best-in-class practice identified in Fekete et al.* (Fekete et al. 2015a) *and Kriegler et al. (2018)*	• Average efficiency improvement of **2%** per year (all appliances) *Based on benchmarks identified in Kriegler et al.* (Kriegler et al. 2018a)
Decarbonising water/space heating	No specifically defined benchmark for EU scenarios	No specifically defined benchmark for best-in-class level(s)' scenarios	• **100%** electrification of water/space heating by **2050** *Based on plans by EU MS to remove natural-gas based heat boilers in the buildings sector and replacing those with zero emissions electric/hybrid heat pumps, or other renewable energy technologies for instance in Netherlands as a good example*
Indicator levels for scenario analysis in the PROSPECTS EU scenario evaluation tool			
	EU scenarios	**Applying best-in-class level(s)**	**1.5°C compatible scenarios**
Renovation rate (High ambition)	• **2.5% per year** renovation rate by **2020, 2.7% per year** from **2022** onward • Linear interpolation for the period 2016-2020	• **2.1%** per year renovation rate from **2020** onward • Rate of current policies before 2020	• **5%** per year renovation rate from **2020** onward • Rate under current policies before 2020

	Low ambition	**2.6%** per year renovation rate from 2016 onward	• **1.5%** per year renovation rate from **2020** onward • Rate of current policies before 2020	
Relative improvement of energy efficiency in renovated/ new buildings	High ambition	**71%** as derived from high ambition end of efficiency improvements of renovated buildings based on the medium renovation scenario from BPIE (2011)	**88.5%** as derived from benchmark for new buildings stock of **20 kWh/m2/year** compared to average historical energy intensity per m^2 in 2015	**100%** as derived from benchmark for new buildings stock of **0 kWh/m^2/year**
	Low ambition	**48%** as derived from low ambition end of efficiency improvements of renovated buildings based on the most ambitious renovation scenario from BPIE (2011)	**45%** as derived from benchmark for renovated buildings stock	
Energy intensity improvement of cooking/ lighting/ appliances (electricity + direct energy)	High ambition	Average efficiency improvement of **1.8%** per year (all appliances)	Average efficiency improvement of **1.8%** per year (all appliances)	Average efficiency improvement of **2%** per year (all appliances)
	Low ambition	Average efficiency improvement of **1.6%** per year (all appliances)	Average efficiency improvement of **1.5%** per year (all appliances)	
Decarbonisation of water heating/space heating	High ambition	Not specified benchmark. Electrification rate under Reference Scenario is applied	Not specified benchmark. Electrification rate under Reference Scenario is applied	**100%** electrification rate in water/space heating by 2050
	Low ambition			

1.5°C Paris Agreement compatible scenarios

A review of relevant literature and studies identifies the following Paris Agreement compatible benchmarks for the three selected indicators in residential buildings sector:

- All new buildings need to be fossil free and zero energy by 2020. This is an average value proposed for OECD regions based on 1.5°C compatible benchmarks as identified in (Kuramochi et al., 2018).
- For the retrofit of existing residential buildings stock, the renovation rate needs to increase to 5% by 2020 (average for OECD regions) with an achieved average reduction of 75-80% in final energy use per retrofit (Kuramochi et al., 2018).
- For the energy efficiency improvements of lighting and residential appliances, an average efficiency improvement of 2.0% p.a. is assumed as implied by the "net zero" policy package proposed by (Kriegler et al. 2018b), which adds policies pushing for zero emission technologies particularly in energy end-use sectors in line with the Paris Agreement's goal to reach net zero CO_2 emissions in the second half of the century.
- For decarbonisation of water heating/space heating, it is assumed that a 100% electrification rate will be achieved in the EU's residential buildings by 2050. Replacing fossil fuel-based heating with renewable energy such as solar thermal heating would achieve equivalent results. This has been mainly inspired by the assessment conducted in (Climate Action Tracker 2016) concluding that the buildings sector needs to completely phase out emissions by mid-century, in line with a 1.5°C pathway. Currently, several EU MS are discussing plans to remove natural-gas based heat boilers in the buildings sector and replacing those with zero emissions electric/hybrid heat pumps, or other renewable energy technologies for instance in Netherlands as a good example.

Based on the Paris Agreement compatible benchmarks as specified above, the following indicator levels have been identified for the quantification of emissions trajectories with the PROSPECTS EU scenario evaluation tool:

- **Renovation rate:** 5% per year renovation rate from 2020 onwards with a renovation rate under currently implemented policies of 1% used before 2020
- **Relative improvement of energy efficiency in renovated/new buildings:** Range of 75% (deep retrofit of existing buildings) to 100% (near-zero emission new buildings)
- **Relative improvement of total energy intensity of cooking/lighting/appliances (electricity + direct energy):** Average efficiency improvement of 2% per year for all appliances from 2016 onwards until 2050.
- **Decarbonisation of space heating/water heating:** 100% electrification of space heating/water by 2050. We assumed a linear interpolation between today level (9%) and the target value.

Applying best-in-class levels

Applying best-in-class levels are implemented according to international frontrunners in increasing energy efficiency of new buildings stock and renovation of existing buildings. This allows to identify the implications of a successful implementation of mitigation measures at the level of international frontrunners for the European residential buildings sector. A review of relevant literature identifies the following best-in-class benchmarks in the residential buildings sector:

- For the new buildings stock, the European Union's Energy Performance of Buildings Directive (EPBD) requires that all newly constructed buildings in EU Member States will have to consume 'nearly net-zero' energy by the end of 2020 and the energy will have to be 'to a very large extent' from renewable sources (Climate Action Tracker, 2016b; Fekete et al., 2015; BPIE, 2011). The EPBD is the main policy driver affecting energy use in buildings at European level and can be considered as international best practice policy. Member States shall include their national definition of nZEB into national legislation and inform the EC on the details in their national plans for increasing the number of NZEB. About 40% of the Member States do not yet have a detailed definition of the nZEB in place (Erhorn-Kluttig 2015). Among the Member States, Denmark has the most ambitious definition of nZEB with proposed (primary) energy consumption level of 20 $kWh/m^2/$ a. We apply this as the best-in-class energy performance level of the new residential buildings stock to be achieved by 2020 for the EU's residential buildings sector. This would translate into 88% energy efficiency improvement by taking 15 $koe/m^2/a$ or 174.5 $kWh/m^2/a$ as the average level for current energy consumption of the European residential buildings stock (JRC 2018a).
- For the retrofit of existing residential buildings stock, a renovation rate of 1.5%-2% with efficiency improvement of 45% from 2020 onwards is applied as best-in-class level, which is comprised of the following components:
    - Renovation rate: 1.5% p.a.-2.1% p.a. renovation rate according to the good practice' policy scenario developed by the recent study conducted in (Kriegler et al. 2018a).
    - Relative improvement of energy efficiency in renovated/new buildings: Subsidies and loans in Germany offered by the government-owned banking group *Kreditanstalt fuer Wiederaufbau* (KfW) provide economic incentives for new buildings as well as energy efficient renovations of existing buildings that meet requirements of the quality label "Effizienzhaus" (efficient building). The maximum subsidy (correspondent to the highest standard) are granted to the buildings which are at least 45% more efficient than the reference house in the respective category, i.e. requires only 55% of the energy needed by a reference house in the corresponding category.
    - Target year: The target year of the renovation rate specified above is 2020 for developed countries as informed by the European Union's Energy Performance of Buildings Directive (EPBD).
- For energy efficiency improvement of residential appliances and lighting, an average efficiency improvement of 1.5% p.a. is considered across all appliances for the lower bound of best-in-class levels according to the good practice' policy scenario developed

by (Kriegler et al. 2018a). An upper bound of efficiency improvement of 1.8% p.a. across all appliances is considered as international best practice according to the study conducted in (Fekete et al. 2015a). This is based on average improvement of appliances' efficiencies between 2001 and 2012 for EU member states with successful efficiency policies implemented before 2005: UK, Sweden, Netherlands, France, Slovakia, Finland, Czech Republic, Latvia according to the MURE database.

The identified best-in-class benchmarks, elaborated above, were translated into the following indicator levels to provide input for the PROSPECTS EU scenario evaluation tool:

- **Renovation rate**: A range of 1.5%-2% per year renovation rate from 2020 onwards with a renovation rate under reference scenario used before 2020
- **Relative improvement of energy efficiency in renovated/new buildings**: A range of 45% (deep retrofit of existing buildings) to 88.5% efficiency improvement based on the European Union's Energy Performance of Buildings Directive (EPBD)
- **Relative improvement of total energy intensity of cooking/lighting/appliances (electricity + direct energy)**: A range of average efficiency improvement of 1.5%-1.8% per year for all appliances

EU scenarios

Indicator values for the 'EU Scenarios' have been inspired based on recently published modelling studies by the European research institutions and universities. A review of relevant literature identifies the following EU-specific scenarios in the residential buildings sector:

- Buildings Performance Institute Europe (BPIE) has undertaken an extensive survey across all EU Member States, Switzerland and Norway reviewing the situation in terms of the building stock characteristics and policies in place. This survey provides an EU-wide picture of the energy performance of the building stock and how existing policies influence the situation. The available data were used to develop and assess the energy performance scenarios for the buildings sector in Europe with the aim of illustrating potential energy savings and CO_2 reduction pathways, reflecting also the EU's long term 80-95% GHG emission reduction target for 2050. BPIE has developed a number of possible scenarios for the renovation of the EU's building stock by 2050. The scenarios built on various combinations of different renovation rates and renovation depths illustrating the impact of different ambition levels regarding the European environment and economy (Buildings Performance Institute Europe (BPIE) 2011). The renovation depths considered vary from minor renovation achieved by implementation of single retrofit measures with an average energy savings of up to 30%, while moderate and deep renovations provide energy savings of 30-60% and 60-90%, respectively. At the most ambitious level of the renovation depth is the nearly Zero Energy Building (nZEB) involving the wholesale replacement or upgrade of all elements which have a bearing on energy use as well as the installation of renewable energy technologies providing energy savings of more than 90%. Based on these EU-specifics scenarios developed by (Buildings Performance Institute Europe (BPIE) 2011), the following indicators are derived:
  - **Renovation rate:** Under the 'Medium' pathway, the renovation rate grows steadily over the next decade to reach a constant rate of around 2.7% p.a. by 2022. This renovation rate is then maintained until 2050. The "FAST" pathway, would require a rapid increase in the rate of renovations followed by a constant renovation rate of around 2.6% for the remainder of the period to 2050.
  - **Relative improvement of energy efficiency in renovated/new buildings:** The 'Medium' scenario, combining the moderate renovation depth profile with the medium growth of renovation rate, implies 48% average improvement in the energy performance of new/retrofitted buildings by 2050. According to the most ambitious renovation scenario, the average improvement in the energy performance of new/retrofitted buildings would reach to 71% in 2050.
- The International Institute for Applied System Analysis has developed the Integrated Assessment Model GAINS. The GAINS models' most recent methodology updates allow for a detailed description of the residential and commercial sector with energy use,

potential for energy demand reduction as well as energy demand reduction costs. In the study conducted by (Astroem et al. 2010), detailed data on energy use, building stocks and control technologies have been compiled and converted into the format suitable for the GAINS model. Bottom-up projections have been calibrated with the EU energy projections currently used as a European baseline in the GAINS model for the EU-27 countries as well as Norway, Switzerland and Turkey. Based on this, range of average efficiency improvement of 1.6% p.a. is assumed for all appliances for the low ambition level of EU scenarios. This has been derived from EU buildings sector energy efficiency improvements in the baseline scenario by (Astroem et al. 2010). For the high ambition level, we assume an efficiency improvement rate of 1.8% p.a. in line with the trend of efficiency improvement of electrical appliances and lighting since 2000 in the European residential buildings sector according to (ODYSSEE-MURE 2015).

Based on the EU-specific scenarios as described above, the following indicator levels have been identified for the quantification of emissions trajectories with the PROSPECTS EU scenario evaluation tool:

- **Renovation rate:** upper bound of 2.7% per year renovation rate from 2022 onwards and a lower bound of 2.6% per year.
- **Relative improvement of energy efficiency in renovated/new buildings:** Range of 48% (least ambitious scenario by BPIE (2011)) to 71% (most ambitious scenario by BPIE (2011)).
- **Relative improvement of total energy intensity of cooking/lighting/appliances (electricity + direct energy):** upper bound of average efficiency improvement of 1.8% per year for all appliances and a lower bound of 1.6% per year average efficiency improvement for all appliances.

