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1 INTRODUCTION AND CONTEXT

The years 2013-2017 were the warmest five-year period on record and 2018 is set to continue this pattern[1]. Climate change is increasing global average temperatures. The recent IPCC report concluded that human-induced global warming reached approximately 1°C above pre-industrial levels in 2017 and is currently increasing at around 0.2°C per decade[2].

We are experiencing the warmest period in the history of modern civilisation, and continued climate change and the related weather extremes across the globe will threaten the livelihood of all of us. If not managed well, these impacts will significantly compromise development, growth, biodiversity and can impact migration flows and spur a downward spiral of fragility and conflict. Climate change is a threat multiplier that can undermine – both inside and outside the EU – security and prosperity, including economic, food, water and energy systems (see also section 6.6 regarding the impact of climate change and the need to adapt to it).

At the same time, acting on climate change presents an unprecedented opportunity to prepare the European Union for a safe, prosperous and competitive 21st century. The transformation away from an emissions-based economy is a vital part of true sustainable development, and can be combined with a host of benefits such as improved human health and air quality, greater energy security and more efficient resource use. It also an important part of our long term competitiveness. As innovation accelerates, and costs of low-carbon energy technologies continue to fall, it is vital to ensure that the EU remains a leader and leaves no-one behind.

Recognising that climate change represents an urgent threat to human societies and the planet, the Paris Agreement sets all countries the goal of keeping global warming well below 2°C, and pursuing efforts to limit the increase to 1.5°C. To achieve this goal, the Agreement also sets out the aim of peaking global greenhouse gas emissions as soon as possible, and achieving a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century.

The Paris Agreement also invites all Parties to communicate, by 2020, to the UNFCCC, mid-century, long-term low greenhouse gas emission development strategies. On the basis of the best available scientific knowledge, these strategies should allow our societies to plan and prepare for the long term, and inform policy making in the short term.

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[1] WMO Statement on the State of the Climate in 2017, World Meteorological Organisation (2018) and Global Climate Report - June 2018, National Oceanic and Atmospheric Administration (2018)
[2] IPCC Special Report on Global Warming of 1.5°C

The EU has been taking the lead in environmental and climate policy almost since its inception. And by the design of the Treaty, the EU has also been developing the EU's internal market, including in the energy sector. Over the years these two pursuits, in the international, domestic European and national contexts, have converged. This is why decarbonisation has become the first pillar of the Energy Union, and why security of supply, renewable energy and energy efficiency measures have become core measures contributing to climate change mitigation. This long term strategy explains not only how energy and climate policy measures have developed and are developing in synchronisation; it also highlights the industrial policy consequences and implications for jobs and economic growth that come with the technological and other innovations necessary to deliver on energy and climate goals. Together with the creation of the circular economy, the transformation of the energy sector is harnessing a range of technologies and new practices which are changing the way our energy markets and indeed the way our economy work, creating dynamic new sectors and opportunities for jobs and growth and a more prosperous Union.

1.1 EU action to reduce greenhouse gas emissions and transform its energy system– stock-taking exercise

Domestic action to reduce EU28 emissions is an absolute necessity. Not only is it our obligation to reduce emissions as our own contribution to the global fight against climate change, it also showcases to other countries plausible economic and technological pathways to decarbonise while maintaining a growing, competitive economy.

In early 2007, the EU agreed on a headline targets for 2020 to reduce GHG emissions by 20% by 2020. These targets were reaffirmed as the EU pledges under the Copenhagen Accord and Cancun decisions. The EU is on track to meet this target. In 2016, EU greenhouse gas emissions were already 23 % below the 1990 level, excluding land use, land use change and forestry (LULUCF) and including international aviation[3].

For 2030 the EU agreed upon an ambitious climate and energy framework, including …

[DG ENER to substantiate text on target achievement up to date]

1.2 Policy initiatives on the EU level

Ever since the initial environmental and climate policies and measures of the 1990s, the relationship between climate policy and the energy sector has been clear. And as this

[3] COM(2017) 646 final [xxx update if new progress report comes out]

has evolved, the relationship between energy and technology innovation and technology innovation and industrial development has also grown and been associated with several EU “energy and climate” policy initiatives or strategies.

1.2.1.1 The building blocks of the pathway to Paris

The first explicit energy and climate policy package that addressed emissions reductions at the same time as energy sector reform was the 20-20-20 targets launched in 2007, with EU ETS improvements, the renewable energy and energy efficiency directives as well as the 3rd package of energy market liberalisation. The implementation of the legislation that emerged proved the turning point in creating recognisable change in the energy sector, generating emissions reductions, renewable energy growth, energy efficiency improvements and better function and integrated energy markets.

Building on this approach and structure, in 2011 the Commission came forward with three strategic roadmaps based on a consistent analytical framework: the *Roadmap for moving to a competitive low carbon economy in 2050*, the *Energy Roadmap 2050*, and the *Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system* (commonly referred to as the *Transport White Paper*)[4]. These Roadmaps presented fundamental aspects of the transition to a low carbon economy in 2050, cost-efficient GHG emission reduction milestones for 2030, and "no-regret options" – i.e.: more energy efficiency, higher shares of renewable energy and energy infrastructure development - for the transition towards a competitive, sustainable and secure energy system. The roadmaps cover all sectors of the economy, with a clear emphasis on energy (a sector which is responsible for 2/3 of emissions) and transport (a sector which accounts for a significant share of both GHG emissions and energy consumption). They jointly serve to demonstrate the consistency of the EU's agreed objective to reduce GHG emissions[5] by 80-95% in 2050 compared to 1990, in the context of necessary reductions by developed countries as a group to limit global warming to below 2°C as stated by the European Council in 2009[6].

Roadmap for moving to a competitive low carbon economy in 2050 showed that the 80% domestic reduction for the overall economy would be reached via different emission cuts in the various sectors. Transport would need to contribute with a 60% reduction, as a reflection of the fact that substituting oil is more costly in transport than in other sectors. The Roadmap concluded that 80% GHG reductions by 2050 goes through transformation the energy system and leads to modernising European economy and that it is feasible with existing technologies and affordable. The Roadmap presented a 40% GHG reduction milestone in 2030 the same level that was later adopted in the legislation for the 2030 climate and energy framework.

The Energy Roadmap 2050 set out four main routes to a more sustainable, competitive and secure energy system in 2050: energy efficiency, renewable energy, nuclear energy

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4 COM(2011)112, COM(2011)885, COM(2011)144

5 Covering all domestic emissions (including agriculture) but not emissions from LULUCF.

6 Ref.

and carbon capture and storage. It analysed seven possible scenarios for 2050 out of which five achieved decarbonisation objective. All decarbonisation scenarios imply some 85% decline of energy-related CO2 emissions including from transport.

The White Paper on Transport defined a 2050 vision for the transport sector that continues to serve the needs of the economy and of the citizens while meeting future constraints: oil scarcity, growing congestion and the need to cut CO2 (by 60% by 2050 relative to 1990) and pollutant emissions and improve air quality particularly in cities. To this aim, the White Paper put forward four broad areas of intervention: internal market, innovation, infrastructure, international aspects. For each of these areas, a ten-year programme (by 2020) was defined with 40 specific action points, containing a handful of specific initiatives. The strategy set in the White Paper is to a substantial degree based on low emission fuels, energy efficiency, better multimodality of transport and new technologies that should lead to optimised journeys[7].

The Roadmaps have been instrumental in setting the EU on track to comply with UNFCCC obligations at that time (Kyoto Protocol), setting 2030 targets and exploring the long-term perspective.

Drawing on the analysis presented in the roadmaps and following discussions and guidance from the European Council, in 2014 the Commission made proposals for a **2030 strategy**, proposing a decarbonisation regime, including 2030 targets. On this basis, the European Council agreed to the creation of the 2030 strategy with 2030 targets for reducing greenhouse gas emissions by 40%, increasing the share of renewable energy to at least 27%, and achieving energy efficiency of 27% or 30%. The Commission also published its **Energy Security Strategy** in 2014. The detailed inter-relationships and synergies available in policies and measures addressing decarbonisation *and* energy policy objectives were such that it became clearer that the nexus between energy and climate policies could be drawn even closer together. At the same time, the Commission published its **vision of the future of a circular economy**, bringing together the themes of environmental policy (waste, pollution) with industrial production policy (e.g. recycling and new materials) and with research and innovation policy.

To put this 2030 decarbonisation strategy more firmly in the energy policy, energy security, economic policy *and* innovation context, the Commission established **the Energy Union in 2015**.

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[7] According to the Commission's evaluation standards the 2011 White Paper is due for review. To date, the Commission has issued proposals in most of the 40 action points of the programme and more than 60% of the initiatives planned could be considered as broadly covered. At the same time, the White Paper mid-term implementation report of 2016[7] noted that there was still little progress achieved towards some of the goals set in 2011, in particular, decreasing the oil dependency ratio and limiting growth of congestion.

1.2.1.2 Energy Union under construction (5 dimensions; energy-efficiency first). (ENER: A1, B1, B2, B3, B4, C1, C2, C3, D3 on respective acquis)

While the dominant time horizon of the Energy Union 2030 and its **main goal to establishing the robust framework for 2030**, this **framework is a sine qua non for *the forward-looking climate change policy*** and the latter necessarily with the mid-century horizon.

In the context of the Energy Union, the European has put in place a robust legislative framework to secure the attainment of its 2030 targets (see chapter below). Besides addressing climate change and clean energy framework, transition, in the same legislative framework, the EU addressed the European Union's internal energy market comprising the infrastructure aspects, energy security, research, innovation and competitiveness (all these aspect constitute so-called "five pillars" of the Energy Union. The transport sector is an integral part and contributes towards three of the five dimensions of the Energy Union: energy efficiency, decarbonisation of the economy and research, innovation and competitiveness[8].

The Commission has already tabled most of the legislative proposals necessary to establish the regulatory framework, and enabling actions are being put in place to accelerate public and private investment and support a socially fair clean energy transition. Further efforts will be required to ensure the completion of the Energy Union by the end of the current Commission's mandate in 2019: not only further progress in adopting the remaining items of the legislative framework but also implementing the enabling framework and securing the involvement of all parts of society. It should be noted that **among those enabling actions, many will have much longer time horizon than 2050**: facilitating access to finance or assistance for carbon-intensive regions as the two key ones.

<u>I. Decarbonisation policy</u>

DG CLIMA input

Energy mix trends under the Energy Union

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As part of the Energy Union Strategy implementation and in accordance with Article 40 of the Euratom Treaty, the Commission presented in 2017 the latest nuclear illustrative programme (PINC)[9]. It is the first presented by the Commission after the Fukushima

[8] COM(2015) 80 final

[9] COM(2017) 237 final.