4.2.2.2 Quantification of emission levels with PROSPECTS

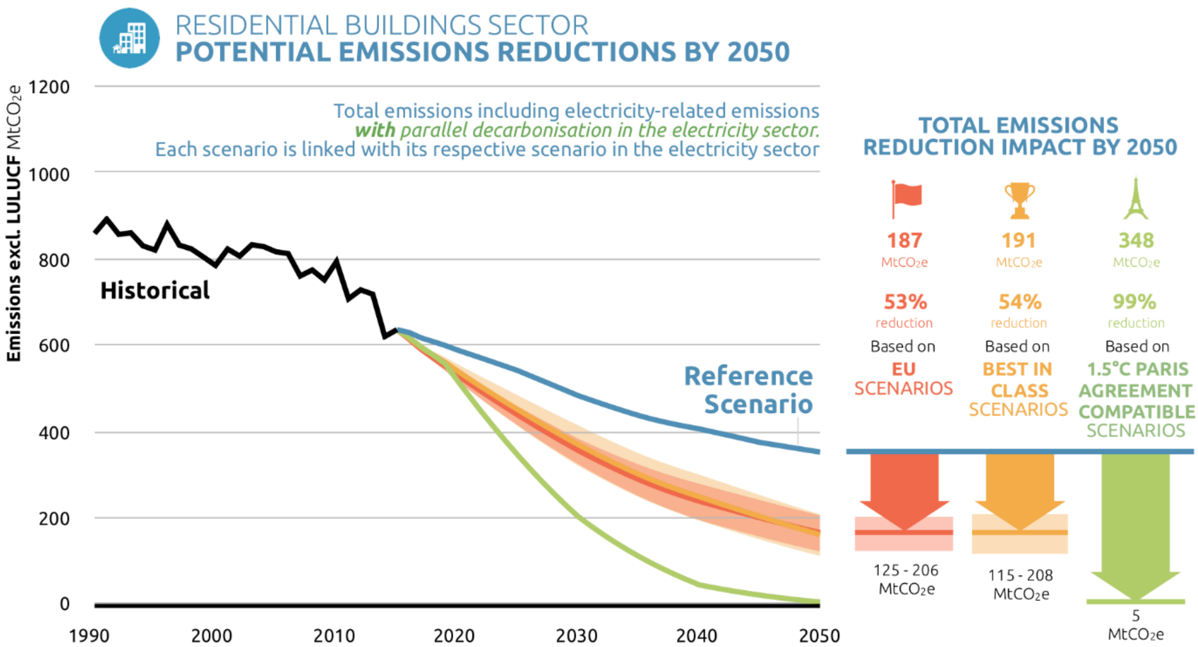


Figure 14: GHG emissions from the EU's residential buildings sector under different scenarios, incl. electricity related emissions and parallel decarbonisation actions in electricity sector beyond Reference Scenario.

Figure 14. illustrates the emissions trajectories from the EU's residential buildings sector until mid-century. This graph includes both direct energy emissions and electricity related emissions but at first no additional climate action in electricity sector beyond current policies is assumed. This reveals how by applying mitigation measures on the demand side such as deep renovations and energy efficiency improvements/energy savings as well as electrification of the heating in residential buildings sector combined with a simultaneous decarbonisation of

the electricity sector, significant reduction of emissions can be achieved by mid-century. Under the reference scenario projections, emissions from the EU's residential buildings sector would reduce to about 350 $MtCO_2e$/a by 2050, i.e. 60% below 1990 levels. Enhancing climate action and strengthening mitigation measures in the residential buildings sector imply further emissions reductions far beyond the reference scenario projections:

- The '**1.5°C Paris Agreement compatible'** pathway substantially reduces emissions and leads to the near complete decarbonisation of the EU's residential buildings sector by mid-century. This is mainly driven by the deep renovations, strong efficiency improvements in renovated and new buildings, energy intensity improvement of buildings' appliances as well as electrification of heating in residential buildings.
- The '**Applying best-in-class levels'** pathway reduces the emissions levels continuously to 76% and 85% below 1990 levels by 2050 under the low and high ambition case, respectively.
- The '**EU scenarios'** reduces emission to 76% and 85% below 1990 levels in 2050 under the low and high ambition level scenario, respectively.

4.3 Passenger transport sector

The Paris Agreement compatible sectoral trajectories almost fully decarbonise the EU's passenger transport sector by 2050. Modal shift from cars to public transportation and enhancing electric mobility in parallel to efficiency improvement of new cars can fully decarbonise the EU's passenger transport sector by mid-century if the electricity supply sector is decarbonised in line with the Paris Agreement temperature goal as outlined in Section 4.1.

Table 19 provides an overview of scenario analysis in the EU's passenger road and rail transport sector, presents the value ranges for selected indicators which considered relevant for the scenario modelling in the passenger road and rail transport sector. Figure 15 displays the resulting emissions trajectories for all scenarios after quantification with PROSPECTS EU scenario evaluation tool.

Table 19: Outcome overview of the scaling up climate action analysis in the passenger road and rail transport sector of the European Union

Indicator		Indicator values for scenario categories		
	Reference Scenario Projection (RSP)	EU scenarios	Applying best-in-class level(s)	1.5°C compatible scenarios
Emission intensity improvement rate for non-electrified personal vehicle transport[9]	• **1.8%** per year for 2016-2050	• **2.2%-2.4%** per year for 2016-2050	• **2.3%-2.4%** per year for 2016-2050	• **2.4%** per year for 2016-2050
	Based on PROSPECTS EU tool developed by Climate Action Tracker (2018). Main reference is IEA Mobility Model.	Based on the 2016 Impact Assessment work of the European Commission (E3MLab & IIASA, 2016) taking the EUCO27 and EUCO+35 scenarios and the EUCO3030 sensitivity case	*Based on EU target of 95 gCO_2/vkm for 2020)/2021 and the target values discussed in EU institutions (35%-40% improvement rel. to 2020,) corresponding to 57-61 gCO_2/vkm by 2030*	*Based on EU target of 95 gCO2/vkm for 2020/2021 and the the EP proposal of 40% improvement rel. to 2020, corresponding to 57 gCO2/vkm by 2030*
Share of public transport (bus, train) in total road and rail passenger transport activity	**14% by 2030** **12% by 2050**	**18-20% by 2030** **20-24% by 2050**	**26-32% by 2030** **27-34% by 2050**	**32% by 2030** **34% by 2050**
	Based on PROSPECTS EU tool developed by Climate Action Tracker (2018). Main reference is IEA Mobility Model.	*Based on the policy scenarios as identified by the Impact Assessment work of the European Commission (EC, 2011)*	*Based on the case of Czech Republic and Austria as the EU frontrunners concerning the share of public transport in passenger transportation*	*Based on the case of Czech Republic as an EU frontrunner concerning the share of public transport in passenger transportation*

9 The EU emission standards apply to the average for the fleet of all new vehicles. Translation of those targets to the indicator level (intensity improvement rate for non-electrified personal vehicles) for the purpose of quantification with PROSPECTS EU scenario evaluation tool has been performed by taking the new vehicle stock and the split between EVs and ICEs into account for each scenario category and applying a stock turn over model.

Share of electric vehicle in total passenger vehicle fleet: Personal Vehicle	• **3%** by **2030** • **6%** by **2040** • **10%** by **2050**	• **7-33%** by **2030** • **21-65%** by **2040** • **34-97%** by **2050**	• **17%** by **2030** • **35%** by **2040** • **54%** by **2050**	• **43%** by **2030** • **94%** by **2040** • **100%** by **2050**
Share of electric vehicle in total passenger vehicle fleet: Buses	• **3%** by **2030** • **9%** by **2040** • **14%** by **2050**	• **3%** by **2030** • **9%** by **2040** • **14%** by **2050**	• **20%** by **2030** • **39%** by **2040** • **58%** by **2050**	• **55%** by **2030** • **98%** by **2040** • **100%** by **2050**
	Based on PROSPECTS EU tool developed by Climate Action Tracker (2018). Main reference is IEA Mobility Model.	*PEV: based on the lowest and highest ambition end of the scenarios for penetration of electric cars in the European car fleet from combined sources* (Kampman et al., 2011) *and* (Höltl et al., 2017) Buses: *Based on Reference Scenario in PROSPECTS EU tool developed by Climate Action Tracker (2018)*	*Based on the 30% current share of EVs in new vehicle sales in Norway applied as 2030 target for middle- and high-income countries according to the 'good practice' scenario developed by* (Fekete et al. 2015a).	*Based 1.5°C compatible benchmarks for the transport sector: last fossil fuel vehicle sold in 2035 and EV shares in new sales of 100% in 2035 according to Kuramochi et al.* (Kuramochi et al. 2018)

Required policy measures for sectoral transformation	Remaining challenges threatening implementation
⇨ Increase ambition level of emissions standards ⇨ Introducing a ban on sales of combustion cars by 2035 to send a clear signal to cars manufacturers ⇨ Investment in electrified public transport ⇨ Facilitating development of charging stations by stable and predictable policy and - if needed – initial co-financing	⇨ Strong reliance on combustion cars manufacturing in most EU member states leading to lower ambition level for emissions standards than could be agreed ⇨ Higher price of electric vehicles ⇨ Underdeveloped and slow public transport in some European cities resulting from heavy traffic.

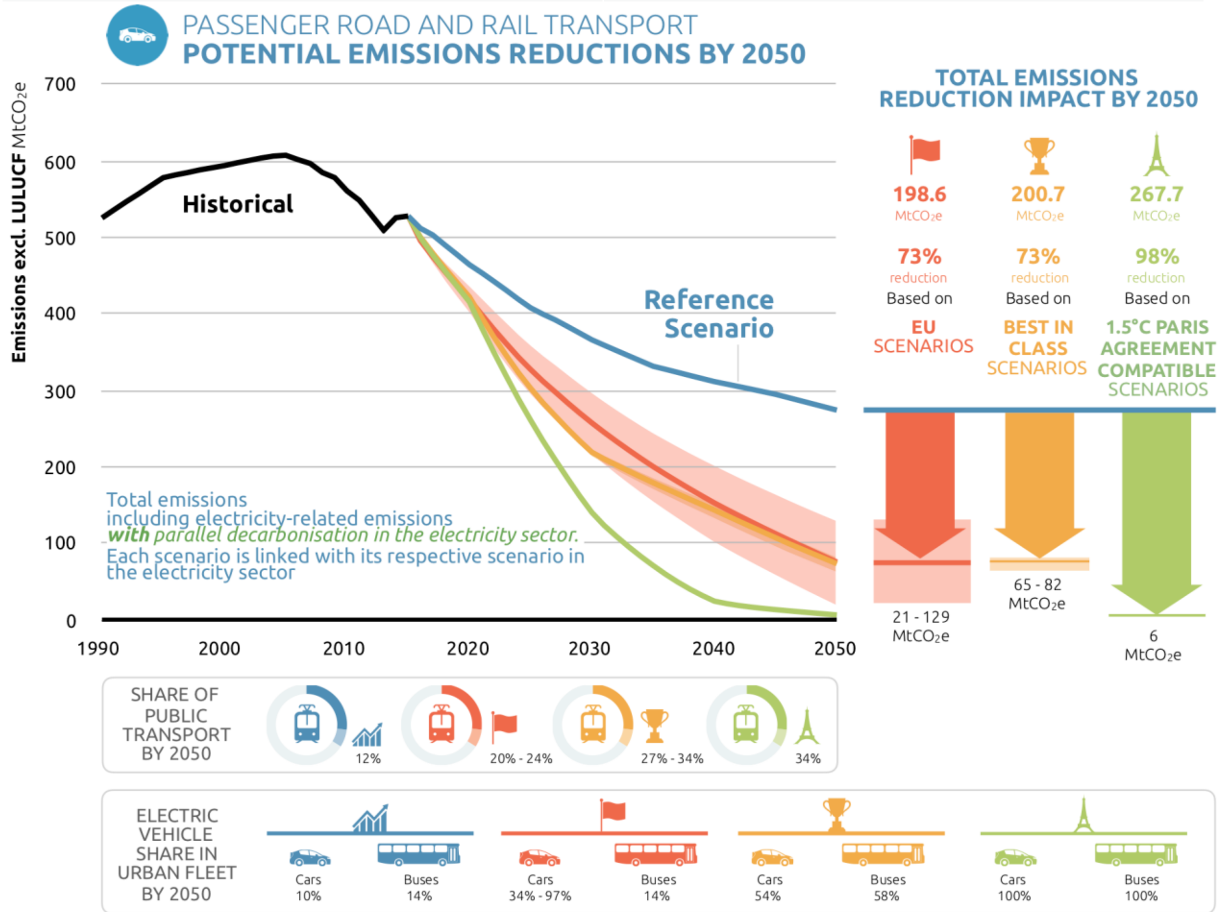


Figure 15: Overview of sectoral emission pathways under reference scenario projections and different levels of accelerated climate action in passenger road and rail transport sector in the European Union. All sectoral projections towards 2050 done in the CAT PROSPECTS European Union scenario evaluation tool.

4.3.1 Context for scaling up climate action in the passenger transport sector

Transport sector playing an important role in the economy

- Manufacturing of motor vehicles in the EU28 provides directly 2.5 million jobs. If indirect jobs are counted, this number reaches 13.3 million jobs (ACEA 2018). This constitutes 1.1% or 5.7% of total employment in the European Union, respectively (Eurostat 2018b).
- Every fifth passenger car in the world is produced in the European Union, positively contributing to the EU's trade balance with export exceeding import by over €90 billion (ACEA 2018).
- The impact of a transformation away from internal combustion cars and towards electromobility on the jobs in the EU depends strongly on the ability of the European car manufacturers to catch and possibly even exceed global trends in this regard. According to a scenario assuming 35% share of electric vehicles in the new sales in 2030 (up from around 2% in 2018), with only 10% of these vehicles coming from the EU, would lead to net job losses of 28%. Should the EU become net exporter of electric vehicles and manufacture an equivalent of 120% of the electric cars sold in the EU, the employment in the automotive sector would reach 108% of the current employment (Transport&Environment 2017).

Significant co-benefits of decarbonising the transport sector

- In addition to other pollutants, road transport is responsible for 30% of the NOx, 7.3% of the NMVOC and 6.5%, of the PM2.5 pollution (European Environment Agency 2017b).
- Road transport is also a significant source of noise pollution with over 70 million Europeans exposed to daily average noise levels from this source above 55 dB (European Environment Agency 2017c). While transport electrification will not reduce aerodynamic or tire noise dominating at higher speeds, the slower, urban traffic noise coming mainly from engines will be reduced dramatically (Barnard 2016).
- Decreasing road transport will improve attractiveness of urban regions by contributing to safer walking and cycling. It will also make public spaces available for open, green spaces thus having a positive impact on the quality of life in the cities (Mulliner and Maliene 2011)
- In 2017 the EU imported almost 520 million tonnes of oil worth €181 billion (Eurostat 2018f). Almost 48% of that oil was used in the road transport (Eurostat 2018l). The exposure to price volatility of this source of energy, which has already led to two recession in the 1970s and the early 1980s, as well as contributed to the recession in 2008/2009 has only increased in the recent years as EU's imports dependency for this fuel reached 88% in 2015 (Cambridge Econometrics 2016).

Infrastructure an important issue

- Replacing combustion cars by electro-mobility or alternative modes of transport (e.g. cycling or low-carbon public transport) requires investment in the necessary infrastructure. Such investment could be financed by adequate price signals that would reflect the external costs of a certain mode of transport. Ensuring that all the additional resources are reinvested in publicly available infrastructure has already proven to gather the necessary support for such measures (UITP 2013).
- With the number of electric cars in the EU increasing steadily (see section 2), access to public charging infrastructure is essential for their acceptance, especially in areas where private parking with a charging option is rare (ICCT 2017). Whereas the number of such stations increases, there are still relatively few high-power stations that would allow charging an electric vehicle in an acceptable time. In 2018 their number ranged from none on Malta and in Cyprus to almost 4000 in Germany (55 Plug-in vehicle per position) (EAFO 2018).

4.3.2 Scenario analysis for scaling up climate action in the passenger transport sector

4.3.2.1 Identification of indicator levels

Error! Reference source not found. provides an overview of indicator levels identified for the three different scenario categories in the passenger road transport sector of the European Union. The upper part presents the respective benchmarks specified in relevant literature. The lower part shows how these benchmarks were translated into indicator levels to provide input for the PROSPECTS EU scenario evaluation tool.

Table 20: Overview of different benchmarks specified in the literature and translation into indicator levels for analysis of scaling up climate action in the passenger road and rail transport sector with PROSPECTS EU scenario evaluation tool

	EU scenarios	Applying best-in-class level(s)	1.5°C compatible scenarios
Support for electric cars driven by renewable electricity	• **7%-33%** share of electric cars in total passenger car fleet **by 2030** (Kampman et al., 2011) • **34%-97%** share of electric cars in total passenger car fleet **by 2050** (Höltl et al., 2017)	International frontrunners in share of electric cars: 30% share of new cars in Norway in 2016 (IEA, 2017)	zero-emissions vehicles would have to constitute **100% of newly-sold vehicles** worldwide **by 2035**, **100%** zero emissions car stock by **2050** (Kuramochi et al. 2018)
CO_2 standards/ fuel economy standards for new cars[10]	Emission intensity of European new cars (E3MLab & IIASA, 2016) • **95** gCO2/vkm by **2021** • **64-75** gCO2/vkm by **2030** • **25** gCO2/vkm by **2050**	EU targets for fuel economy of new vehicles as one of the strictest standards in the world: • **95** gCO2/vkm by **2020/2021** • **35%-40% reduction rel. to 2020** corresponding to **57-61** gCO2/vkm by **2030**[11]	No specifically defined benchmark for Paris Agreement compatible benchmarks. Accordingly, emission standards defined in the most ambitious end of 'Applying best-in-class level(s)' scenarios are used.
Share of public transport (bus, train) in passenger transport	**8.7%-13.4%** share of rail transport in total passenger transport activity **by 2050** (EC, 2011)	EU frontrunners in share of public transport in passenger transportation: • **33.5%** share of public transport in total passenger transport on land (Czech Republic 2016) • **27.4%** share of public transport in total passenger transport on land (Austria 2016)	No specifically defined benchmark for Paris Agreement compatibility of share in public transport. Accordingly, modal shifts defined in the most ambitious end of 'Applying best-in-class level(s)' scenarios are used.

[10] The EU emission standards apply to the average for the fleet of all new vehicles. Translation of those targets to the indicator level (intensity improvement rate for non-electrified personal vehicles) for the purpose of quantification with PROSPECTS EU scenario evaluation tool has been performed by taking the new vehicle stock and the split between EVs and ICEs into account for each scenario category and applying a stock turn over model.

[11] The European Parliament recommends a target of 40% reduction compared to 2021, the European Council has proposed a 35% reduction target. Note these are not yet described in absolute values because of the plans to introduce a new test cycle and address the increasing divergence between test cycle and real-world emissions performance, which has been estimated to be up to around 40% (EU Commission IA 2017).

Indicator levels for scenario analysis in the PROSPECTS EU scenario evaluation tool

		EU scenarios	Applying best-in-class level(s)	1.5°C compatible scenarios
Share of electric vehicles	High ambition	• **33%** share in total vehicle stock by **2030** • **97%** share in total vehicle stock by **2050**	Starting from today's share increasing to **30%** share of EVs in new vehicle sales by **2030** and linearly rising to **70%** by **2050**	S-curve uptake of EV share with **100% EV market share** for newly sold vehicles **from 2035 onwards**
	Low ambition	• **7%** share in total vehicle stock **by 2030** • **34%** share in total vehicle stock **by 2050**		
Emission intensity for non-electrified personal vehicle transport	High ambition	• **2.4%** per year average emission intensity improvement rate of non-electrified personal vehicle transport activity for **2016-2050**	• **2.4%** per year average emission intensity improvement rate of non-electrified personal vehicle transport activity for **2016-2050**	**2.4%** per year average emission intensity improvement rate of non-electrified personal vehicle transport activity over **2016-2050** **(But note also indicator for share of electric vehicles: 100% EV share from 2035 onwards for newly sold vehicles)**
	Low ambition	• **2.2%** per year average emission intensity improvement rate of non-electrified personal vehicle transport activity for **2016-2050**	• **2.3%** per year average emission intensity improvement rate of non-electrified personal vehicle transport activity for **2016-2050**	
Modal split	High ambition	• **20%** share of public transport in total passenger road and rail transport activity by **2030** • **24%** share of public transport in total passenger road and rail transport activity by **2050**	• **32%** share of public transport in passenger road and rail transport activity by **2030** • **34%** share of public transport in total passenger road and rail transport activity by **2050**	• **32%** share of public transport in total passenger road and rail transport activity by **2030** • **34%** share of public transport in total passenger road and rail transport activity by **2050**
	Low ambition	• **18%** share of public transport in total passenger road and rail transport activity by **2030** • **20%** share of public transport in total passenger road and rail transport activity by **2050**	• **26%** share of public transport in total passenger road and rail transport activity by **2030** • **27%** share of public transport in total passenger road and rail transport activity **by 2050**	

1.5°C Paris Agreement compatible scenarios

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 a 15-year lifetime (Kuramochi et al., 2018). Of course, such a transition will be much easier with a reduction and modal shift of the demand for transport(Climate Action Tracker 2016)(Climate Action Tracker 2016)(Climate Action Tracker 2016)(Climate Action Tracker 2016)(Climate Action Tracker 2016)(Climate Action Tracker 2016. Therefore, modal shift and electrification of the transport sector must be seen as complementary measures and not as alternatives. Additionally, the extensive reduction of emission intensity of new, non-electric cars is an important intermediate measure until the full electrification of the passenger transport sector is achieved by mid-century. Lacking a clear benchmark for a Paris compatible modal share as well as emission intensity levels of new cars, we apply the EU targets as identified in best-in-class scenario also reflected in the 1.5°C compatible scenario, combined with the electrification of the passenger transport sector according to the 1.5°C Paris Agreement compatible benchmark based on (Kuramochi et al., 2018).

Paris Agreement compatible deployment of electric vehicles in passenger transport are combined with the modal shift and CO_2 standards for new non-electric cars from the high ambition case of the best-in-class scenario:

- **Electrification:** The share of EV's in new sales would reach to 100% before 2035 and will constitute 100% of the total vehicle stock by 2050. The share of EVs in new sales is modelled with a s-curve that reaches 100% in 2035. With a 15-year assumed lifetime for personal vehicles and a 12-year assumed lifetime for buses, the new sales were translated into the share of the total fleet via a stock turnover model.
- **Modal shift:** The share of public transport is assumed to increase from 18% in 2015 to 33.5% in 2050 corresponding to the high ambition case of the best-in-class scenario.
- **Emission intensity of new cars:** Penetration of EVs will not alone guarantee a sustainable, emissions free transport sector. Simultaneous decarbonisation of the power sector along with emission intensity improvements of new cars are complementary measures to achieve a clean transport sector. According to the (CAT, 2016), the emissions intensities of LDVs in the EU need to continuously decrease from current levels (150 gCO_2/vkm) reaching the fuel economy target of 95 gCO_2/vkm by 2021 and declining further by at 40% 2030 (57 gCO_2/vkm). We assume that the emission intensity of new cars further declines after 2030 based on the most ambitious and of the EU scenarios as specified later throughout this section. However, this is only relevant up to 2035, given the assumption of 100% electrification for new sales by 2035. The EU emission standards apply to the average for the fleet of all new vehicles. Translation of those targets to the indicator level (intensity improvement rate for non-electrified personal vehicles) for the purpose of quantification with PROSPECTS EU scenario evaluation tool has been performed by taking the new vehicle stock and the split between EVs and ICEs into account for each scenario category and applying a stock turn over model.

Applying best-in-class levels

For selected indicators, fuel economy standards as well as modal shift and penetration of electric vehicles, there exist numerous illustrative examples of regulations around the world and international and regional frontrunners paving the way towards a sustainable transport system.

For electric mobility, Norway's support for electric cars serves as a good example. The global market share for electric vehicles (EVs) was only 0.8% in 2016 (IEA 2018a). However, in Norway, EVs (including plug-in hybrids) accounted for nearly 30% of new cars in 2016 (IEA 2018b). Second to Norway is the Netherlands, where the share of EVs (including plug-in hybrids) among new cars reaches 6.4% (IEA 2018a). The reason for the high diffusion rate of electric cars in Norway and the Netherlands is due to generous public support. For example, in Norway, EVs are exempt from import duty and value-added tax, while heavy duties and taxes are imposed on poor fuel efficiency gasoline cars. This makes the actual price of EVs lower than that of gasoline cars. In addition, the cost of ownership and operation is lower due to automobile tax and highway toll exemption for EVs. As a result, EV owners receive more economic merit compared to gasoline car owners. Note that both the European Council and the European Parliament are asking to demand carmakers to ensure that zero- and low- emission vehicles have a 35 % market share of sales of new cars and vans by 2030.

For fuel economy of new vehicles, the EU sets one of the strictest standards in the world. As the CO_2 emissions are proportional to the consumption of fuel, restrictions on CO_2 emissions have the same impact as fuel economy regulations. On April 23, 2009, the European Parliament and the Council approved regulations setting a target of 130 gCO_2/vkm (5.6 l/100km or 42 mpg) for the average emissions of new cars to be phased-in by 2015. A longer-term target of 95 gCO_2/vkm (4.1 l/100km or 57.6 mpg) has been established for 2020/2021. According to the 'good practice policy' scenario by (Fekete et al. 2015a) a level of 38 km/l (61 gCO_2/vkm) is assumed for new LDVs by 2030. Applying the proposed 35% (Council) and 40% (European Parliament) proposals for reduction targets compared to 2021, this leads to a range of 57-61 gCO_2/vkm.