Daiichi accident in March 2011. The programme provides a full overview of developments and investments needed in the nuclear field in the EU for all the steps of the nuclear lifecycle. It underlines the significant role of nuclear energy in the energy mix in Europe with a 2050 horizon[10], as well as identifies some priority areas, such as ways to continuously increase safety, improve cost-efficiency of nuclear power plants (also by efforts to standardise their supply chain) and enhance the cooperation among Member States in licensing new and existing nuclear power plants.

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Renewable energy

The Renewable Energy Directive[11] has been and will continue being a central element of the Energy Union policy and a key driver for providing clean energy for all Europeans, in view of making the EU a global leader in renewables. The goal is to make the European Union the global leader in renewables providing.

II. Energy efficiency

The Energy Union Strategy treats energy efficiency as an energy resource in its own right thus putting in practice the *"Energy efficiency first"* principle. The key elements of the legislative framework that was put in place to deliver this objective were: the revised Energy Efficiency Directive[12], the revised Energy Performance of Buildings Directive[13], the new Ecodesign legislation adopted or under co-decision. The major pieces of legislation (revised Emission Trading Scheme, Effort Sharingand the revised Energy Labelling Regulation[14].

III. The internal market

The free movement of goods and services is a fundamental element of the EU and its governing Treaty; the creation of internal markets for goods and services lowers

[10] In the PINC, the Commission predicts a decline in nuclear generation capacity at EU level up to 2025, taking into account the decisions of some Member States to phase out nuclear energy or to reduce its share in their energy mix. This trend would be reversed by 2030 as new reactors are predicted to be connected to the grid and the lifetime of others will be extended. Nuclear capacity would increase slightly and remain stable at between 95 and 105 GWe by 2050. Since electricity demand is expected to increase over the same period, the share of nuclear electricity in the EU would fall from its current level of 27% to around 20%. Taking the lower range of the projected capacity presented above (95 GW), between EUR 349 and EUR 456 billion would have to be invested in new nuclear generation capacity by 2050.

[11] Directive 2009/28/EC on the promotion of the use of energy from renewable sources, OJ L 140, 5.6.2009

[12] Directive 27/EU/2012

[13] Directive 30/EU/2010

[14] Regulation (EU) 2017/1369

transaction and administrative costs across the Union, it brings regulatory and commercial efficiencies and cost savings, and it provides competition for EU companies on a level European playing field. Thus the efficiency drivers of EU internal energy market policy – the improvement of infrastructure links and interconnectors, the cooperation in developing consistent and coherent national regulatory regimes and transmission systems - a fully integrated internal energy market will enable the free flow of energy through the EU through adequate infrastructure and without technical or regulatory barriers, to lower costs, improve efficiencies and to facilitate the decarbonisation of the energy sector.

Infrastructure and regional cooperation

The Energy Union supports infrastructure development to enable a smooth energy transition.

Since 2013, the European Union has a dedicated infrastructure policy in place with the TEN-E Regulation[15] that's meant to ensure that the necessary infrastructure with cross-border impact is built in time. A major innovation brought by the Energy Union is the regional cooperation now enshrined into law. The regional cooperation has given hands and feet to the security, solidarity and trust dimension with the aim to expand the benefits of the internal market to all corners of the European Union. The TEN-E Regional and Thematic Groups decide on the priorities for the projects of European relevance; they receive the Project of Common Interest (PCI) label[16].

While the first PCI lists mainly focussed on the security, solidarity, trust and internal market pillars under the Energy Union. The current third PCI list focuses largely on the decarbonisation objective. It contains more electricity projects that contribute to the 10% interconnection target for 2020; it promotes smart grids interfaces across borders between TSOs and contains the first CO2 transport infrastructure projects.

IV. The security of supply

The Security of Supply package included two legislative proposals now adopted: (1) the Regulation on Security of Gas Supply[17] that aims at preventing gas supply crises and ensuring a regionally coordinated and common approach to security of supply measures

15 reference

16 The PCI label confers advantages on these projects, such as earlier involvement of the public, streamlined permitting, better cooperation between regulatory authorities involved in the project and, if necessary, some European financial aid towards construction of the project (Connection Europe Facility). All PCI labelled projects can receive seed money for studies into feasibility and financial engineering.

17 Regulation (EU) 2017/1938 of the European Parliament and of the Council of 25 October 2017 concerning measures to safeguard the security of gas supply and repealing Regulation (EU) No 994/2010, OJ L 280, 28.10.2017, p. 1.

among the Member States and (2) the Strategy for Liquefied Natural Gas (LNG) and gas storage [18] that outlined future EU action that will contribute to a greater flexibility of gas supply, in particular through LNG and gas storage.

In parallel, the IGA Decision[19], adopted in April 2017 significantly increased the transparency of intergovernmental agreements between Member States and third countries in the field of energy that have become subject to a mandatory ex-ante assessment by the Commission regarding their compatibility with EU law.

Additional measures were put forward under the Clean Energy for All European package (see below).

V. Research & Innovation

In the vision of the energy Union it is clear that enhanced performance in terms of research and innovation is necessary to reach the 2030 targets and 2050 decarbonisation goals. Result-oriented R&I will be essential to shape an energy system that is integrated, smart, flexible, secure and decarbonised and which ensures participation of consumers, digitalisation and decentralisation of energy. The focus must be on the efficient and fast delivery of new low carbon technologies and improving the performance existing ones.

The Strategic Energy Technologies (SET) Plan is a crucial component of this work linking EU, Member State and industry action. Following the new strategy as published in 2015[20] public and private parties, at EU and national level, have joined forces to identify targets for R&I in energy technologies in the next 5 to 15 years[21]. These have been turned into 14 implementation Plans that identify concrete action where Member States, industry and the European Commission cooperate to increase the impact of R&I investments. The SET Plan structure and the experience so far will be instrumental in finding synergies and defining concrete cooperation initiatives for the 2050 horizon.

[18] Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions on an EU strategy for liquefied natural gas and gas storage, COM(2016) 49 final.

[19] Decision (EU) 2017/684 of the European Parliament and of the Council of 5 April 2017 on establishing an information exchange mechanism with regard to intergovernmental agreements and non-binding instruments between Member States and third countries in the field of energy, and repealing Decision No 994/2012/EU, OJ L 99, 12.4.2017, p. 1.

[20] https://ec.europa.eu/energy/sites/ener/files/documents/1_EN_ACT_part1_v8_0.pdf

[21] For example, in relation to the cost reduction or energy density of future batteries – for the full list of targets see: https://publications.europa.eu/en/publication-detail/-/publication/9546f4e9-d3dc-11e6-ad7c-01aa75ed71a1

The coordination of regional cooperation via the smart specialisation platforms helps Member States and regions to focus their efforts and use regional funds to strengthen the innovation capacities in regions.

An important aspect of the Energy Union is the recognition that citizens must be at the core of the Energy Union, the Commission is committed to delivering a new deal for energy consumers helping them to save money and energy through better information; giving consumers a wider choice of action as regards their participation in energy markets; and, maintaining the highest level of consumer protection.

Building on this all-encompassing coherence provided by the Energy Union, and following the request of the European Council, the Commission came forward with the legislative proposals necessary to deliver. The Clean Energy For All Europeans package, currently being reviewed, adapted and adopted by EU Ministers and Parliament, contains the legislation to deliver on the 2030 objectives and to further implement Energy Union objectives.

1.2.1.3 Clean Energy for All Europeans. More competitive, secure and sustainable energy system (ENER: A1).

The 40% GHG emissions reduction target is now enshrined in law by the revised ETS Directive and the Effort Sharing Regulation.

The other two interlinked targets were presented in a the Clean Energy Package for All Europeans (CE4AE) on 30 November 2016, composed of eight legislative proposals and the European strategy on Cooperative Intelligent Transport Systems in the field of mobility[22]. It was a major **milestone in the construction of the Energy Union and setting the EU on the ambitious decarbonisation trajectory**. Paris Agreement that by the time of the adoption of CE4AE was already ratified (TBC) was clearly the strong driver for the high level of ambition.

The European Parliament and the Council **have by now reached an agreement on [four] out of the eight legislative proposals** from the 2016 Clean Energy for All Europeans package (the Energy Performance in Buildings Directive, Renewable Energy Directive, Energy Efficiency Directive, and Regulation on the Governance of the Energy Union and Climate Action). These [four] pieces of legislation complement the revision of the Emissions Trading System, the Effort Sharing Regulation and the Land Use Change and Forestry Regulation that were adopted earlier this year. Thus, progress and momentum towards completing the Energy Union and combatting climate change are well under way.

[22] COM(2016)766 final

This newly agreed May 2019. An EU targets represent high level of ambition, demonstrates the remarkable pace of change of new technologies and reduced costs through economies of scale and **strong push from co-legislators to put the EU on best trajectory towards long-term decarbonisation**. Clearly, Paris Agreement goals were one of the main reasons for the agreement on such ambitious targets.

The European Union-wide target of at least **32%** and energy efficiency target of **renewable energies** in final energy consumption for 2030 is supported by ambitious measures addressing untapped potential for renewables in heating, cooling and transport. Moreover, measures are put in place to facilitate the participation of citizens in the energy transition through self-consumption and energy communities and to enhance the sustainability of bioenergy. An ambitious review of electricity market rules underpin the European Union’s ambition to further boost penetration of renewables in power, for example by introducing the flexibility required to respond to increasing shares of renewables (see chapter below).

As for energy efficiency, the political agreement was to have at least **32.5% for energy efficiency** to be achieved collectively by the EU in 2030. The co-legislators also agreed for 2030.on an annual energy savings obligation of 0.8% of final energy consumption to be achieved in the next decade 2021-2030. Other important changes were made to strengthen the rules for metering and billing of thermal energy - especially in multi-apartment buildings with collective heating systems. The primary energy factor for electricity generation was updated to 2.1. The revised and improved EPBD includes measures to strengthen the energy performance of new buildings, to accelerate the rate of building renovation towards more energy efficient systems and tapping into the huge potential for efficiency gains in the building sector, the largest single energy consumer in Europe. It also encourages the use of information and communication technology (ICT) and smart technologies to ensure buildings operate efficiently and supports the roll-out of the infrastructure for e-mobility.

As a result of the Governance Regulation, Member States are expected to establish and to submit by December 2018 the draft of the first integrated national energy and climate plans (NECPs) defining their contribution to the EU targets and putting them in a good position to reduce the greenhouse gas emissions by more than 40% by 2030 and setting them on decarbonisation trajectory.

The rest of the **Clean Energy Package** is foreseen to be delivered under the Austrian Presidency, whose main political objective is to conclude negotiations on the four Electricity Market Design proposals: the **Electricity Directive** and **Regulation**, the **ACER** regulation and the **Risk Preparedness**.