Concerning the modal split, Austria has achieved the highest share of railways in the modal split for passenger transport among all EU countries. In 2015, passenger car trips represented almost 72.6 % of the passenger-kilometers travelled on land, recording a lower use of passenger cars by around 9 % than the EU average. The share of railways (11.2%) and urban transport (6.7%) was well above the EU average: 7.6% for railways and 1.8% for urban transport (European Commission 2018l). Additionally, the Czech Republic records a relatively low use of passenger cars. In 2015, car trips represented more than 67% of the passenger-kilometers travelled on land which is 14.2% below the EU average. On the other hand, the Czech Republic records a much higher use of buses and coaches than the EU average (15.6% versus 9.4% on average in the EU). Regarding rail passenger transport, this mode of transport is slightly higher than the EU average (7.8% vs. 7.6%). Use of urban transport is very high at 9.5% in comparison with 1.8% on average in the EU. According to the historical trends, the share of public transport has increased by around 0.5% p.a. in Austria and Czech Republic through the period 2007-2016 (European Commission 2018l).

Applying best-in-class level(s) – High ambition

- **Electrification:** The 30% current share of EVs in new vehicle sales in Norway is applied as 2030 target for middle- and high-income countries according to the 'good practice' policy scenario developed by (Fekete et al. 2015a). We further extrapolate this target and assume a linear increase to 70% share of electric cars in new sales by 2050. With a 15-year assumed lifetime for personal vehicles and a 12-year assumed lifetime for buses, the new sales were translated into the share of the total fleet via a stock turnover model. Additionally, we assume a linear interpolation between today and the target years.
- **Modal shift:** Taking Czech Republic as the EU frontrunner concerning the share of public transport in passenger transportation, we assume a public transport share of 33.5% in total road and rail transport activity, while the target year is set to 2050. This implies almost doubling the current share of public transport in the EU (18%) by mid-century. The share of public transport is then modelled with a s-curve that reaches 33.5% in 2050.
- **Emission intensity of new cars:** For emission standards of new cars, we apply the EU targets of 95 gCO_2/vkm for 2020/2021. According to the most ambitious target proposed by the European Parliament, an emission intensity of 57 gCO_2/vkm is assumed for new LDVs by 2030. We assume that the emission intensity of new cars further declines after 2030 based on the most ambitious and of the EU scenarios as specified later throughout this section. We took the reference developments of annual activities in vehicle-kilometres travelled, total and new vehicle stock as well as the share of EVs and as input. By assuming an average life expectancy of 15 years and adding new cars with the efficiency standards specified above using a stock turnover model, we calculated the average emission intensity improvement rate of non-electrified personal vehicle transport activity as required for input to PROSPECTS EU scenario evaluation tool.

Applying best-in-class level(s) – Low ambition

- **Electrification:** The 30% current share of EVs in new vehicle sales in Norway is applied as 2030 target for middle- and high-income countries according to the 'good practice' policy scenario developed by (Fekete et al. 2015a). We further extrapolate this target and assume a linear increase to 70% share of electric cars in new sales by 2050. With a 15-year assumed lifetime for personal vehicles and a 12-year assumed lifetime for buses, the new sales were translated into the share of the total fleet via a stock turnover model. Additionally, we assume a linear interpolation between today and the target years.
- **Modal shift:** Taking Austria as EU frontrunner next to Czech Republic concerning the share of public transport in passenger transportation, we assume a public transport share of 27.4% in total road and rail transport activity, while the target year is set to

2050. The share of public transport is then modelled with a s-curve that reaches 27.4% in 2050.

- **Emission intensity of new cars:** For emission standards of new cars, we apply the EU targets of 95 gCO_2/vkm for 2020/2021. According to the least ambitious target proposed by the Council, an emission intensity of 61 gCO_2/vkm is assumed for new LDVs by 2030. We assume that the emission intensity of new cars further declines after 2030 based on the most ambitious and of the EU scenarios as specified later throughout this section. We took the reference developments of annual activities in vehicle-kilometres travelled, total and new vehicle stock as well as the share of EVs as input. By assuming an average life expectancy of 15 years and adding new cars with the efficiency standards specified above using a stock turnover model, we calculated the average emission intensity improvement rate of non-electrified personal vehicle transport activity as required for input to PROSPECTS EU scenario evaluation tool.

EU scenarios

For electric mobility, in the study conducted by (Kampman et al 2011), CE Delft, ICF and Ecologic were commissioned to study the status and prospects of EV technology, the potential market uptake of EVs and their likely impacts for the EU. Their study focuses on passenger cars and light commercial vehicles and covers the various types of EV: full electric vehicles, plug-in hybrid EVs and EVs with range extenders. The time frame of the scenario analysis covers the period from 2010 until 2030. The assessment was made for three scenarios with different assumptions on EV and conventional car developments and one Reference Scenario. The 'most realistic' scenario is intended to provide the most realistic outlook of EV developments with a share of EVs in total passenger car fleet of 18% by 2030. The Scenario 'ICE breakthrough' assumes that the costs of batteries reduce less than anticipated in the first scenario. The scenario 'EV breakthrough' is the most optimistic scenario from the EV development perspective. R&D leads to a rapid decrease of battery costs and increase of battery lifetime. In Scenario 'ICE breakthrough', the EV share in total passenger car fleet reaches to 7% by 2030, while the most ambitious scenario "EV breakthrough" envisages an EV share of 33% in total vehicle stock by 2030.

Additionally, the study conducted in (Höltl et al 2018) developed decarbonisation scenarios for the European passenger car fleet until 2050. The scenarios have been developed using the back-casting approach and aim to reduce greenhouse gas (GHG) emissions of passenger cars to a level defined in the Transport White paper that is 60% below 1990 levels. The White Paper target initially considers the transport sector as a whole, while for the purposes of their study, this target is assigned to the EU-27 passenger car fleet, accounting for 64% of total transport sector emissions in 2010. The information about the European car fleet on an aggregated level has been taken from the EU-27 transport scenarios using TREMOVE model data. TREMOVE is a policy assessment tool to study the effects of different transport and environment policies on the emissions of the transport sector, and it is a common source for vehicle-based emission data on European level. According to their findings, total European electric passenger cars (including BEVs and PHEVs) in 2050 reaches to 97% of total passenger car fleet stock by 2050 dominated by BEVs in the 'Electrification' scenario as the most ambitious scenario. A less strong transition to battery electric cars is expected in the 'Green Energy' Scenario with 34% share in total passenger car fleet stock by 2050. The least ambitious scenario 'Shared Mobility' envisages a total EV stock of 32 million corresponding to a share of 22% in the European passenger car fleet by 2050.

For emission intensity standards, in the context of the 2016 Impact Assessment work of the European Commission, two core policy scenarios, EUCO27 and EUCO30, were prepared by the consortium led by E3Mlab, hosted at the National Technical University of Athens (NTUA), and including the International Institute for Applied System Analysis (IIASA) (E3MLab & IIASA 2016) The two policy scenarios were built based on the EU Reference Scenario 2016 and designed to achieve the 2030 targets as agreed by the European Council. In addition, the EUCO+ scenarios and the EUCO3030 sensitivity case were also prepared. The EUCO+ scenarios were presented only in the Impact Assessment accompanying the proposal for revised Energy Efficiency Directive. The EUCO3030 sensitivity was presented both in the Impact Assessment accompanying the proposal for revised Energy Efficiency Directive and the Impact Assessment accompanying the proposal for recast of the Directive on the promotion of energy from renewable sources. These scenarios assume the following emission intensity standards for the European new car fleet:

Table 21: CO2 standards for new cars under different scenarios

Scenario	CO_2 standard for new cars in gCO_2/vkm		
	2025	2030	2050
EUCO27	85	75	25
EUCO30	80	70	25
EUCO+33	77	67	25
EUCO+35	74	64	25
EUCO3030	74	64	25

For the modal shift, in the context of the Impact Assessment work of the European Commission, the Commission has identified three policy options besides the baseline scenario (European Commission 2011b). All three policy options have been designed to reach the same CO_2 emission reduction target, i.e. 60% rel. to 1990 levels. In policy scenarios, rail transport would constitute a share between 8.7% and 13.4% of total passenger kilometre transport activity in 2050. The greatest changes occur in "Policy Option 2" due to very intensive policies with the objective of managing demand and encouraging a shift in modal choices: demand for road passenger transport and aviation drops by over 20% relative to "Policy Option 1" by 2050, while demand for rail passenger transport increases by 35%.

EU Scenarios – High ambition

- **Electrification:** The share of EVs in total vehicle fleet reaches to 33% by 2030, while it continuously rises to 97% in 2050. These ranges have been inspired based on the highest ambition end of the scenarios developed by the studies conducted in (Höltl et al., 2017; Kampman et al., 2011). Additionally, we assume a linear interpolation between today and the target years.
- **Modal shift:** We assume that the passenger rail transport would linearly increase from today to 13.4% of total passenger transport activity by 2050 as envisaged by the Impact Assessment scenario 'policy option 2'. To get the share for other transport modes, we further combine this scenario with transport activity projections based on (IEA MoMo., 2017) as used for reference scenario projections in PROSPECTS EU scenario evaluation tool. On this basis, the share of public transport would constitute 24% of total road and rail transport activity by 2050.
- **Emission intensity of new cars:** For the high ambition end of emission standards of new cars, we consider the "EUCO+35" and "EUCO3030" scenarios concerning their most ambitious targets for the emission intensity standards of the European new cars: 64 gCO_2/vkm by 2030, and 25 gCO_2/vkm by 2050.

EU Scenarios – Low ambition

- **Electrification:** The share of EVs in total vehicle fleet reaches to 7% by 2030, while it rises to 34% in 2050. These ranges have been inspired based on the lowest ambition end of the scenarios developed by the studies conducted in (Höltl et al., 2017; Kampman et al., 2011). Additionally, we assume a linear interpolation between today and the target years.
- **Modal shift:** We assume that the passenger rail transport would constitute 8.7% of total passenger transport activity by 2050 as envisaged by the Impact Assessment scenario 'policy option 3' as the least ambitions scenario. To get the share for other transport modes, we further combine this scenario with transport activity projections based on (IEA MoMo., 2017) as used for reference scenario projections in PROSPECTS EU scenario evaluation tool. On this basis, the share of public transport would remain

nearly constant at today level of 18% of total road and rail transport activity, which is also comparable with the reference scenario projections.

- **Emission intensity of new cars:** For the low ambition end of emission standards of new cars, we consider the "EUCO27" scenario imposing the highest targets for the emission intensity standards of the European new cars: 75 gCO_2/vkm by 2030, and 25 gCO_2/vkm by 2050.

4.3.2.2 Quantification of emission levels with PROSPECTS

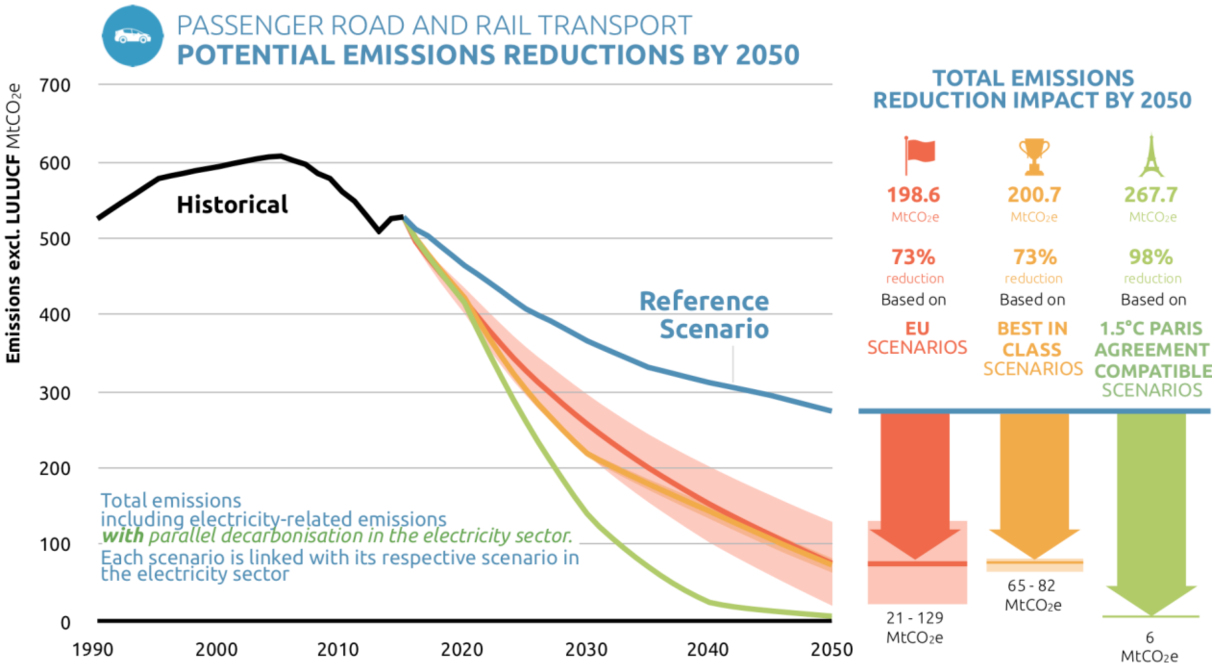


Figure 16: GHG emissions from the EU's rail and road passenger road and rail transport sector under different scenarios, incl. electricity-related emissions and parallel decarbonisation actions in electricity sector beyond Reference Scenario

Figure 16 illustrates the emissions trajectories from the EU's passenger road and rail transport sector until mid-century. This graph includes electricity related emissions but at first no additional climate action in electricity sector beyond current policies is assumed. **Error! Reference source not found.** illustrates the emission trajectories from the EU's passenger road and rail transport for different analysed scenarios, while enhanced climate action in the passenger transport sector is further combined with decarbonisation of the electricity sector. This reveals how by applying mitigation measures on the demand side such as strong electrification of the transport sector and modal shift combined with a simultaneous decarbonisation of the electricity sector, significant reduction of emissions can be achieved by mid-century. Under reference scenario projections, the emissions would decline to 250 $MtCO_2e$/a by 2050, i.e. 52% below 1990 levels. The Reference Scenario results in emissions from the EU's total transport sector decreasing from 863 $MtCO_2$/a in 2015 to 617.5 $MtCO_2$/a emissions in 2035, while the EEA projection (see section 3) based on current policies shows emissions staying at a high level of 867 $MtCO_2$/a .