The Clean Energy Package has **very strong consumer focus** that is also bound to be the **leitmotiv of the 2050 decarbonisation strategy**. The Package entitles consumers as active and central players on the energy markets of the future. It is designed to facilitate all consumers across the EU to have a better choice of supply, access to reliable energy price comparison tools and the possibility to produce and sell their own electricity. The package also proposes further transparency rules and EU-wide regulation principles to facilitate more opportunities for civil society to become more involved in the energy system and respond to price signals. Last, but not least, the package also contains a number of measures aimed at protecting the most vulnerable consumers.

Interestingly, although it was not originally foreseen in the Commission's original proposal, the legislators agreed to include in the legislation (the revised EED) a definition of "energy efficiency first" principle which should now apply across the five dimensions of the Energy Union. Putting such definition in the legislation gives a right recognition of the importance of energy efficiency as a possible solution in energy planning, policy and investment decisions.

Regarding SoS, the Commission proposed the Electricity Risk Preparedness Regulation[23]. That addresses the existing shortcomings in the area such as different, often not transparent national rules and procedures and lack of cross-border co-operation. The Risk Preparedness Regulation will entail rules on (1) how to assess risks, (2) what a risk preparedness plan should look like, (3) how to deal with crisis situation and (4) how to monitor security of supply – what indicators to use, what information to provide to whom. The Risk Preparedness Plans should also include agreements on regional cooperation, especially arrangements how to manage situation of simultaneous electricity crisis.

Regarding internal market, further regulatory improvements are needed to ensure Europe creates the right market design to undertake the multiple tasks ahead: greater coordination and coherence is needed if national markets are to be integrated, if views and requirements for generation adequacy and security of supply converge, markets can function more efficiency and treat market participants more fairly. And such coherence and coordination is also needed to facilitate decarbonisation and energy efficiency objectives.

In addition to the legislation now adopted and the legislation being finalized, there is also the need to upgraded the EU regulatory regime for the European gas market. For this reason a **Gas Package** is under preparation to ensure a similar degree of coherence

[23] Proposal for a Regulation of the European Parliament and of the Council on risk-preparedness in the electricity sector and repealing Directive 2005/89/EC, COM/2016/0862 final - 2016/0377 (COD).

and cooperation in the gas market as will be created by the new legislation on Europe's electricity markets.

A further major and large sector, critical for energy consumption, emissions and indeed for the functioning of the whole economy, is **the transport sector.** Here too, the EU has been preparing major advances to improve the functioning of the transport sector and to instil it centrally in Europe's decarbonisation and energy sector strategies. The ***European Strategy for Low-Emission Mobility***[24] was adopted in July 2016. The Strategy aims at ensuring that Europe stays competitive and is able to respond to the increasing mobility needs of people and goods, while meeting the challenge of shifting towards low-emission mobility. The Strategy reconfirms and somewhat strengthens the 2011 White Paper goals: by mid-century, greenhouse gas emissions from transport need to be at least 60% lower than in 1990 and be firmly on the path towards zero. Emissions of air pollutants from transport that harm our health need to be drastically reduced without delay.

To this end, the Strategy proposed a comprehensive Action Plan building on three pillars: (1) higher efficiency of the transport system, (2) low-emission alternative energy for transport, and (3) low- and zero emission vehicles, including both legislative and non-legislative action.

The European strategy on Cooperative Intelligent Transport Systems in November 2016[25] has been put forward as part of the "Clean Energy for All Europeans" package (see above).

The Commission has acted swiftly by adopting proposals on most of the actions listed in the Action Plan of the Strategy, notably through the adoption of the "Clean Energy for all Europeans" package in November 2016, the first Mobility Package in May 2017, the second Mobility Package in November 2017 and the third Mobility package in May 2018.

The ***second Mobility Package*** included legislative initiatives on road transport vehicles, infrastructure and combined transport of goods[26]. The initiatives focus on the reduction of greenhouse gas emissions and air pollutant emissions and aim for a broad take up of low-emission alternative fuels and low-emission vehicles on the market.

With the ***third Mobility Package***, the Commission aimed to ensure a smooth transition towards a mobility system which is safe, clean and connected & automated[27]. Through these measures, the Commission is also shaping an environment allowing EU companies to manufacture the best, cleanest and most competitive products.

[24] COM(2016)501 final
[25] COM(2016)766 final
[26] https://ec.europa.eu/transport/modes/road/news/2017-11-08-driving-clean-mobility_en
[27] https://ec.europa.eu/transport/modes/road/news/2018-05-17-europe-on-the-move-3_en

1.2.1.4 CAP (contributions AGRI), Waste policy (contributions ENV), F-gas regulations. In

In 2014, a new F-gas Regulation was adopted to phase-down the total amount of HFCs that can be sold in the EU from 2015 to one fifth of today's sales by 2030. The regulation is expected to reduce the EU's F-gas emissions by two thirds compared to today's levels. A proposal for a new CAP was made that also offers incentives to reduce GHG emissions from agriculture and enhance soil carbon. (Simon K)

1.2.1.5 MFF and climate mainstreaming (ENER: A4 financial instruments).

The overview of the initiatives of European policy making reflects that for over a decade, supra-national sectorial policy has been defined with moving sustainability and climate change into focus. The range of sectors has evolved throughout this process and the emphasis on de-carbonisation has become stronger with more sophisticated measures to design and achieve targets. Giving clear policy signals, these targets and policy measures have been crucial to guide investors, allowing world clean energy investments to peak (USD 360.3 billion in 2015[28]), new technologies to emerge and technology costs to start decreasing in the energy sector. Although the bulk of the necessary capital will have to be mobilized by the private sector, the remaining market failures and barriers provide the rationale for public intervention at a European level and call for European public finance.

The long-term budget of the European Union has an important role to play for decarbonisation by supporting investments in and mobilizing capital towards climate mitigation and adaptation – importantly to research and innovation, energy efficiency, renewable energy and network infrastructure. With respect to its 2014-2020 multiannual financial framework, the EU has decided to commit 20% (EUR 206 billion) of the overall budget to climate change. The climate mainstreaming target has been a useful measure to attract capital: average annual investment in the EU energy sector can be estimated around EUR 240 billion in the 2014-2020 period[29] of which the EU allocates circa EUR 7 billion per annum to the innovation- and supply chains of the sector. Concerning transport sector, Horizon 2020 will deploy over €2 billion in the period 2018-2020, focussing on four key energy and climate priorities, including (urban) e-mobility[30].

Strengthening the Commission's efforts to deliver on the Paris Agreement and the UN Sustainable Development Goals and supporting the 2030 climate and energy targets, the Commission has designed its 2021-2027 long-term budget with a more ambitious, 25% (the equivalent of EUR 320 billion) goal for climate mainstreaming across all EU programmes. The new ambition is supported by additional measures that define

[28] Bloomberg New Energy Finance, 2018
[29] European Commission – PRIMES modelling projections
[30] COM(2017) 688 final

specific and achievable climate mainstreaming targets for the most relevant individual programmes. Catalysing strategic investments, such as those in the energy and mobility sectors is not only dedicated to under a separate sub-heading, but identified as a policy goal more clearly in horizontal programmes (eg. Horizon Europe, Cohesion Policy, the InvestEU Programme). Repayable and non-repayable forms of budgetary support and providing technical assistance to areas, where large investment gaps exist (energy efficiency in buildings), which are niche areas (cross-border renewable projects), or where the rapid technological and market development has not yet been picked up (capacity building, policy implementation) will provide additional financial impetus to decarbonized investments, complementing the programs that have been and will be crucial for constructing a secure, clean and integrated European energy system.

Drawing all of the different policy threads together through the Energy Union, the Paris Agreement and the economic and technological changes and advances that have occurred since 2011 require an updated analysis and roadmap. The technological developments have been particularly prominent, reshaping energy supply as well as affecting consumer behaviour (notably due to automation and digitalisation but also the decrease in technology costs).

On the energy supply side, opposing technological developments, with lower than expected costs for renewable energy sources[31] and higher than expected challenges for CCS and nuclear, have made the Roadmaps visions unlikely for both the supply and demand side in energy system. In the final energy consumption sectors: industry, transport, tertiary and residential, rapid development of technologies has made actors more willing to look at alternative low-carbon energy carriers (i.e. decarbonised electricity, hydrogen and e-fuels (synthetic fuels produced from decarbonised electricity). Energy storage emerges as a key enabling technology for both integration of renewables in power generation and providing low-carbon electricity for electrified transport, industry and buildings sectors (and thus providing further rationale and helping the sector coupling). The promise of new technologies in delivering the Paris Agreement is well illustrated by the fact that the Agreement itself was flanked by the launch of Mission Innovation[32], the global initiative to accelerate clean energy innovation and make clean energy widely affordable.

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[31] According to IRENA, Solar PV costs have decreased around 75% and costs of wind power decreased around 50% since 20131. Bioenergy for power, hydropower, and geothermal projects commissioned in 2017 largely fell within the range of, or even lower, costs of fossil-based generated electricity.

[32] The 23 countries and the European Union participating in MI committed to double their governments' clean energy research and development investments over five years. This technology research effort under MI has been translated into 8 work streams (Innovation Challenges). The European Commission took on the leadership of the "Affordable heating and cooling of buildings" and the 'Converting Sunlight' and 'Hydrogen' Innovation Challenges.

Recent years have also seen significant changes on other fronts than energy technologies which also have or will have impacts on decarbonisation pathways. Notably in the field of mobility connected and automated driving has potentially big impacts on safety, efficiency and emissions. In the future, some paradigm shifts towards 'mobility as a service', 'accessibility' and 'connectivity' concepts will also become more prominent. Considering behavioural change is now possible either because technology progress made certain solutions easily available to consumers (e.g. own energy production from renewables, regulating indoor temperature or more effective travel planning mindful of the carbon footprint) or because consumer awareness has grown that certain choices can lessen the carbon footprint and consumer now esteem that even if there are some inconveniences, the effort is worth taking to safeguard the climate for future generations (e.g. consuming less meat, choosing active transport modes) and often side-benefits can be reaped (less meat in a diet and active mobility both benefits health).. Healthy diets, limiting food waste or changing mobility modes are now mainstream consumer considerations in Europe and other options can follow this suit (e.g. limiting long distance travel or commuting, limiting the purchase of new consumer goods).

Importantly, there have been developments in overall emissions trajectory which would indicate that EU might not be on track towards long-term decarbonisation. These aspects are discussed more in detail in section xxx. It has become increasingly clear that **reducing the emissions outside the energy sector will be difficult**. While historically non-CO2 emissions have been reducing, recent developments are more mixed.

1.3 Policy initiatives on national level

1.3.1 MS own policies, Monitoring Mechanism and implementing the EU acquis

The swift and complete implementation of the EU acquis by Member States is a primary precondition for the delivery of the decarbonised, more competitive and dynamic economy Europeans seek. So in each of the areas where European law exists, or is being newly created, national action is needed to implement the law, as well as to complement it with appropriate national actions.

On infrastructure, Member States formulate and coordinate national infrastructure development plans to manage their energy demand, also by maintaining and increasing capacity on existing infrastructure. Such plans are developed and implemented in conjunction with TEN-E policy, including the identification and co-financing of projects of common interest. Some 77 PCIs will have been finalised by 2020 have received 2 billion euro from the EU

Regarding research & innovation, whilst private investment in R&I constitutes 80% of R&I spending, national and EU R&I programmes competent and steer such investments as well as fostering efficiency and cooperation to help bring together all the necessary stakeholders to embark on the large projects and demonstrations needed to develop new technologies, materials and processes needed for the energy transition.

Security of energy supply, also has a significant acqui that builds on national measures, in electricity, oil, gas and transport sectors. Despite these measures (e.g. oil stocks directive, N-1 infrastructure planning, generation adequacy coordination etc.) Member States have to improve regional cooperation and trust. This is currently being fostered through "preventive action plans" and "emergency plans" that are to be notified to the Commission by 1 March 2019, the conclusion of "solidarity arrangements" containing technical, legal and economic details and the preparation of national risk preparedness plans.

Regarding renewables, Member States are, by and large, implementing their national renewable energy action plans and are nearly all on track to deliver their 2020 national binding targets. Together with the administrative and flanking national measures Member States have taken to foster the development and growth of renewable energy technologies across the Union, the delivery of the plans and the targets demonstrates a successful European regime which has contributed across the board. Renewable energy reduce emissions, create indigenous energy supplies, create new jobs, and drive innovation and technological and industrial developments. At the same time, renewable energy needs more intelligent infrastructure and system management to be integrated on a large scale into Europe's energy systems, and more coordination or synchronisation is needed across Member States (for instance in biofuels regulations) to ensure the internal market functions properly and energy resources flow efficiently between Member States.

Regarding energy efficiency, the Energy Efficiency Directive (EED) implemented by Member States required energy efficiency policy measures at national level (and reported in the NEEAPs) targeting each sector of the economy (residential, services, industry, transport and energy supply sector). The measures include regulations, standards, funds, financial & fiscal measures (including taxation and incentives), market-based instruments and awareness raising measures , knowledge & advice as well as education, qualification & training.

The residential and service sectors benefit from a wide range of national policy measures to support energy efficiency improvements. In addition to the regulatory measures related to Energy Performance of Buildings Directive and specific Eco-design Regulations, other regulatory measures have been enacted in some countries with the aim to address the issue of split incentives or to enhance requirements for buildings. These include grants, low-interest loans and fiscal incentives or more innovative programmes. Information and awareness-raising measures have also been implemented with the focus on residential and service sectors. In addition, various Member States have mentioned in their NEEAP on-going or planned efforts related to alleviation of energy poverty.

<u>Regarding decarbonisation,</u>

DG CLIMA please consider input on nuclear power below

Currently, there are 128 nuclear power reactors in operation in 14 Member States33,34. Nuclear energy accounts in the EU for about 28% of the domestic production of energy, and 50% of its low carbon electricity[35]. Diverging views exist among Members States on the use of nuclear energy in Europe, and the contributions of nuclear energy to the gross electricity production and to the energy mix differ among them.

New build projects are envisaged in ten Member States, with four reactors already under construction in Finland, France and Slovakia. Other projects in Finland, Hungary and the United Kingdom, are under licensing process, while projects in other Member States (Bulgaria, the Czech Republic, Lithuania, Poland and Romania) are at different stages of preparation. The United Kingdom has announced its intention to close all coal-fired power plants by 2025 and to fill the capacity gap mainly with new gas and nuclear power plants. On the other hand, some national energy policies have fixed a ceiling for the share of nuclear in their respective range of energy generation sources (e.g. France) and some countries (Germany and Belgium) have decided to gradually phase-out from nuclear.

Current investment conditions present a challenging environment for achieving the projections of nuclear new build, which are shared with all low-carbon technologies, facing a large upfront capital expenditure and low operating costs (including renewables). There may be a funding shortage of a magnitude that will be mainly determined by the cost of the most competitive technology (taking into account the carbon prices set at the EU emissions trading system, or ETS) and the wholesale market price of electricity.

[33] Data as of end of 2017.
[34] Member States that make use of nuclear for domestic production of energy are: Belgium, Bulgaria, the Czech Republic, Germany, Spain, France, Hungary, the Netherlands, Romania, Slovenia, Slovakia, Finland, Sweden and the United Kingdom.
[35] Source: Eurostat, May 2015.

Based on the PINC, the importance of long term operations is expected to increase in the coming years, and by 2030 the majority of the fleet would be operating beyond its original design life. Long term operations are expected to represent the majority of nuclear investments in the short to medium term. Regulatory approval has been granted for operational lifetime extension of certain nuclear power reactors in Hungary and the Czech Republic. Decisions on operating lifetimes depend on current and forecast electricity market conditions and sometimes also on social and political factors. Such decisions are always subject to a safety review by the competent national regulator.

Additional MS policies such as coal phase-out, alternative fuels deployment, carbon tax (ENER: A1, B1, B2, B3, B4, C1, C2, C3, D3) – no input received so far

In the transport sector, a wealth of measures has been adopted at national level to ***incentivise the uptake of alternative fuels in transport, including electromobility***. These measures can take the form of purchase subsidies, registration tax benefits, ownership tax benefits, company tax benefits, VAT benefits, local incentives and infrastructure incentives[36].

Action at national level to support electro-mobility

In France, electric and plug-in hybrid electric vehicles emitting 20 gCO_2/km or less benefit from a premium of €6,000 under a bonus-malus scheme. For vehicles emitting between 21 and 60 g CO_2/km, the premium is €1,000. In addition, a diesel scrappage scheme is in place: switching a 11 year old (or older) diesel car for a new battery electric vehicle grants an extra €4,000 (€2,500 for a plug-in hybrid vehicle). The "L" category (quadricycles, motorbikes, scooters...) also benefits of a purchase subsidy (lead battery vehicles excluded) with €250 per kWh, with a limit of €1,000 or 27% of the purchase price. Electric vehicles are exempt from the company car tax. Hybrid vehicles emitting less than 110 g/km are exempt during the first two years after registration. Other registration and ownership tax benefits are also in place[37].

In Austria, private customers benefit of purchase subsidies of €4,000 for a battery electric vehicle (€2,500 from the federal government, €1,500 additional rebate by the industry) and €1,500 for a plug-in hybrid vehicle (€750 from the federal government, €750 additional rebate by industry). This is under the condition that the purchase price is not over €50,000 including VAT, and the minimum electrical range is not lower than 40 kilometres for plug-in hybrid vehicles. Businesses and municipalities benefit of purchase subsidies of €3,000 for a battery electric vehicle and €1,500 for a plug-in hybrid vehicle without additional conditions. Additional incentives are in place for businesses for the L1 and L3 categories and for other vehicle categories (i.e. buses, light commercial vehicles and trucks). Several bigger cities have already in place exemptions from parking charges. The Austrian automobile club ÖAMTC publishes the incentives granted by local authorities on its website (www.oeamtc.at/elektrofahrzeuge) [38].

[36] http://www.eafo.eu/incentives-legislation
[37] http://www.eafo.eu/content/france#incentives
[38] http://www.eafo.eu/content/austria#incentives

Rail transport is energy-efficient, has a high potential for decarbonisation and is particularly suited for medium to long distance transport[39]. Policies supporting the shift of freight transport to rail therefore directly contribute to decarbonisation. In order to strengthen the alignment between EU and Member State policies, the Commission recently carried out a survey of initiatives and ***measures implemented or planned by Member States supporting modal shift*** beyond the obligations following from EU legislation. The results of a first analysis are provided in the box below.

Action at national level to incentivise shift to rail

As an immediately effective measure to boost the competitiveness of rail freight transport, a number of Member States provide final support to lower the charges for the use of railway infrastructure ("rail toll"). Such charges typically account for 20 to 40% of the total costs of railway operators. In some cases, the support is targeted towards market segments with a particularly difficult competitive situation as compared to road transport, in order to ensure the efficiency and additionality of the public funds provided (i.e. to achieve the highest possible effect on modal shift).

In addition to this, some Member States directly subsidise the provision of rail freight transport services. Financial support is typically provided under a state aid scheme justified by the reduction of the external costs of transport induced by modal shift to rail. The schemes are usually targeted towards market segments facing particular costs challenges, such as single wagon load – i.e. shipments in individual or groups of wagons requiring costly last mile operations to collect and deliver wagons and recompose trains – and combined transport – which incurs additional costs due to the transhipment of loading units.

Another lever to support modal shift to railway transport is the facilitation of access to rail freight services. A recent study commissioned by the European Commission has shown that the existence of adequate infrastructure providing access to the railway network is a key precondition for the success of rail freight transport[40]. In this context, some Member States have put in place programmes that support investment for the construction of new or for upgrading existing facilities providing access to railway services, such as ports, terminals as well as tracks connecting industrial and commercial centres to the main railway network.

Finally, a few Member States have launched joint initiatives with their railway infrastructure managers to implement short-term improvements in the operational conditions for cross-border railway traffic. These initiatives take into account that barriers to a truly Single European Railway Area are often due to a complex system of historical rules and regulations under the control of different actors, therefore requiring a common effort in order to achieve tangible improvements.

According to the Odyssee-Mure database, more than 200 measures have been adopted at national level that: incentivise modal shift toward collective passenger transport modes or to rail and waterborne transport for freight, improve the integration of the transport modes and multimodality, incentivise inter-urban traffic management and optimisation, promote reduction in traffic volumes, promote tax deductions for home/job travel favouring public transport, promote cycling or walking, etc[41]. However, many of these measures may also be driven by the Member States obligations under the EU legislation

[39] The 2011 White Paper on Transport therefore defined the explicit goal to shift 30% of road freight over 300 km to rail or waterborne transport by 2030, and more than 50% by 2050.
[40] https://ec.europa.eu/transport/sites/transport/files/2016-06-rail-final-report-design-features-for-lm-investments.pdf
[41] http://www.measures-odyssee-mure.eu/topics-energy-efficiency-policy.asp

(e.g. Energy Efficiency Directive, Effort Sharing Decision, Renewable Energy Directive, Directive on alternative fuels infrastructure).