All scaled-up climate action pathways imply much further emissions reductions in the passenger transport sector far beyond the reference scenario projections:

- The '**1.5°C Paris Agreement compatible'** pathway substantially reduces emissions and leads to the near complete decarbonisation of the passenger transport sector by mid-century. This is mainly driven by the strong electrification of the passenger vehicle fleet. Further influencing factors include modal shift towards a higher share of public transport as well as emission intensity improvement of the remaining non-electric personal vehicles.

- The '**Applying best-in-class levels'** pathway also implies an immediate reduction of emissions. The 2050 emissions vary between 50 and 80 MtCO2e/a for the high and low ambition case, respectively.
- The '**EU scenarios'** pathway reveals a broad range across the upper and lower ambition end. The high ambition end implies a substantial reduction of emissions and the 2050 emissions are only slightly above the Paris Agreement compatible scenario. The upper trajectory reduces emissions to around 108 MtCO2e/a in 2050, i.e. around 140 MtCO2e/a below reference scenario projections.

To reduce emissions from the whole EU's transport sector across additional policies would have to be introduced for land freight transport and for maritime and aviation transport. Freight transport should be decarbonised by 2050 (Climate Action Tracker 2018b) (refer to freight decarb memo).

5 Conclusions

The analysis shows that upscaled mitigation action in electricity generation, residential buildings, and passenger transport in the EU can alone significantly exceed EU's current emissions reduction target for 2030 and decarbonise the three focus areas of this analysis by mid-century, in line with a global Paris Agreement-compatible pathway. Further actions in all other sectors will be required to ensure economy-wide Paris Agreement-compatible development.

The upscaled mitigation actions come with important co-benefits, such as improved air quality and increased energy independence. While in some regions job losses resulting from the phase out of coal extraction and combustion constitute an important challenge, our analysis indicates that renewable energy can replace coal to enable a nearly fossil fuel-free electricity sector in 2030 and result in significant net job creation.

The policies negotiated and adopted in the EU in 2018 are a step in the right direction but the EU need to take advantage of the opportunity for upward revision of the renewable energy and energy efficient targets in 2023. It must be ensured that the EU member states transpose and implement the respective EU directives to reach and subsequently exceed those targets as the basis for the upward revision.

The reform of the EU Emissions Trading Scheme (EU ETS), especially the introduction of the Market Stability Reserve, combined with the new renewable energy directive (REDII) creates a conducive framework for full decarbonisation of the power sector. Whereas the former allows member states to phase out coal without contributing to increasing the oversupply of emissions allowances, the latter facilitates development of alternatives. However, to be compatible with the Paris Agreement all countries need to commit to coal phase out by around 2030. The EU also needs to stop utilization of public resources to finance construction of natural gas infrastructure.

For the transport sector, in 2013 the emissions trend reversed and emissions began to increase. Our analysis has shown that emissions from the passenger transport can decrease significantly if the appropriate measures are introduced. The currently discussed stricter emissions standards for cars for 2030, which also include quota for electric vehicles, can contribute to changing this trend. Decisions to phase out the sale of internal combustion cars, as already introduced by some EU member states, could accelerate this trend.

Measures to reduce emissions from the residential sector – or their lack – will have a long-lasting impact on EU emissions. Increasing the deep renovation rate to 5% - five times the current rate – and decarbonising heating in particular through electrification would allow the EU member states to significantly reduce emissions, while at the same time contributing to lower energy bills for their citizens, lower energy dependency and – especially in countries using coal or oil for heating – significantly improved air quality.

KEY FINDINGS

- ⇨ The European Union's targets and policies are not yet compatible with the Paris Agreement's 1.5°C limit. This report analyses areas where the European Union could accelerate its climate action.
- ⇨ Scaling up climate action in the European Union's electricity supply, residential building and passenger road and rail transport —covering around 60% of the EU's current energy related emissions—can decarbonise these sectors by 2050.
- ⇨ The reductions in these three sectors alone are enough to reduce EU28 total greenhouse gas emissions by up to 52% below 1990 levels in 2030. This shows that the EU can and needs to ratchet up its 2030 target to make it consistent with the Paris Agreement.
- ⇨ To get on track toward Paris Agreement-compatible emissions reductions, the EU needs to urgently scale up climate action in the transport and buildings sectors, decarbonising them by 2050, with decarbonisation of electricity generation and electrification of transport, heating and cooling as essential steps.

Electricity supply

- ⇨ With the recently adopted EU policies including a binding target of 32% for the share of renewable energy in total energy demand (not just the power sector), the EU would reach a share of renewable energy in electricity generation of 55% by 2030. This is a step in the right direction, but not enough to be consistent with the Paris Agreement-compatible pathway, which according to our analysis, would require increasing the share of renewable energy sources for electricity (RES-E) to between 60 and 75% in 2030 and full decarbonisation by 2050.
- ⇨ To be Paris Agreement-compatible, the EU needs to deploy renewable energy faster than Denmark, the "best in class" country with the highest growth rate of renewables between 2009 and 2015. Applying Denmark's rate of growth to the whole of the EU would lead to the share of RES-E reaching between 49–59% in 2030 and 76–95% in 2050.
- ⇨ An essential step to decarbonising electricity generation is phasing out coal: globally by 2050, and in the EU by 2030. There are steps being taken in the right direction: by mid-2018, ten out of 28 EU member states—accounting for 26% of EU coal capacity—have already set phase-out goals for 2030.
- ⇨ The Paris Agreement 1.5°C-compatible scenario would create, on average, around 350,000 more direct jobs between 2020 and 2030 in the electricity sector alone than the reference scenario, particularly in wind and solar energy.

Residential buildings

- ⇨ Paris Agreement-compatibility requires the renovation rate of the building sector to increase significantly from the current 1%—ideally to around 5%—with the energy demand per square meter decreasing by between 75% and 100%.

  Together with electrification, and phasing out fossil fuels for space heating and cooling, and replacing these with renewable energy, this would result in an almost complete decarbonisation of the sector. It implies higher renovation rates and more efficiency improvements than those achieved if "best in class" policies applied in Denmark were to be adopted in all EU member states.
- ⇨ Apart from improving quality of life and helping to reduce energy poverty affecting between 50 and 125 million Europeans, improving efficiency and replacing fossil fuels for heating would significantly decrease energy dependency in the EU by reducing gas imports and reduce air pollution.

Passenger road and rail transport

- The CAT Paris Agreement-aligned benchmark requires the EU to increase its share of electric vehicles (or other emissions-free vehicles) in new sales from today's 2% to 100% in 2035 resulting in full decarbonisation by the middle of the century. The EU also needs to apply stringent standards for CO_2 emissions intensity of new vehicles. Member states also need to increase their share of public transport, and follow the example of frontrunner member states such as the Czech Republic and Austria.
- Decarbonising the transport sector would significantly decrease reliance on energy imports and help reduce air and noise pollution. Road transport is responsible for 30% of NO_x emissions in the EU28.

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The Climate Action Tracker (CAT) is an independent scientific analysis produced by three research organisations tracking climate action since 2009. We track progress towards the globally agreed aim of holding warming well below 2°C, and pursuing efforts to limit warming to 1.5°C.

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The Consortium

Ecofys, a Navigant company, is a leading international energy and climate consultancy focused on sustainable energy for everyone. Founded in 1984, the company is a trusted advisor to governments, corporations, NGOs, and energy providers worldwide. The team delivers powerful results in the energy and climate transition sectors. Working across the entire energy value chain, Ecofys develops innovative solutions and strategies to support its clients in enabling the energy transition and working through the challenges of climate change.

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Climate Analytics is a non-profit climate science and policy institute based in Berlin, Germany with offices in New York, USA, Lomé, Togo and Perth, Australia, which brings together interdisciplinary expertise in the scientific and policy aspects of climate change. Climate Analytics aims to synthesise and advance scientific knowledge in the area of climate, and by linking scientific and policy analysis provide state-of-the-art solutions to global and national climate change policy challenges.

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Annexes

Annex 1: Overview of studies on the decarbonisation of the EU's electricity sector analysed in this study

Below we describe the long-term scenario analyses on the decarbonisation of the EU's electricity sector that we reviewed in our assessment.

- Quantification by (Fraunhofer ISI , 2014) investigates pathways towards a European electricity sector in line with the goal of keeping global warming below 2°C. An emission cap of 75 Mt is applied to the annual CO_2 emissions in 2050, equivalent to a 95% reduction compared to 1990 levels. The analysis has been carried out using a least cost approach, modelling the time frame until 2050 in steps of 10 years by applying the PowerACE optimization model. Electricity demand in 2050 is assumed to be less than 5% higher than in 2010. CCS technologies are included as an additional decarbonisation option and are built by the least cost optimization approach. Nuclear generation capacity follows an exogenous development path and declines to ca. 55 GW generation capacity by 2050. The 'Modified wind Scenario' particularly incorporates increasing land availability in Europe for wind onshore. All three modelled scenarios of 'Modified wind' scenario, 'Efficiency' scenario and 'High Demand' scenario include CCS technologies as part of the optimization, while the nuclear technology follows an exogenously given development path. The 'Efficiency Scenario' assumes the same development of electricity demand as in 'Modified Wind' Scenario, i.e. electricity demand in 2050 is assumed to be less than 5% higher than in 2010. The 'High Demand' scenario assumes a considerably higher electricity demand which increases to approximately 4200 TWh by 2050. Modelling results indicate a RES share of 67% by 2030, 80% by 2040, and 85% by 2050 for the 'Modified wind' scenario. The RES indicator values from the 'Efficiency' scenario are 65% by 2030, 77% by 2040, and 82% by 2050. The RES indicator values from the 'High Demand' scenario is 66% by 2030, 74% by 2040, and 81% by 2050. Due to the high share of nuclear and low ambition level of the RES share in the long-term (2050), this scenario has not been selected for the high ambition end of the range of EU scenarios considered here.
- The model-based sensitivity analysis on underlying technological and institutional assumptions conducted in (Knopf et al., 2015) shows that the cost-effective RES share varies between 45% and 56% by 2030.
- The 'Regional Policy' scenario by (Odenberger et al., 2015) assesses the consequences of a stringent climate-mitigation target in the EU, with almost 100% reduction of CO_2 emissions in the electricity-supply system, together with dedicated policy targets for renewables and energy efficiency. The RES indicator value ranges from this scenario are 50% by 2030 and 80% by 2050. The 'Green Policy' scenario assesses the impact of an electricity-supply system that is close to 100% renewable by year 2050. This scenario is loosely based on the EC Roadmap scenario "High RES". However, the primary objective of this scenario is to analyse a European electricity system that is almost exclusively made up of renewable electricity generation. The conditions for reaching such a system are, in this case, of less relevance. The RES indicator value ranges from this scenario are 59% by 2030 and 95% by 2050.
- The 'Energy Revolution' scenario by (Greenpeace et al., 2015) is designed to achieve a set of environmental policy targets resulting in an optimistic and feasible pathway towards a widely decarbonised global energy system by 2050, following the key target to reduce worldwide carbon dioxide emissions from energy use down to a level of around 4 Gt/year by 2050 in order to hold the increase in global temperature under 2°C. A second objective is the global phasing out of nuclear energy. The RES indicator value ranges from this scenario are 61% by 2030, 82% by 2040 and 94% by 2050 for OECD Europe. Due to the

regional inconsistency, this scenario is not prioritized over the EU specific studies for selection of the higher ambition end of the range of EU scenarios considered here.