1.3.2 Regional cooperation: BEMIP, Pentalateral, CESEC etc

Delivery of decarbonisation and energy objectives – indeed delivery of any European policy objectives, is more efficient and cheaper when undertaken in a coordinated manner – the story of the EU is one of cooperation to deliver on common objectives. This continues to be true and is highly relevant for the Energy Union. Whether the EU applies single European schemes (eg the EU ETS), adopts legislation, or fosters and coordinates cooperation amongst energy regulators, the clear lesson is that sharing knowledge, experience and expertise brings mutual benefits. This is why the Governance regulation requires regional coordination of national energy and climate plans, and why regional coordination of infrastructure planning and the common development of projects of common interest is required.

These **existing regional cooperation fora will be important to promote regional cooperation in all five pillars of the Energy Union**, such as the Baltic Energy Market Interconnection Plan (BEMIP), Central and South-Eastern Europe Connectivity (CESEC), Central-West Regional Energy Market (CWREM), the North Seas Countries' Offshore Grid Initiative (NSCOGI), the Pentalateral Energy Forum, Interconnections for South-West Europe and the Euro-Mediterranean Partnership. Cooperation with Energy Community contracting parties, with members of the European Economic Area and, if they consider it appropriate, with other relevant third countries can also be envisaged.

Such cooperation can be further enhanced through Member States opening their R&I support programmes to other EU Member States or companies (such as the recent initiative by France[42]), creating the instruments that underpin a European R&I agenda for the energy transition.

1.4 Action agenda by industry, regions and civil society

SECTION TO BE COMPLETED BASED ON PUBLIC CONSULTATION]

[42] Provide ref

Since the Paris-Lima call for global climate action, stakeholders have been encouraged much more actively to participate in climate action and have their voluntary action recorded[43]. EU stakeholders have been at the forefront of these developments[44].

Regional governments and local cities, with their impact on economic, spatial, environmental planning and energy provision challenges, have seen a strong increase in their role in achieving the energy transition and becoming resilient. The Covenant of Mayors initiative, where local governments voluntarily commit to implementing climate and energy objectives, has already 7383 EU signatories, representing in total 198 million EU citizens. A recent analysis of the local climate plans of 885 representative EU cities (both Covenant cities and non-Covenant cities) concluded that approximately 66% of EU cities have a climate mitigation plan and about 26% of EU cities have adopted adaptation plans.[45] For regional governments, initiatives such as the Under 2 Coalition actively reach out to its members to draft 2050 pathways to set a dedicated goal of reaching less than 2 t of CO2eq/capita by 2050, or 80% below 1990 levels. 200 jurisdictions globally have already committed to this long term goal.

Industry and their sectoral representatives have also become much more active. Industries in Europe recognise the need to reduce emissions in 2050 strongly. Private actors, large companies and sector associations are increasingly providing reports that elaborate their thinking on how to significantly reduce EU greenhouse gas emissions in the coming decades (see section 5.3). This can also be clearly seen in the responses we got on the public consultation (see section 11), which shows a considerable evolution of their position in the last decade.

Citizens have started to act both individually and collectively much more explicitly on climate change. Consumer choice can have impact and has created new markets as well as pressure on industry to adapt their offers allowing for more sustainable products coming to market. Already 1.5 million households in Germany provide through solar energy in their self-consumption[46]. Consumer choices prompts companies from all sectors to introduce renewable energy and carbon offset programs. An ambitious long term greenhouse gas emissions reduction strategy?

It is of importance to plan ahead when developing climate policies. The European Commission already presented in 2011 a number of long term roadmaps looking at the climate and energy challenges ahead[47]. This in turn was the start of numerous such exercises by stakeholder and authorities. Overall this has contributed too much better

[43] http://climateaction.unfccc.int/
[44] http://unfccc.int/tools/GCA_Yearbook/GCA_Yearbook2017.pdf
[45] D. Reckien et al., How are cities planning to respond to climate change? Assessment of local climate plans from 885 cities in the EU-28, Journal of Cleaner Production, 26 March 2018, https://www.sciencedirect.com/science/article/pii/S0959652618308977?via%3Dihub
[46] https://www.eurobserv-er.org/pdf/photovoltaic-barometer-2018-en/
[47] the Roadmap for moving to a competitive low carbon economy in 2050, the Energy Roadmap 2050, and the Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system (commonly referred to as the Transport White Paper), COM(2011)112, COM(2011)885, COM(2011)144.

understanding of what actions will be required to achieve our long term temperature goals, and in turn impacting in shorter actions and policy development.

This Long Term Greenhouse Gas Emissions Reduction Strategy revisits this exercise. It does so to prepare for domestic purposes going beyond climate action alone. The EU needs to further develop a competitive, secure and sustainable energy system which also requires long term planning. This is strongly recognised in the governance legislation of the Energy Union[48], which foresees that both the EU and its Member States will prepare long-term strategies for greenhouse gas emissions reduction.

But Europe's climate action does not stop at its border and the EU has always taken a leading role in the international climate policy arena. While in absolute terms the impact of EU domestic reductions on global emissions will progressively become more and more limited, EU action is crucial to inspire global action, demonstrating that emissions can be reduced without harming economic growth. In this context it is of importance that the EU delivers on time its long term Strategy. The Paris Agreement's invited to do so by 2020. Others that have already submitted their mid-century strategies to the UNFCCC.49

The EU is already the most GHG efficient of the world's major economies**Error! Bookmark not defined.**, and our NDC projects us to further advance this lead by 203050. But the strategy needs to look further than that, at least until 2050 and raise the question what the EU should do to deliver as its domestic contribution to achieve the Paris Agreement temperature goals of keeping global warming well below 2°C, and pursuing efforts to limit the increase to 1.5°C. Not only to inspire domestic reflection, but also to inform third countries when developing their own long term strategy.

This section will first look at by how much the world should see emissions reduce to meet the Paris Agreement's temperature objections (section 2) and then look at the EU's required ambition for its long term strategy, taking into account the global emission pathways.

MOVE:

In transport and mobility, the Urban Agenda was led by the Urban Mobility Package (2013) which included also Guidelines on Sustainable Urban Mobility Plans (SUMPs)[51]. Its actions and initiatives are currently under implementation and cover various non-binding measures that help and encourage cities in designing and implementing

[48] Xxx add reference

[49] Canada, Germany, Mexico, the US, Benin, France, Czech Republic, UK and Ukraine have officially submitted their strategies to the UNFCCC in response to article 4.19 of the Paris Agreement (status: August 2018),

[50] UNEP, The Emissions Gap Report 2016

[51] Source: http://ec.europa.eu/transport/themes/urban/urban_mobility/ump_en.htm

ambitious measures through SUMPs, in particular to increase the share of public transport, cycling and walking. The SUMPs promote a comprehensive approach which includes links and synergies with spatial planning, energy infrastructure planning, road safety, health impacts, and other related areas.

Generally, the SUMPs constitute a widely accepted EU concept which can be regarded as a good practice example, with consultation of citizens and taking into account of their needs being at the heart of the process which is key to successfully implement transport projects that often significantly affect the life of city inhabitants. The European approach to SUMP has inspired many cities within and beyond Europe. A recent study[52] identified an estimated 1000 SUMPs in the EU. The concept is being strengthened and is likely to rise in importance in the future, supporting municipalities in transition towards liveable cities with high quality of life[53].

Action by cities

The city of Milan has adopted its Sustainable Urban Mobility Plan in April 2018, after 3.5 years of preparation. Measures such as traffic calming, traffic reduction and shared mobility are core elements of the city strategy. For example, the new shared system "free floating", operated by cars, bikes and scooters, is a fully integrated mobility system that supports both individual mobility and local public transport. The number of alternatives to private cars has risen: nearly 3,000 shared cars (27% fully electric) and more than 600,000 subscribers, 4,650 bikes (among which 1,000 e-bikes) from traditional station based bike sharing system and almost 60,000 yearly subscribers, 12,000 free-floating shared bikes since October 2017 and 100 fully electric shared scooters are currently circulating in Milan. The city of Milan also increased its bike lane network from 128 km in 2011 to 200 km in 2015 and the Sustainable Urban Mobility Plan foresees a total of 453 km by 2024.[54]

As a growing city, Malmö faces the challenge of preventing the further increase of motorised transport and related emissions. The city's strong walking and cycling programmes encourage the use of alternative modes and highlight the health aspects of active travel. The planned tram network reflects the city's ambition to provide competitive public transport services, with a Bus Rapid Transport (BRT) System being set up to bridge the period of construction. Local authorities have a strong strategic vision and have set modal split targets, which have been carefully assessed up to neighbourhood level. Transport planning is closely linked to the overall urban planning process and takes into account commuter patterns as well as social factors, including accessibility for different social groups. Malmö's planning process has a clear focus on improving sustainable transport modes, which goes far beyond planning infrastructure, and includes a clear and consistent urban freight policy. Malmö is an outstanding example of a city which has developed a holistic, ambitious and realistic vision for its mobility system summarised in an award-winning (4th SUMP Award) sustainable urban mobility plan (SUMP).

The Partnerships under the Urban Agenda for the EU will offer a framework for cities, Member States and other stakeholders to exchange experiences and best practices for the urban mobility dimension, will involve cities in the design of policies and the delivery on the ground by establishing a new working method based on a multilevel and cross

[52] Conducted jointly by CIVITAS Prosperity and SUMPs-Up projects
[53] https://ec.europa.eu/transport/themes/urban/urban_mobility/urban_mobility_actions/sump_en; http://www.eltis.org/mobility-plans/sump-concept; http://www.create-mobility.eu/create/project
[54] http://www.eltis.org/discover/case-studies/shared-mobility-enabling-maas-milans-sump

sectoral multilevel approach. Through initiatives such as the Covenant of Mayors, the European Innovation Partnership on Smart Cities and Communities, CIVITAS or Urban Innovative Actions, the Commission supports cooperation of public and private actors. More details are provided in Annex 1.

Improving urban mobility has a high potential to reduce the CO_2 emissions from transport and high exceedances of air pollutants that are widespread over European urban areas. *Sustainable Urban Mobility Plans (SUMPs)* help dealing with the complexity of urban mobility which could stimulate a shift towards cleaner and more sustainable transport modes such as public transport, cycling and walking. Effectiveness of such action also depends on specific characteristics of the urban context and requires partnerships between EU institutions, national, regional and municipal authorities (for instance initiatives such as CIVITAS, the Covenant of Mayors, and the Smart Cities & Communities European Innovation Partnership). Synergies may be found e.g. by making SUMPs a pre-condition for receiving EU funding/increasing the co-financing rate.

New societal developments and behaviour changes have large potential for improving mobility and contributing to decarbonisation, but also represent important question marks for the transport system and existing policy. *Integrating the sharing economy and automated and connected vehicles* in the existing transport institutional and technical set-up, and making full use of *digitalisation, mobility as a service and the potential of active modes*, would need to be part of the transport agenda.

Action by cities

Some cities and towns have regulations or restrictions for vehicles going into all or part of their area to improve issues such as air quality, congestion or how people experience the city. There are many Low Emission Zones (LEZs) already implemented in many European countries. Low Emission Zones are areas where access by vehicles is limited by their emissions. They are implemented to improve air quality. For example, the Austrian LEZs concern lorries over 3.5 tonnes, in Belgium (Antwerp, Gent) all vehicles with four and more wheels are affected, in Czech Republic (Prague) the LEV concerns lorries over 3.5 tonnes or 6 tonnes, in Denmark all diesel-powered vehicles above 3.5 tonnes are affected, in Finland the LEVs concern buses and garbage trucks (dustbin lorries), in Germany all vehicles with four wheels are affected, in Greece (Athens) all vehicles over or under 2.2 tonnes are concerned, in Italy the LEVs affect all vehicles, including mopeds and motorcycles, in the Netherlands lorries over 3.5 tonnes gross vehicle weight are concerned, in Portugal (Lisbon) petrol & diesel, light duty and heavy duty vehicles are affected, in Sweden all heavy, diesel-powered trucks and buses are concerned, in UK (London) vans and similar over 1.205 tonnes unladen, and vehicles over 3.5 tonnes gross vehicle weight are concern while in Norwich, Oxford and Brighton public service buses only are affected.[55]

DG MOVE provided even more extensive material (maybe for an annex)

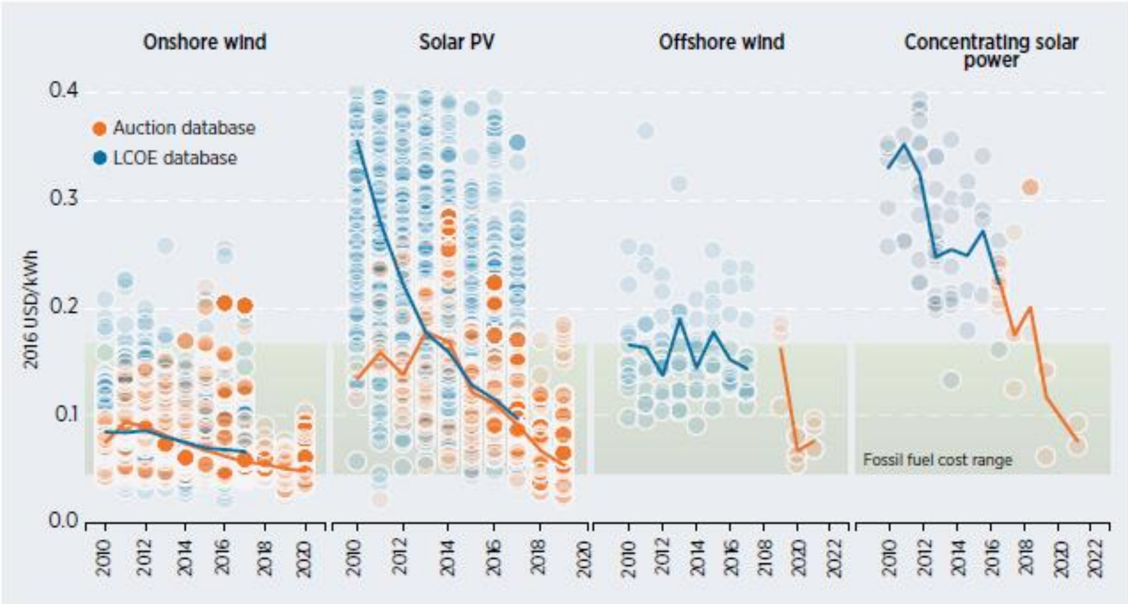
1.5 Decarbonisation to date – stock-taking exercise

Since 2011, the policy implemented by the European Union and other frontrunners in the fight against climate change have transformed the energy

[55] http://urbanaccessregulations.eu/overview-of-lezs

industry. Support programs worldwide have kick-started a dramatic decrease of the cost of renewable energy technologies.

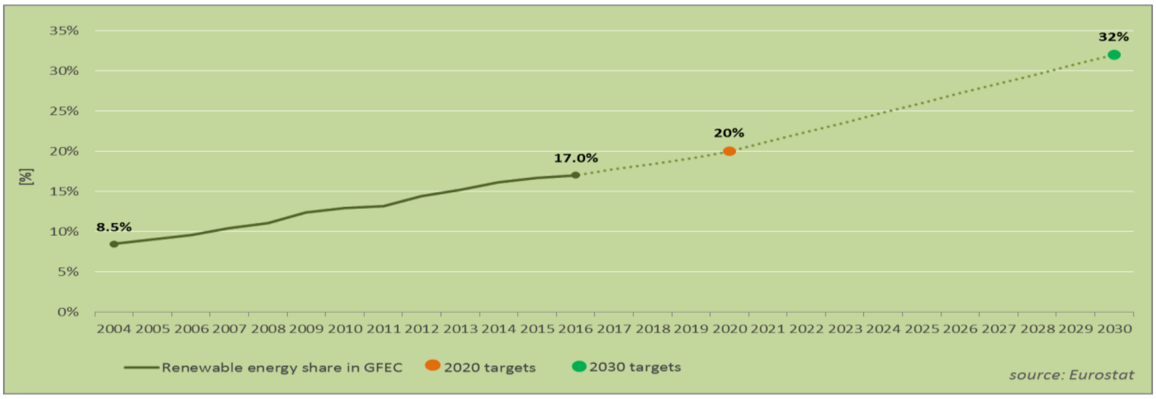
Figure 1: The levelised cost of electricity for projects and global weighted average values for CSP, solar PV, onshore and offshore wind, 2010-2022[i].



Renewable energy technologies such as wind energy, bioenergy and solar photovoltaic are now mainstream market players. Although it declined compared to the previous year, investment in renewable power accounted for two-thirds of global spending in power generation in 2017. The increasing share of renewable energy investments is partly the result of a slump in the commissioning of new fossil fuel capacity (in particular coal-fired power plants in India, China and Europe)ii.

Helped by the European support policies, renewable energy has been increasing continuously in the EU, with its share doubling since 2004 when renewables covered only 8.5 % of gross final energy consumption. In the period 2004-2016, the share of renewable energy grew annually by 6.0 % on average. Annual growth slowed slightly to 5.2 % in the short-term period 2011-2016. Compared to 2008, direct and indirect employments in renewable energy more than doubled, increasing from 660 000 to 1.43 million Jobsiii. Figure 2 shows the share of renewable energy in the EU.

Figure 2: Share of renewable energy in Final Energy Consumption in the EU.

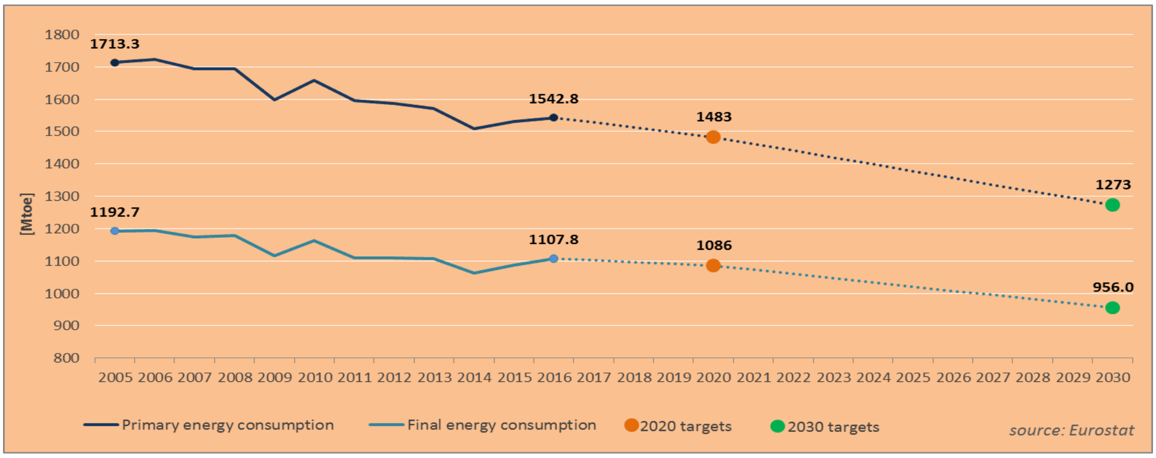


The power sector has made most important steps towards decarbonisation with the closure of most inefficient thermal generation, the growth of renewables; better interconnection; better operating, more liquid and more flexible markets. However, the power sector still accounts for over 2/3 of GHG emissions. Developments in the power market structure allowed integrating an increasing share of variable renewable generation. Connecting markets through appropriate infrastructure and cross border trading rules allowed to increase liquidity and security of supply significantly. The EU-wide electricity market now allows to aggregate demand and supply of almost 500 million citizens.

Dedicated infrastructure was built to enable higher penetration of renewable electricity, for instance through interconnection of areas with complimentary renewable energy resources (e.g. in the case of the Spain-France interconnections) or by connecting offshore wind parks to the transmission network. To date, more than 30 Projects of Common Interest (PCIs) have been completed in the power sector and 47 are scheduled to be built around 2020.

The EU energy consumption gradually decreased between 2007 and 2014 – the annual average decrease amounted to 0.9 % between 2005 and 2014 and 0.6 % in the short-term period, 2011 to 2014. Final energy consumption decreased by 7.1% between 2005 and 2014 — with average annual decreases of 0.6 % between 2005 and 2014 and almost zero between 2011 and 2014. However, energy consumption started to rise again as of 2015 in part due to harsher winters, continued economic growth and lower fuel prices. The preliminary data for 2017 [to be updated] show that both primary and final energy consumption are no longer on track to meet the 2020 target, if such recent trend would persist in the coming years. The latest data show a gap of 5.5% and 4% for primary and final energy consumption respectively to their targets. It is clear that with the economic growth pushing the energy consumption upwards, further efforts would be needed in order to reach the 2020 target. In this context, a stricter enforcement of the existing legislation is desirable. Figure 3 shows energy consumption trends in the EU.

Figure 3: Primary and Final energy consumption in the EU.



Structural changes in the European economy and policies for supporting Renewable energy efficiency resulted in a decoupling of economic growth from GHG emissions and energy consumption. Historically GHG emissions in the EU increased with the GDP. GHG emissions in the EU peaked several decades ago and decoupling of growth and jobs creation from GHG emissions and energy has been observed in the last decade. In 2016, the recovery of Europe's economy led to an increase in industrial and economic activities and an overall increase of 1.9% in GDP. This could have increased greenhouse gas emissions. Instead, emissions decreased by 0.7% overall and even faster (2.9%) in the sectors covered by the EU Emission Trading System. Overall, between 1990 and 2016, the EU's combined GDP grew by 53%, while total emissions decreased by 23%.