- The ‘Remap’ scenario by (IRENA, 2018b) has been developed through a least-cost power sector modelling approach. This is an accelerated renewable energy scenario which analyses the transformation of the global energy system with the goal of limiting the rise in global temperature to below 2°C above pre-industrial levels by the end of the century (with a 66% probability). This scenario envisages a RES indicator value of 94% for the European Union by 2050. (IRENA, 2018b) particularly focuses on the EU specifications of the ‘Remap’ case over a time horizon until 2030. This study envisages a RES indicator value of 50% by 2030.
- The ‘Opportunity’ Scenario by (ECF et al.) includes the main elements of the current EU energy policies, while going beyond in two ways. On one hand, Member States advance national plans to retire coal plants, reflecting existing plans or the potential outcome of ongoing debates in the UK, France, Italy, Germany, Poland and Spain (amounting to a total reduction of 37 GW, compared to EUCO30). In France, this also means a reduction of 20 GW of nuclear capacity by 2030. In comparison with 2015, coal and nuclear capacities drop from 289 GW in 2015 to 153 GW under the Opportunity Scenario (-47%). On another end, smart electrification phases in by assuming that Member States implement robust policies to activate demand flexibility across the energy system with a specific focus on the smart integration of new and existing distributed loads coming from solar PV, electric vehicles (Evs), industrial processes (boilers) and heat pumps (HPs). The methodology is based on a bottom-up energy system model that allows for a joint optimization of investments and of the management of the energy system assets using an hourly time resolution and covering the EU-28 plus Norway and Switzerland. The RES indicator value ranges from the ‘Opportunity’ Scenario and the ‘Current Plans’ Scenario are 55% and 61% by 2030, respectively.
- The EUCO scenario published by (Banja and Jégard, 2017) use as the starting point of the energy modelling the EU Reference Scenario 2016 projections for indicators such as the share of renewable energy sources or levels of energy efficiency over a five-year period until 2050 for the EU as a whole and for each Member State. Using the EU Reference Scenario as a starting point, EUCO scenarios are created to model the achievement of the 2030 climate and energy targets as agreed by the European Council in 2014 as well as some additional scenarios. The JRC has developed a global energy model (JRC POLES) that examines the effects on greenhouse gas emissions and energy markets. The assessment in this study aims to compare the estimated progress path of renewable energy technologies in the electricity sector as described in the PRIMES and PRIMES climate mitigation scenarios: (i) the Reference 2016 scenario, (ii) the EUCO27 scenario; (iii) the EUCO30 scenario, (iv) the EUCO3030 scenario and (v) the EUCO+40 scenario, used as official European Commission projections of energy and greenhouse gas emissions in the EU. The assessment also includes two additional scenarios produced using the global energy and GHG model JRC-POLES: (vi) the INDC scenario and (vii) the below 2 °C scenario. The analysed scenarios specify a total RES indicator range of 43-54% in 2030.

Annex 2: Approach for the analysis of employment effects in the electricity sector in the EU

For the analysis of the employment impact for the European Union (EU), a different methodological approach has been applied. Large heterogeneity in costs and salaries between EU countries is likely to be a confounding factor when applying the Economic Impact Model for Electricity Supply (EIM-ES) which has largely been designed to analyse countries in which average costs and salaries serve well to give a representative picture. Moreover, the EIM-ES provides valuable insights for countries where pre-existing analyses applying complex modelling approaches are not available. For the EU, we therefore decided to illustrate the implications for the different analysed climate policy scenarios focusing on *direct jobs* using employment factors empirically derived for Europe. The results of our analysis are shown in Table 23 and Table 24 (sensitivity analysis).

We follow the approach proposed by Rutovitz et al. (2015) which has also been used in the Energy [R]evolution Report by Greenpeace International, Global Wind Energy Council and Solar Power Europe (Greenpeace 2015). The 'Advanced Energy Revolution (ADV E[R])' scenario from this Energy [R]evolution Report is also the underlying benchmark for the 1.5°C Paris Agreement compatible Upper Bound-Scenario for the EU. The approach estimates direct jobs associated with electricity generation and includes jobs in manufacturing, construction & installation, operations & maintenance as well as fuel supply (e.g. mining). We cover all technologies playing a role in electricity generation in the EU: Coal, natural gas, oil & diesel, nuclear, large scale hydro, small scale hydro, geothermal, biomass, onshore wind, offshore wind, solar photovoltaics (PV), solar thermal (mainly CSP), ocean/marine energy and waste. Figure 17 provides an overview of the approach.

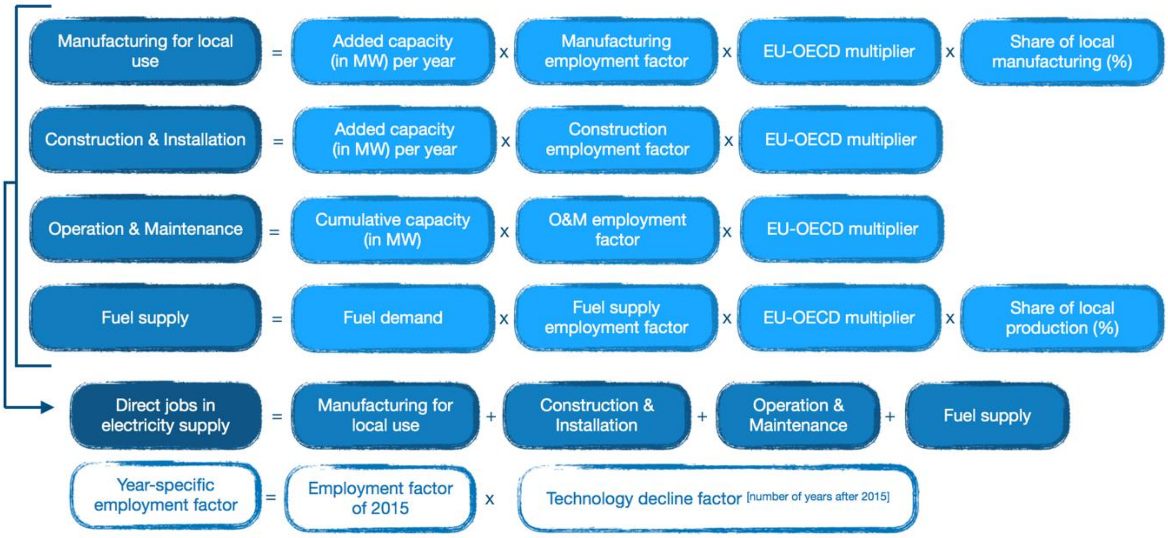

Figure 17: Overview of approach. Adapted from Rutovitz et al. (2015)

As Figure 17 shows, employment factors are mainly applied per Megawatt (MW) of cumulative installed or added capacity. Based on the scenarios for electricity generation in PROSPECTS, we calculate the respective installed capacities as well as the capacity additions and retirements for each technology and year for each scenario based on capacity factors. Capacity additions are calculated based on whether there is a positive difference (increase in MW) in the following year, and retirements of capacities are calculated based on whether there is a decline in installed MW in the following year. Therefore, both additions and retirements are lower-bound estimates as potential capacity additions coinciding with retirements in the same year cannot be identified.

To disaggregate PROSPECTS data on 'solar', 'wind' and 'hydro' into different technologies, we used information from the shares of onshore and offshore wind as well as solar PV and solar thermal in electricity generation calculated from the Greenpeace (2015) ADV E[R] Scenario. For hydro, we used the share in the total installed hydro capacity of small-scale hydro and large-scale hydro calculated from the Platts database[12] and assume the share remains constant over time. Though the threshold definitions differ between EU countries and within the literature, we assume small-scale hydro to be facilities with a capacity of up to 10 MW (including 10MW) and large hydro above 10MW following the definition used by the European Commission & SETIS (SETIS and European Commission n.d.)[13]. This yields a share in the total installed hydro capacity in the EU of around 13% for small scale hydro and 87% for large-scale hydro.

Capacity factors

We calculate the technology- and year-specific capacity factors based on data on GWh of electricity production and MW installed capacity from PRIMES (EU Open Data Portal n.d.) and the 'Advanced Energy Revolution (ADV E[R])' scenario Greenpeace (2015). While capacity factors for RE-technologies are assumed to mainly depend on technical constraints (e.g. hours of sun/wind, technical progress), the capacity factors for fossil-based technologies are expected to be influenced by changes in the composition of the energy system affecting the utilization/load of power plants. We therefore assume that capacity factors differ for the Reference and the 'Scaling up Climate Action' scenarios (i.e. the 1.5°C Paris Agreement compatible benchmarks, the Best-in-class Scenarios and the EU scenarios).

The technology- and year-specific capacity factors applied in the 'Scaling up Climate Action' scenarios have been derived based on data from 'Advanced Energy Revolution (ADV E[R])' scenario (which was also used as an input for the Upper Bound Paris Agreement-compatible Scenario). For the reference scenario, the capacity factors have mainly been derived based on PRIMES data on electricity generation and installed capacities (PRIMES is the underlying data for the reference scenario). As PRIMES data does not differentiate between offshore and onshore wind nor between solar PV and solar thermal electricity, nor does it provide data for 'marine', we use the capacity factors for these derived from ADV E[R]- scenario data Greenpeace (2015) also for the reference scenario. To have capacity factors for all technologies relevant to the EU and to ensure calculated capacity factors are in line with empirically observed ranges in the literature, e.g. from IRENA (IRENA 2018b), we made the following adjustments to the calculated capacity factors:

- For geothermal, we apply the capacity factor calculated based on PRIMES for the year 2015 for all scenarios and all years, as calculated capacity factors fall outside the empirically observed ranges in some years.
- For hydro, we assume that the capacity factors calculated based on PRIMES and the Greenpeace ADV E[R]-Scenario apply to both small- and large-scale hydro.
- For marine, we use capacity factors derived from the Greenpeace ADV E[R]-Scenario data for all scenarios. However, as Greenpeace assumes 0% marine electricity in 2015 resulting in a 0% capacity factor the value of the capacity factor in the year 2020 is used for 2015 to 2020.
- For waste, neither Greenpeace (2015) nor PRIMES data allows to derive capacity factors. Therefore, we assume that the capacity factors for waste are the similar to those for coal and therefore proxy them by using the respective coal capacity factors derived from Greenpeace and PRIMES.

To avoid differences in installed capacities (MW) in 2015 stemming solely from differences in applied capacity factors and not from differences in underlying generated electricity (TWh), we apply PRIMES capacity factors for 2015 to all scenarios and for the 'Scaling up Climate Action' scenarios, we start applying ADV E[R]-Scenario -based capacity factors starting in 2020. For the years 2016 to 2020 we assume that capacity factors smoothly transition from PRIMES-based capacity factors to ADV E[R]-Scenario -based capacity factors by linear interpolation for the Policy Scenarios. For the other years, for which no scenario data from PRIMES or Greenpeace (2015) is provided, we also use linear interpolation.

Employment Factors

12 WEPP World Electric Power Plant Database. Available: http://www.platts.com/products/world-electric-power- plants-database

13 https://setis.ec.europa.eu/system/files/Technology_Information_Sheet_Hydropower.pdf

We apply technology and region-specific employment factors as shown in Table 22. These employment factors are mainly based on the employment factors for OECD-Europe[14] from Rutovitz et al. (2015), which are also used in Greenpeace (2015). To improve the match with historical employment data, we used employment factors for solar PV from Ortega et al. (2015b)[15]. To obtain a better match with observed data, we derived the employment factor for O&M for coal using an weighted average[16] over EU-country-specific employment factors reported in the JRC Science for Policy Report (Alves Dias et al. 2018). This employment factor is higher than the employment factor suggested by Rutovitz et al. (2015).

Rutovitz et al. (2015) adjust the 'base'- employment factors with regional adjustment factors to account for differences in productivity. However, as most of the employment factors have been derived empirically based on EU country analyses or other OCED countries, the regional adjustment factor for OECD-EU suggested by Rutovitz et al. (2015) is 1. The regional adjustment factor has yet been included to in the methodology overview for completeness (see Figure 17).

While Table 22 shows the employment factors applied for the year 2015, employment factors are adjusted over time to reflect 'learning', e.g. improvements in technology efficiency and maturing production techniques. For this, we follow the methodology suggested in Rutovitz and Atherton (2009) and Rutovitz et al. (2015) and apply technology- and Europe-specific decline factors assuming that the employment factor changes by a certain percentage each year.

Employment factors for Construction and Installation as well as Manufacturing measure employment in 'job years'. To obtain the number of jobs for each year, we distribute the number of job years evenly over the duration for construction of the respective technology. For technologies with longer construction duration, this can lead to hypothetical job creation in the base year 2015 or other historical years before 2015.

14 Almost all EU-member countries have OECD status except Bulgaria, Malta, Cyprus, Croatia and Romania.

15 For PV manufacturing, the average of the component-specific employment factors (modules and inverters) reported in (Ortega et al. 2015b) is used to proxy the overall employment factor. However, as we assume that only 25% of solar PV parts are manufactured in the EU, the results are not very sensitive to this assumption.

16 For weighing, we use the country-specific MW installed capacity for coal ("solids fired") reported in PRIMES.

Table 22: Employment factors applied in 2015

	Construction duration *(in years)*	Construction & Installation *(Job years per MW)*	Manufacturing *(Job years per MW)*	Operation & Maintenance *(Jobs per MW)*	Fuel Supply *(Jobs per PJ or GWh)*	Notes
Coal	5	11.2	5.4	0.35	40.1 jobs per PJ primary energy	EF for O&M derived from Alves et al. (2018); fuel supply: Efficiency loss accounted for
Gas	2	1.3	0.93	0.14	7.9 jobs per PJ primary energy	Fuel supply: Efficiency loss accounted for
Oil and diesel	2	1.3	0.93	0.14	7.9 jobs per PJ primary energy	Fuel supply: Efficiency loss accounted for
Nuclear	10	11.8	1.3	0.6	0.001 jobs per GWh	
Hydro-large	2	7.4	3.5	0.2		
Hydro-small	2	15.8	10.9	4.9		
Geothermal	2	6.8	3.9	0.4		
Biomass	2	14	2.9	1.5	29.9 jobs per PJ primary energy	Fuel supply: Efficiency loss accounted for
Wind onshore	2	3.2	4.7	0.3		
Wind offshore	4	7.1	10.7	0.2		
Solar PV	1	6.6	3.58	0.2		EFs from Ortega et al. (2016)
Solar thermal	2	12.2	4	1		
Ocean	2	10.2	10.2	0.6		
Waste	5	11.2	5.4	0.49		Assumed same as for coal
Nuclear decommissioning		0.95 jobs per MW decom-missioned				

Note: Employment factors based on Rutovitz et al. (2015) for OECD-Europe if not indicated otherwise. Employment factors for years after 2015 are adjusted using technology-specific decline factors.

Assumptions for assessing local jobs

For the calculation of employment in manufacturing, the share of technology parts that is manufactured locally has to be defined. While Rutovitz et al. (2015) assume that the share of local production for manufacturing is 100% for OECD-Europe for all technologies, we instead assume that it is 25% for PV due to the large fraction of solar panels manufactured outside of Europe, and 100% for all other technologies. We conducted a sensitivity analysis reducing the share of local manufacturing for all renewable energy technologies to 80% (PV remained at 25%). The results are shown in Table 24. We do not assess jobs in manufacturing for exporting, our estimates of jobs in manufacturing refer to manufacturing for local use only. Total jobs in manufacturing could thus be higher, if a part of the manufactured energy technologies (e.g. wind turbines) is exported to other countries. In line with Rutovitz et al. (2015), we assume that jobs in construction and installation are all local jobs.

Assumptions for assessing jobs in fuel supply

To assess the local employment effects in fuel supply (e.g. in coal mining), we need to define the share of fuel for electricity production that is provided locally within the EU as compared to the fuel imported from outside the EU. We calculated the share of local fuel supply to be the observed share of fuel consumption covered by fuel production within EU countries based on data in the BP Statistical Review of World Energy (Version June 2018). We use the observed share of locally supplied fuels for coal, natural gas, oil & diesel for the year 2015 and assume that this proportion remains constant over time. For biofuel, we assume that 100% of fuel demand is covered by local sources, in the sensitivity analysis (see Table 24) we, however, also present results assuming only 80% of biofuels supplied locally. For nuclear, we assume that 100% of nuclear material is supplied by imports (i.e. local fuel supply being 0%). For all other technologies (e.g. wind, solar), it is assumed that no fuel supply is required.

Rutovitz et al. (2015) provide employment factors for fuel supply for coal, natural gas, oil, nuclear and waste (see Table 22). For employment factors referring to jobs per peta joule (PJ), we assume efficiencies for electricity generation of 35% for coal, 51% for natural gas, 35% for oil and 32% for biomass.[17] The employment factor for 'fuel supply' for nuclear refers to jobs per GWh final energy demand, however, as we assume that all material for nuclear is imported, we do not calculate any jobs for 'fuel supply' for nuclear. For waste, we also do not calculate jobs in 'fuel supply' as we assume that employment in waste collection is mainly independent from developments in waste-to-energy and would be rather attributed to other sectors than the energy sector.

Limitations of the approach

The employment numbers reported in this study are indicative only, as they are subject to a range of limitations. These are discussed in the following.

Meta analyses on employment effects for renewable energy show that there is considerable variation between employment factors reported for different countries, also within EU countries (Cameron and van der Zwaan 2015; Meyer and Wolfgang 2014; Rutovitz et al. 2015). Moreover, most employment factor estimates have been derived on data for OECD countries and only very few on less developed countries. While most EU countries have OECD status, the level of development and labour productivity within the EU cannot be considered homogenous. Rutovitz et al. (2015) suggest to apply a regional multiplier of 6.0 in 2015, 5.0 in 2020 and 3.6 in 2030 for countries in "Eastern Europe/Eurasia" to account for lower labour productivity suggesting higher employment, however in their definition this region includes majorly non-EU countries.

Though we account for 'learning effects' changing employment factors over time, the approach does not account for more complex dynamics and for major structural changes in the energy sector induced by the policies. As the employment factors have been derived from empirical observations, the employment factors for new or future technologies, such as hydrogen, coal with carbon capture and storage (CCS), or bioenergy with CCS (BECCS) are not available. For our analysis, we apply the employment factors for coal and biomass independent of whether these are actually combined with CCS-technologies in the scenarios.

For transferring the estimates in 'job years' for Construction and Installation as well as Manufacturing to 'jobs for each year' we distribute the number of job years evenly over the duration for construction of the respective technology as explained above. However, for technologies with longer construction duration (see Table 22), this can lead to future added capacities inducing hypothetical job creation in manufacturing and construction reaching back into the base year 2015 or other historical years before 2015 which are not part of the scenario analysis. This thus induces differences in the job estimates for 2015 for the different scenarios, although the technology mix an electricity generation data are the same for all scenarios in the base year. We therefore report job estimates for the Scaling Up Climate Policy Scenarios starting from 2020 onwards.

Moreover, several types of jobs related to the energy sector have not been accounted for in the analysis. This includes jobs in replacement, energy efficiency and heat supply. Rutovitz et al. (2015) indicate that wind and solar PV facilities need to be replaces about every twenty years while coal power facilities have a lifetime of approximately 40 years. Our analysis only accounts for net changes in installed capacity, with net decreases being interpreted as newly installed added capacity and net decreases as retirements, therefore likely underestimating jobs stemming from added or retired capacities coinciding for the same year. Accounting for replacement of capacities would likely lead to higher employment effects for solar and wind as compared to coal, as solar and wind have a lower lifetime and therefore need more frequent replacement. While we account for jobs in nuclear decommissioning, we also do not account for

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17 Estimates on efficiencies have been derived based on data from the IEA Energy Balances https://www.iea.org/classicstats/topics/energybalances/.

jobs in dismantling coal power plants in case of a coal phase out. Additionally, generated electricity falling into the category 'other', i.e. which could not be attributed to one of the technologies, was neglected in the analysis. In the reference scenario, the category 'other' is zero, while it is non-zero in most of the scaling up climate action scenarios. Thus, the estimates of the net employment impacts can be seen as conservative to this regard, as electricity generated from 'other' technologies would have additional job impacts.

As mentioned earlier, the employment factor approach used here only assesses direct employment. This means that jobs in indirect employment and induced employment are not accounted for in our analysis. As only direct employment is assessed, complex dynamics and interactions are neglected, jobs in newly emerging technology types may not yet be represented appropriately in available empirical employment factors and jobs in replacement, energy efficiency, and heat supply are not accounted for, a comparison of jobs for the different technologies over time can only yield an indicative picture of the overall developments and employment effects for the analysed scenarios. Therefore, our estimates should not be interpreted as a projection of net employment effects.

Comparison with reported employment data

Another limitation of the approach is that it is challenging to calibrate it to available current data on employment, despite the fact that the employment factors have been derived empirically. We compare our job estimates for the base year 2015 for the reference scenario with reported data on employment. IRENA (IRENA 2017) and EurObserv'ER (EurObserv'ER 2017) both report estimates for jobs in renewable energy aggregating direct and indirect employment and not differentiating between job types.

For wind the number of direct and indirect employment reported by EurObserv'ER is 315,900 and reported by IRENA is 329,700. We find 157,660 direct jobs in wind, which is well within the expected range as indirect employment is usually found to be about the same order of magnitude as direct employment.

The employment factors for indirect employment for wind and solar PV suggested by (Ortega et al. 2015b) support this, while indicating that the relation of direct and indirect employment can vary depending on the type of job.

For solar PV, we estimate 80,516 direct jobs as compared to 113,400 direct and indirect jobs reported in EurObserv'ER and 114,450 direct and indirect jobs reported by IRENA. Out results for PV are therefore well within the expected order of magnitude for direct jobs and are well in line with the finding of a study by EY, estimating around 81,000 full-time equivalent jobs in the PV sector in the EU-28 for the year 2016 (EY and Solar Power Europe 2017).

For solar thermal for electricity use (which is mainly Concentrated Solar Power – CSP), IRENA reports about 3,700 jobs in CSP while EurObserv'ER only reports CSP jobs for Spain (which is however the largest European player for CSP) which amounted to around 8,000 in 2016. Our estimate of 4,199 direct job for solar thermal electricity generation is therefore roughly in line with re reported data. Also for geothermal, numbers reported in IRENA (116,8000) and EurObserv'ER (12,200) differ strongly. Our estimate for direct jobs of 1,549 is even substantially lower. One reason for the large differences on reported total job numbers and our low estimate on direct jobs could be that we focus on geothermal and solar thermal used for electricity generation while these technologies are also applied in the heating sector. EurObserv'ER reports 178,200 jobs (direct + indirect) in biofuels (EurObserv'ER 2017), which is well in line with our estimate of 108,133 jobs in biofuels covering direct jobs only.

For hydro, EurObserv'ER reports 94,800 direct and indirect jobs. We estimate slightly higher job numbers 105,872 for direct jobs only, 83,157 of these in small hydro. IRENA reports around 45.700 jobs in small hydro. Our estimates therefore seem to overestimate jobs in hydro, which could be due to differing definitions of small- and large-scale hydro. While we used the observed share of small and large hydro derived from the Platts data base applying thresholds used by the European Commission, the employment factors for small hydro reported by Rutovitz et al. (2015) are substantially higher than for large hydro, so that differing shares due to differing threshold assumptions can have an impact on the job estimates.

Also the overall estimate for total jobs in RE (excluding large scale hydro) is in line with job numbers reported by IRENA (IRENA 2017); For IRENA states about 1,16 Mio direct and indirect jobs in RE in 2015 while we estimate 435,392 direct jobs.

For coal, we compare data in Eurostat (Eurostat 2018a) and estimates reported in JRC (Alves Dias et al. 2018) with our estimates. Eurostat reports 155,963 employees in coal and lignite mining in the EU for 2015. Our estimates of 188,571 jobs in coal fuel supply are above this number, but are very close to the estimates of JRC of 184,800 jobs in coal mining. For Operation and Maintenance of coal power plants, our estimates of 60,416 O&M jobs for coal are also well in line with JRC estimating 52,600 direct jobs in the EU-28.

For the employment numbers for oil & diesel and natural gas it is harder to find appropriate numbers for comparison as these fuels are also substantially used for heating which is not included in our results. This may explain why our estimate for jobs in fuel supply for oil, diesel and natural gas of 8,845 jobs is well below the number of employees in extraction of crude petroleum and natural gas reported by Eurostat (Eurostat 2018a) (reporting 76,917 in 2015). According to the IEA energy balances, only about one fourth of natural gas is used for electricity generation in the EU and for oil and diesel, the share is substantially lower. Assuming that then also less than one fourth of the over 75,500 jobs reported in Eurostat are jobs in electricity generation from natural gas, oil and diesel, the order of magnitude of our job estimate of almost 9,000 direct jobs does not seem out of line.