Over the past years, economic growth and energy consumption have also decoupled. The steadily declining demand for energy in the EU is attributed primarily to energy efficiency measures in the Member States. (UPDATE) Although energy consumption increased slightly in 2015 and 2016 as mentioned above, the long-term decoupling trend is clear: in 2015, the EU consumed 2.5 % less primary energy than it did in 1990, while GDP grew by 53% over the same period.

In the transport sector, however, greenhouse gas emissions continue to rise and abating transport emissions remains challenging. Transport emissions appeared to have peaked in 2007, however the upward trend resumed in [20xx]. New technologies i.e. electrification are penetrating the market, but at a relatively slow rates. In certain regions, the impact air pollution from fuel combustion on the population is a concern. [contribution from CLIMA, MOVE].

Industry achieved significant improvements in energy intensity. Has a result emissions in the industrial sector decreased faster than in the rest of the economy. In 2015 the energy intensive industry sectors directly emitted approximately 700 million tonnes of CO2, which represents a reduction by more than 30% compared to 1990 levels. Since 1960 the EU steel industry has reduced its total CO2 emissions by about 50% and today, primary steelmaking Blast Furnace technology in the EU is very close to the thermodynamic limits of the process. For the Chemical industry, the GHG emissions were reduced by 60% between 1990 and 2014[56].

However, use of renewable energy other than renewable electricity and diffusion on advanced low-carbon technologies (e.g. CC(U)S, hydrogen, etc.) in industry remains limited [contribution C2, GROW]. The role of new circular economy business models is promising but still unclear (e.g. in energy, industry, food…). [contribution GROW, ENV]

Non CO2 emissions have seen large reductions except for methane leakages. Global methane emissions have been on a renewed increase since 2007[57] and research results are divided on whether the source of such increase is fossil fuels, agricultural emissions or natural wetlands. Being able to accurately measure methane emissions from specific sources, while challenging, is critical in order to devise the right policy response. Fugitive methane emission estimates are not yet robust and often underestimate real emissions. Based on greenhouse gas inventories, non-CO2 emissions have seen large reductions.

Agriculture reductions have recently flattened, efficiency gains still ongoing but compensated by increasing production. The mitigation potential is limited [contribution CLIMA]. Emissions from waste have fallen significantly and the trend is expected to continue as a consequence of environmental policies aiming at reducing landfilling of untreated waste.

Abandoned land has increased. The carbon sink has increased but further significant increases are not expected to continue. Not clear that from the perspective of carbon productivity we are using our land optimally in the EU. [contribution CLIMA]

Climate Change is already occurring, we are starting to adapt. [contribution CLIMA]

[56] EEA and CEFIC analysis (PetrochemicalsEurope_EU40_TotalVisit_092017.pdf – to be checked)

[57] Human activities caused a 2,5 fold increase since the preindustrial era. Average rate of increase since 1900 is 8,3 ppb/year and after a period of stagnation between 2000-2007, 7,7 ppb/year since 2007, equivalent to net emissions increase of 25 Tg of methane per year. Source: Reduced biomass burning emissions reconcile conflicting estimates of the post-2006 atmospheric methane budget, article in Nature Communications, 2017.

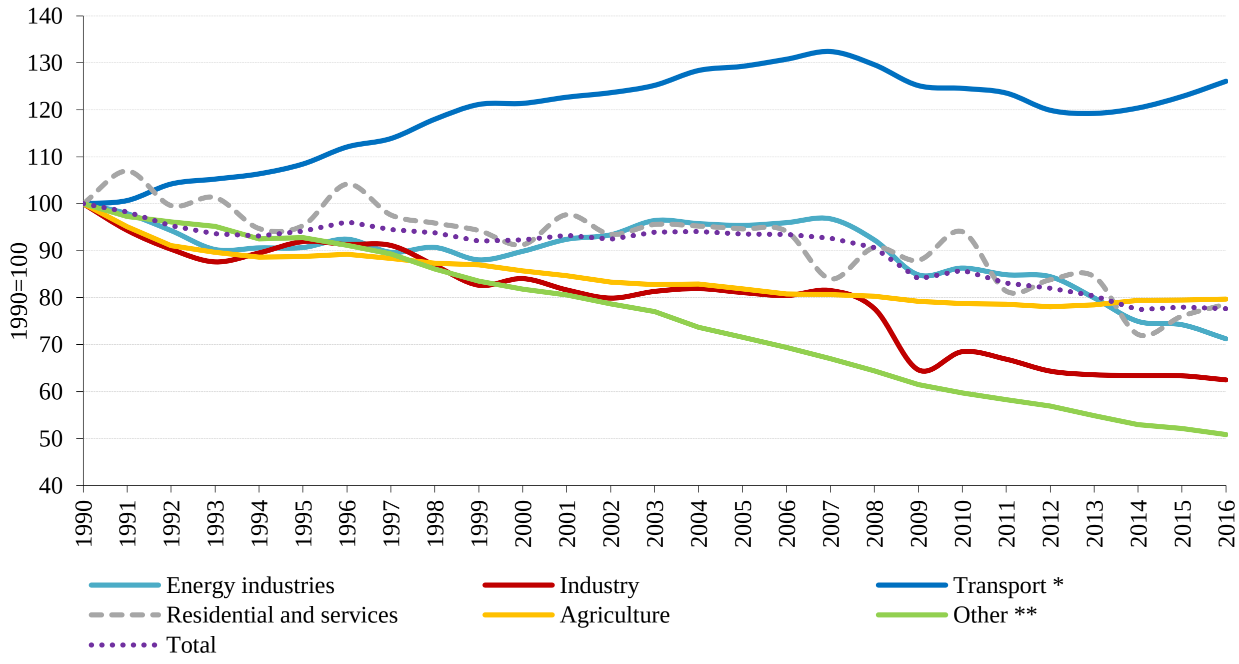
MOVE contribution:

Emissions in transport did not show the same decline as those in other sectors (see **Error! Reference source not found.**). Whereas in industry emissions started to decline s of the 1990s and in power generation they are below 1990 levels, in transport they are still 26% above their 1990 levels due to large increases during the 1990s. Emissions from transport have gone down by 10% during 2007-2013 due to increased road vehicle efficiency, high oil prices and slower growth in activity as a result of the crisis. Since then they started picking up again driven by the recovery of transport activity in the context of the low oil price environment. By 2016, transport emissions excluding international maritime represented about 24% of the total emissions[58], compared to 15% in 1990 - the base year for measuring progress in EU climate action. Transport is therefore a sector with a significant role in the energy and climate policy.

Road is by far the main emitter of greenhouse gas (GHG) emissions from transport. In 2016, it accounted for 72% of all GHG emissions from transport. Waterborne transport (inland navigation and international maritime) and air transport follow with shares of 13.6% and 13.3%, respectively. Rail transport contributed only 0.5% of GHG emissions.[59]

[58] Including international maritime, transport provides about 27% of the total greenhouse gas emissions.
[59] Emissions from rail transport do not include emissions from producing the electricity used in rail.

Figure 4: Evolution of greenhouse gas emissions by sector (1990=100), EU28



*Note: * Transport includes international aviation but excludes international maritime; ** Other include fugitive emissions from fuels, waste management and indirect CO_2 emissions*
Source: EEA

The evolution of ***energy use in transport*** was broadly similar to that of greenhouse gas emissions over time. By 2016, final energy consumption in transport was at similar levels with those observed in 2005. According to the findings of the Odyssee-Mure project, improvements in energy efficiency of cars, trucks and aircraft counterbalanced the increased transport activity over this period. The impact of modal shift was more limited. Other factors like behavioural change and low capacity utilisation in road freight transport had a negative impact, slightly increasing the energy consumption[60].

The currently dominant transport technologies are tightly linked to liquid fossil fuels. Liquid fuels, with their high energy density, are particularly suited for mobile applications and have displaced most alternatives. Transport relied on oil for 95% of its energy needs in 2016. Most energy consumed in air and waterborne transport was petroleum-based. While air transport relies only on kerosene, inland navigation uses few types of fuels, but all petroleum based. Road transport depended on oil products for 95% of its energy use and rail transport for 30% in 2016. Transport dependence on oil not only needs to be reduced, but the energy sources also need to be diversified.

The ***EU share of renewable energy in transport*** reached 7.1% in 2016. Biodiesel remains the most widely used form of renewable energy in transport with 11.1 Mtoe in

[60] http://www.odyssee-mure.eu/publications/efficiency-by-sector/transport/drivers-consumption.html

2016, followed by bioethanol with 2.6 Mtoe.[61] However, biofuels consumption slightly declined since 2014, being below the peak levels registered in 2012. Renewable electricity in transport went up significantly over time, representing 1.9 Mtoe in 2016. The vast majority of it is consumed in rail transport, while road transport represents only around 2% of the total[62].

As a result of both EU and Member State level measures, the average ***specific fuel consumption of the EU passenger cars fleet*** went down from around 7.4 l/100km in 2005 to 6.9 l/100km in 2015 according to the findings of the Odyssee-Mure project[63]. However, after several years of steady decline, the average CO_2 emissions of a new car sold in the EU rose by 0.4 gCO_2/km in 2017 to 118.5 gCO_2/km, according to provisional data published by EEA[64,65]. Since 2010, when monitoring started under current EU legislation, official emissions have decreased by 22 gCO_2/km (16%). Nevertheless, further improvements need to be achieved by manufacturers to reach the 2021 target of 95 gCO_2/km.

According to provisional data published by EEA, ***sales of plug-in hybrid electric vehicles (PHEV) and battery-electric vehicles (BEV)*** increased by 42% in 2017. However, the share of these categories in the new fleet remains low, at around 1.5%. Around 97,000 BEV were registered in 2017 (51% increase compared to 2016), while sales of new PHEVs increased by 35%. The largest number of BEV were registered in France (more than 26,110 vehicles), Germany (more than 24,350 vehicles) and the UK (more than 13,580 vehicles). However, the relative share of PHEV and BEV sales combined in the national car sales in 2017 was highest in Sweden (5.5%), Belgium (2.7%) and Finland (2.6%)[66]. For the first year since monitoring started, petrol cars became the most sold vehicles in the EU, constituting almost 53% of sales.