Table 23: Estimates on direct employment by technology for the different scenarios as well as differences in employment compared to the Reference Scenario

in 1000 jobs (direct jobs)	**Reference Scenario**			**Paris Agreement compatible benchmarks**						**Best-in-Class-Levels**						**EU-Scenarios**					
				upper bound			*lower bound*			*upper bound*			*lower bound*			*upper bound*			*lower bound*		
	2020	**2025**	**2030**	**2020**	**2025**	**2030**	**2020**	**2025**	**2030**	**2020**	**2025**	**2030**	**2020**	**2025**	**2030**	**2020**	**2025**	**2030**	**2020**	**2025**	**2030**
Coal	229.4	195.3	165.9	196.5	135.2	70.4	174.2	89.7	0.9	215.5	174.1	129.9	225.7	195.1	161.9	214.5	172.0	126.7	215.5	174.2	132.8
Natural gas	38.9	40.3	39.3	32.9	34.5	34.8	29.7	27.6	25.7	30.9	30.0	36.8	35.4	39.7	54.1	30.6	29.5	32.4	50.2	64.6	64.2
Oil and diesel	4.5	3.0	2.2	6.3	3.4	0.8	6.6	3.9	1.5	7.4	5.4	3.9	7.7	6.0	4.9	7.3	5.3	3.8	6.1	3.0	0.0
Nuclear	70.2	63.0	56.9	57.4	34.8	12.3	86.3	81.0	79.6	64.0	51.0	36.3	66.0	55.9	43.6	63.8	50.5	35.6	66.2	69.2	72.7
Hydro large	28.3	26.3	25.1	94.9	96.7	73.4	55.7	52.4	45.3	23.5	23.0	24.0	22.1	20.2	17.6	23.3	22.7	21.5	42.1	37.1	33.2
Hydro small	88.2	90.1	91.1	132.9	155.1	167.0	108.1	116.9	122.7	86.0	84.3	81.2	81.0	73.8	64.3	85.4	83.1	78.6	99.5	103.6	106.4
Geothermal	0.7	0.5	0.5	6.8	6.5	6.5	1.9	1.8	1.9	0.3	0.2	0.1	0.3	0.2	0.1	0.3	0.2	0.1	0.2	0.1	0.0
Biofuel	167.6	135.8	142.1	113.1	87.1	79.7	236.4	257.7	299.9	121.7	97.7	99.8	111.0	84.6	75.9	120.4	95.7	93.4	246.7	272.0	327.7
Wind onshore	103.5	58.2	56.3	196.0	181.9	176.7	152.6	140.6	121.7	205.0	190.5	183.5	164.7	152.1	157.6	212.6	197.7	207.2	55.7	48.4	61.1
Wind offshore	43.5	51.1	30.6	76.3	111.9	100.4	62.7	89.9	68.2	79.1	116.4	103.9	66.5	96.0	91.7	81.4	120.2	119.5	32.6	41.0	40.2
PV	67.6	50.5	22.0	208.2	194.3	112.0	55.8	52.8	25.1	131.1	122.7	68.1	105.2	98.6	53.3	136.0	127.2	70.8	32.0	30.6	133.5
Solar thermal	7.0	17.3	21.8	18.3	47.4	70.6	6.6	17.2	23.7	12.4	32.1	46.1	10.4	27.0	39.2	12.7	33.1	49.4	4.8	12.5	43.4
Ocean/Marine	0.0	0.0	0.0	22.5	18.2	27.2	6.9	5.6	16.8	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.0	0.0
Waste	3.1	3.3	3.2	2.2	1.1	0.0	2.2	1.1	0.0	2.7	2.0	1.4	2.6	1.8	1.1	2.7	2.0	1.4	2.2	1.1	0.0
Total jobs in electricity generation	**852.7**	**734.8**	**657.0**	**1,164.3**	**1,108.2**	**931.8**	**985.8**	**938.1**	**833.1**	**979.5**	**929.6**	**815.0**	**898.6**	**851.1**	**765.2**	**991.1**	**939.3**	**840.4**	**853.9**	**857.5**	**1,015.2**
Jobs in RE (excluding large hydro)	***478.2***	***403.5***	***364.5***	***774.1***	***802.3***	***740.1***	***631.1***	***682.5***	***680.0***	***635.7***	***644.0***	***582.7***	***539.0***	***532.4***	***482.0***	***648.9***	***657.2***	***619.1***	***471.6***	***508.3***	***712.3***
RE-jobs as share of total electricity sector jobs	***56%***	***55%***	***55%***	***66%***	***72%***	***79%***	***64%***	***73%***	***82%***	***65%***	***69%***	***71%***	***60%***	***63%***	***63%***	***65%***	***70%***	***74%***	***55%***	***59%***	***70%***
Jobs in fossil-based electricity	***272.9***	***238.6***	***207.3***	***235.7***	***173.2***	***106.0***	***210.5***	***121.1***	***28.1***	***253.7***	***209.5***	***170.6***	***268.8***	***240.8***	***220.9***	***252.4***	***206.9***	***162.8***	***271.8***	***241.8***	***196.9***
Fossil-based' jobs as share of total electricity sector jobs	***32%***	***32%***	***32%***	***20%***	***16%***	***11%***	***21%***	***13%***	***3%***	***26%***	***23%***	***21%***	***30%***	***28%***	***29%***	***25%***	***22%***	***19%***	***32%***	***28%***	***19%***
Difference to jobs in Reference Scenario																					
Jobs in RE (excluding large hydro)				295.9	398.9	375.7	152.9	279.0	315.5	157.5	240.5	218.3	60.9	128.9	117.6	170.7	253.7	254.6	-6.6	104.8	347.9
Jobs in fossil-based electricity				-37.2	-65.5	-101.4	-62.4	-117.5	-179.2	-19.2	-29.2	-36.7	-4.1	2.1	13.5	-20.5	-31.8	-44.5	-1.1	3.1	-10.4
Difference in total jobs				**311.6**	**373.4**	**274.8**	**133.1**	**203.4**	**176.1**	**126.9**	**194.8**	**158.0**	**45.9**	**116.3**	**108.2**	**138.4**	**204.6**	**183.3**	**1.2**	**122.7**	**358.2**

Table 24: Sensitivity analysis - Estimates on direct employment by technology for the different scenarios as well as differences in employment compared to the Reference Scenario with different assumptions on share of local manufacturing and biofuel supply

Sensitivity analysis *in 1000 jobs (direct jobs)*	**Reference Scenario**			**Paris Agreement compatible benchmarks**						**Best-in-Class-Levels**						**EU-Scenarios**					
				upper bound			*lower bound*			*upper bound*			*lower bound*			*upper bound*			*lower bound*		
	2020	**2025**	**2030**	**2020**	**2025**	**2030**	**2020**	**2025**	**2030**	**2020**	**2025**	**2030**	**2020**	**2025**	**2030**	**2020**	**2025**	**2030**	**2020**	**2025**	**2030**
Coal	229.4	195.3	165.9	196.5	135.2	70.4	174.2	89.7	0.9	215.5	174.1	129.9	225.7	195.1	161.9	214.5	172.0	126.7	215.5	174.2	132.8
Natural gas	38.9	40.3	39.3	32.9	34.5	34.8	29.7	27.6	25.7	30.9	30.0	36.8	35.4	39.7	54.1	30.6	29.5	32.4	50.2	64.6	64.2
Oil and diesel	4.5	3.0	2.2	6.3	3.4	0.8	6.6	3.9	1.5	7.4	5.4	3.9	7.7	6.0	4.9	7.3	5.3	3.8	6.1	3.0	0.0
Nuclear	70.2	63.0	56.9	57.4	34.8	12.3	86.3	81.0	79.6	64.0	51.0	36.3	66.0	55.9	43.6	63.8	50.5	35.6	66.2	69.2	72.7
Hydro large	28.0	26.1	25.1	90.7	92.8	71.4	53.8	51.0	44.5	23.5	23.0	23.8	22.1	20.2	17.6	23.3	22.7	21.5	41.0	36.5	33.0
Hydro small	88.1	90.1	91.1	130.9	153.3	166.1	107.2	116.2	122.3	86.0	84.3	81.2	81.0	73.8	64.3	85.4	83.1	78.6	99.0	103.3	106.3
Geothermal	0.7	0.5	0.5	6.4	6.2	6.2	1.8	1.7	1.9	0.3	0.2	0.1	0.3	0.2	0.1	0.3	0.2	0.1	0.2	0.1	0.0
Biofuel	154.7	122.1	126.8	102.6	78.0	71.5	217.7	234.7	272.2	110.5	87.4	89.9	100.6	75.7	68.1	109.3	85.7	83.9	227.3	247.8	298.1
Wind onshore	97.7	57.8	56.2	180.7	170.6	167.7	141.6	132.6	117.2	188.8	178.5	174.2	152.4	143.2	149.4	195.6	185.1	195.4	54.2	47.9	59.1
Wind offshore	38.6	45.6	27.8	67.5	99.4	90.0	55.6	80.0	61.3	70.0	103.4	93.1	58.9	85.4	82.1	72.1	106.8	106.9	29.0	36.6	36.0
PV	67.6	50.5	22.0	208.2	194.3	112.0	55.8	52.8	25.1	131.1	122.7	68.1	105.2	98.6	53.3	136.0	127.2	70.8	32.0	30.6	133.5
Solar thermal	6.8	16.6	21.2	17.6	45.6	68.5	6.4	16.6	23.0	11.9	30.9	44.7	10.0	26.0	38.0	12.3	31.9	47.9	4.6	12.1	41.7
Ocean/Marine	0.0	0.0	0.0	20.5	16.8	25.1	6.3	5.2	15.3	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.0	0.0
Waste	3.1	3.3	3.2	2.2	1.1	0.0	2.2	1.1	0.0	2.7	2.0	1.4	2.6	1.8	1.1	2.7	2.0	1.4	2.2	1.1	0.0
Total jobs in electricity generation	**828.4**	**714.3**	**638.1**	**1,120.6**	**1,066.1**	**896.7**	**945.3**	**893.9**	**790.5**	**942.7**	**893.2**	**783.4**	**868.0**	**821.6**	**738.4**	**953.3**	**902.1**	**804.9**	**827.7**	**826.9**	**977.3**
Jobs in RE (excluding large hydro)	***454.2***	***383.2***	***345.6***	***734.6***	***764.2***	***707.0***	***592.4***	***639.7***	***638.3***	***598.8***	***607.6***	***551.2***	***508.5***	***502.9***	***455.3***	***611.1***	***620.0***	***583.6***	***446.4***	***478.4***	***674.7***
RE-jobs as share of total electricity sector jobs	***55%***	***54%***	***54%***	***66%***	***72%***	***79%***	***63%***	***72%***	***81%***	***64%***	***68%***	***70%***	***59%***	***61%***	***62%***	***64%***	***69%***	***73%***	***54%***	***58%***	***69%***
Jobs in fossil-based electricity	***272.9***	***238.6***	***207.3***	***235.7***	***173.2***	***106.0***	***210.5***	***121.1***	***28.1***	***253.7***	***209.5***	***170.6***	***268.8***	***240.8***	***220.9***	***252.4***	***206.9***	***162.8***	***271.8***	***241.8***	***196.9***
Fossil-based' jobs as share of total electricity sector jobs	***33%***	***33%***	***32%***	***21%***	***16%***	***12%***	***22%***	***14%***	***4%***	***27%***	***23%***	***22%***	***31%***	***29%***	***30%***	***26%***	***23%***	***20%***	***33%***	***29%***	***20%***
Difference to jobs in Reference Scenario																					
Jobs in RE (excluding large hydro)				280.4	381.0	361.5	138.2	256.5	292.7	144.6	224.4	205.7	54.3	119.8	109.7	156.9	236.8	238.0	-7.8	95.2	329.2
Jobs in fossil-based electricity				-37.2	-65.5	-101.4	-62.4	-117.5	-179.2	-19.2	-29.2	-36.7	-4.1	2.1	13.5	-20.5	-31.8	-44.5	-1.1	3.1	-10.4
Difference in total jobs				**292.2**	**351.8**	**258.6**	**116.9**	**179.5**	**152.4**	**114.3**	**178.8**	**145.3**	**39.6**	**107.3**	**100.3**	**124.9**	**187.7**	**166.8**	**-0.7**	**112.6**	**339.2**

Note: For this sensitivity analysis, we assume that the share of local manufacturing is reduced to 80% for hydro (large and small), geothermal, biofuel, wind (onshore and offshore), solar thermal and marine technologies. For solar PV, the assumed share remains 25% local manufacturing. For energy from coal, natural gas, oil, nuclear and waste, the share of local manufacturing remains 100% in this analysis. Moreover, we assume that the share of biofuel that is locally supplied is reduced to 80%.

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