1.6 Conclusion

This chapter has reviewed the host of legislative and policy work undertaken by the EU, by Member States and by other actors over the last decade. Great progress has been made in linking up policies and measures in different fields and sectors. Following the creation of a strong and clear regime for taking the first steps towards decarbonisation through the first energy and climate package of 2007, further initiatives have continued to steer Europe towards the transformation, culminating in the Energy Union and the Clean

[61] According to Art. 17 (1) of the Renewables Directive, non-certified biofuels cannot be counted towards national and EU renewable energy targets.
[62] Eurostat
[63] http://www.indicators.odyssee-mure.eu/online-indicators.html
[64] https://www.eea.europa.eu/highlights/no-improvements-on-average-co2
[65] Since 1 September 2017, the 'Worldwide harmonized Light vehicles Test Procedure' (WLTP) has been introduced so that laboratory results better represent actual vehicle emissions on the road. For 2017 EU Member States had for the first time the possibility to report WLTP emission factors, but values were reported for just 7300 vehicles (0.05 % of new registrations). According to EEA, the low number of WLTP values means it is not yet possible to provide a representative assessment of the new measurement protocol.
[66] https://www.eea.europa.eu/highlights/no-improvements-on-average-co2

Energy for all European’s legislative package. In tandem, Member States, either in implementing EU law or through complementation national initiatives, have contributed to making great progress, as illustrated, in all five dimensions of the Energy Union.

However, our economies, our technologies, our societies and we ourselves are not static, stable or fixed. Despite the solid framework that has been established to deliver our 2030 objectives, much as changed, in our economies our technologies and in our societies, that we need to reassess the possible routes to delivering the EU’s commitment to the Paris Agreement, and to the energy transformation overall. Having brought divers sectors together in analysis and policy to date, this strategy seeks to explore the drivers , technologies and pathways to decarbonisation, that will bring delivery of the transformation in a manner which drives forward the European economu and instyr, maintaining its world leading role in innovation nd industrial development, demonstrating its dynamism and flexibility, and securing prosperity in a sustainable form for the future.

2 GLOBAL ACTION TO ACHIEVE THE PARIS AGREEMENT'S TEMPERATURE OBJECTIVES

2.1 Global emission pathways to achieve the Paris Agreement's temperature objectives

The global picture: a well below 2°C world

To keep average global temperature rise well below 2°C compared to pre-industrial levels will require global action. The EU has the long-standing objective to reduce global emissions by at least 50% globally by 2050 compared to 1990[67].

Recent science (including the recent Special Report of the IPCC[68]) provides an updated vision of what a well below 2°C world looks like and confirms that the 50% global reduction objective remains consistent with pathways limiting warming to this level. For a likely chance (above 66% chance[69]) of keeping temperature rise below 2°C this century, global GHG emissions projections that reduce by over 50% GHG emissions by 2050 compared to 1990 see net GHG emissions decline to near zero by 2100 or just below. This finding is also supported in analysis conducted by the JRC and Netherlands Environmental Assessment Agency for this report[70].

[67] European Council Conclusions, 29/30 October 2009,
[68] See in particular Table [2.4 – confirm upon report approval] of the IPCC Special Report on Global Warming of 1.5°C. Findings in this section are also informed by recent research conducted by the Joint Research Centre and Netherlands Environmental Assessment Agency. See Section 14 for further details.
[69] While there is no official definition of 'well below' 2°C, studies typically refer to pathways with a >66% chance of keeping global warming below 2°C. The *average* temperature change expected in such pathways is therefore lower – typically 1.7-1.8°C in 2100.
[70] Xxx include reference

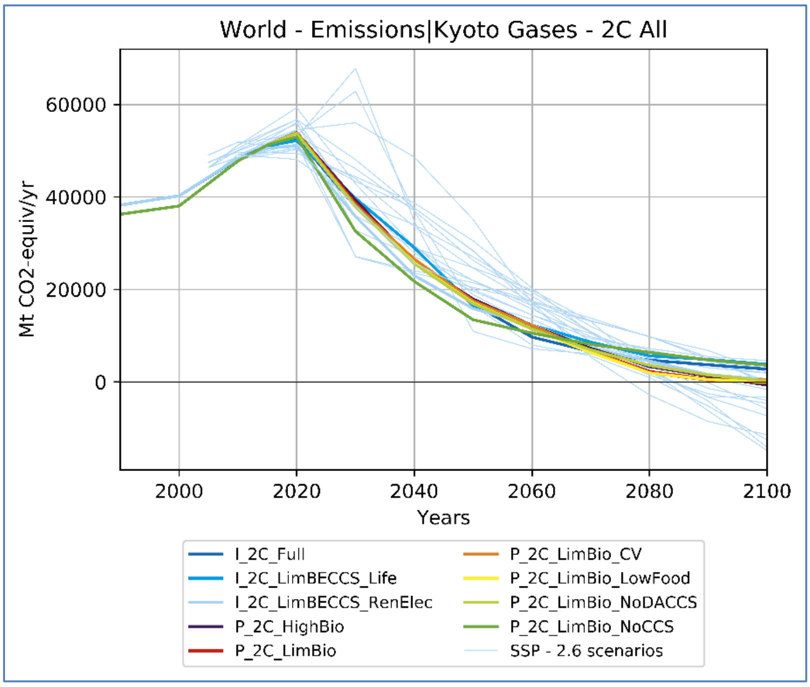


Figure 5: Well below 2°C runs from analysis using POLES model (P), IMAGE model (I) and comparable runs from other sources (SSP – 2.6).
Source: [JRC and Netherlands Environmental Assessment Agency, reference to be added]

Looking beyond 2050, global emissions would need to continue fall strongly to achieve zero net GHG emissions by the end of the century. This will require significant amounts of negative emissions from afforestation or carbon dioxide removal technologies (CDR) to compensate for the remaining emissions that are hardest to eliminate, for instance non-CO2 emissions related to agriculture to feed a global population.

But acting to reduce global emissions as quickly as possible will place the world on a safer path and reduce the need for negative emissions technologies later on. A slower pace of emissions reduction by 2050, with less reductions achieved by 2050, would require steeper reductions thereafter, including deployment of negative emissions technologies at even greater scale and faster. This may require net negative greenhouse gas emissions towards the end of this century with a net withdrawal of CO2 from the atmosphere to compensate for past emissions and, possibly, reduce global temperatures following an overshoot of the 2°C threshold.

The global picture: a 1.5°C world

Limiting global warming to 1.5°C requires even greater, and more immediate, action. In a 1.5°C world, typical projections reach net zero before 2070, and become negative afterwards (see **Error! Reference source not found.** as well as the IPCC 1.5°C report[71]).

[71] See in particular Table [2.4 – confirm upon report approval] of the IPCC Special Report on Global Warming of 1.5°C.

Global CO_2 emissions already become net zero earlier, by 2050, and continue to decline thereafter. Overall, negative CO2 emissions in energy, industry and land use have to compensate not only for residual emissions of CO2 and non-CO_2 gases but also to correct for a temperature overshoot by withdrawing CO2 from the atmosphere on a net basis.

The IPCC 1.5°C report is also clear. Scenarios with least or no overshoot of the 1.5°C objective, and low amounts of net negative emissions by 2050, tend to be close if not at zero GHG emissions globally by 2050.

This finding are also supported in analysis conducted by the JRC and Netherlands Environmental Assessment Agency (see **Error! Reference source not found.**). Scenarios with smallest net negative emissions by 2100 see global net emissions close to zero by 2100.

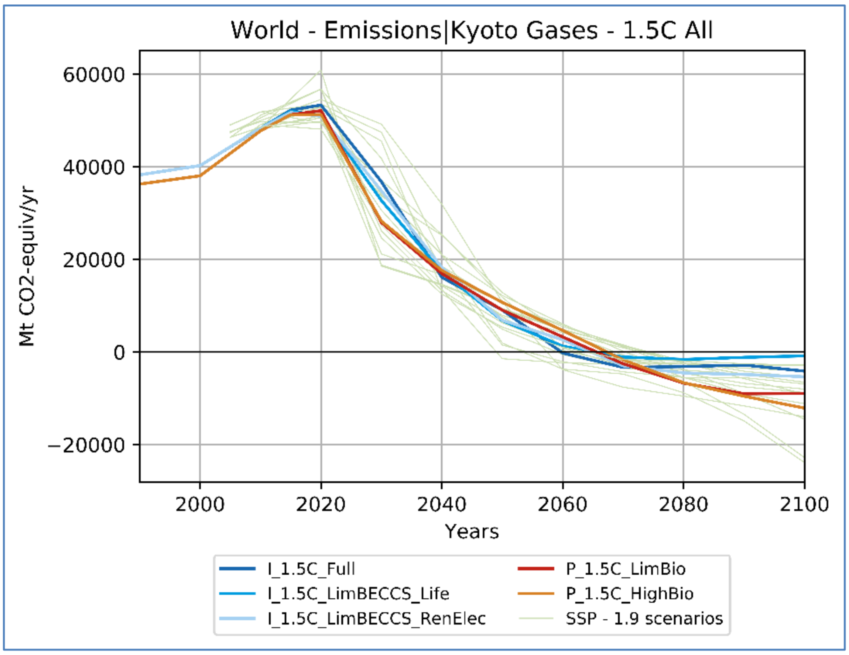


Figure 6: 1.5°C runs from analysis using POLES model (P), IMAGE model (I) and comparable runs from other sources (SSP – 1.9).
Source: [JRC and Netherlands Environmental Assessment Agency]

The above pathways for well below 2°C and 1.5°C cover all major sectors and greenhouse gases (the so called Kyoto basket of greenhouse gases[72]). This includes the land sector (which as well as a source, can also be a net sink of CO2) and the international aviation and maritime sectors. They are consistent with the most recent global pathways as reported in the IPCC Special Report on 1.5°C, which themselves are based on the remaining emission budgets as included in the previous IPCC report (the Fifth Assessment Report). The IPCC Special Report on 1.5°C also

[72] These are carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O) and the so-called F-gases (hydrofluorocarbons and perfluorocarbons and sulphur hexafluoride)

contains an updated upward assessment of the remaining emission budgets which is not yet incorporated in the literature that project mitigation action and associated emission pathways. But it is clear that above pathways are conservative taking into account the most recent science. See section 14 for further discussion of the pathways and budgets associated with well below 2°C and 1.5°C.

2.2 Current Global Action is not in-line with the Paris Agreement's temperature objectives

In pursuit of Paris Agreement goals, over 190 countries made mitigation pledges to reduce emissions, so called nationally determined contributions (NDCs). The NDCs' collective contribution to the Paris goals has been examined in a number of studies[73]. These clearly show that the achieving the NDCs would leave global emissions in 2030 far above a level consistent with well below 2°C, although they do represent a considerable step forward compared to a baseline without global climate action. The Joint Research Centre, in its annual Global Energy and Climate Outlook[74], found that achieving the targets of the NDCs[75] would still lead to continued global emission increases in the coming decade, with potential global emissions peaking at 51 GtCO2e per year as early as 2025. Before Assuming a continuation of efforts at this level[76] beyond 2030, would see emissions starting to decrease at a global scale but not at all at the scale required to achieve the well below 2°C objective. Projections rather see these efforts as consistent with a temperature rise of around 3°C by the end of the century.

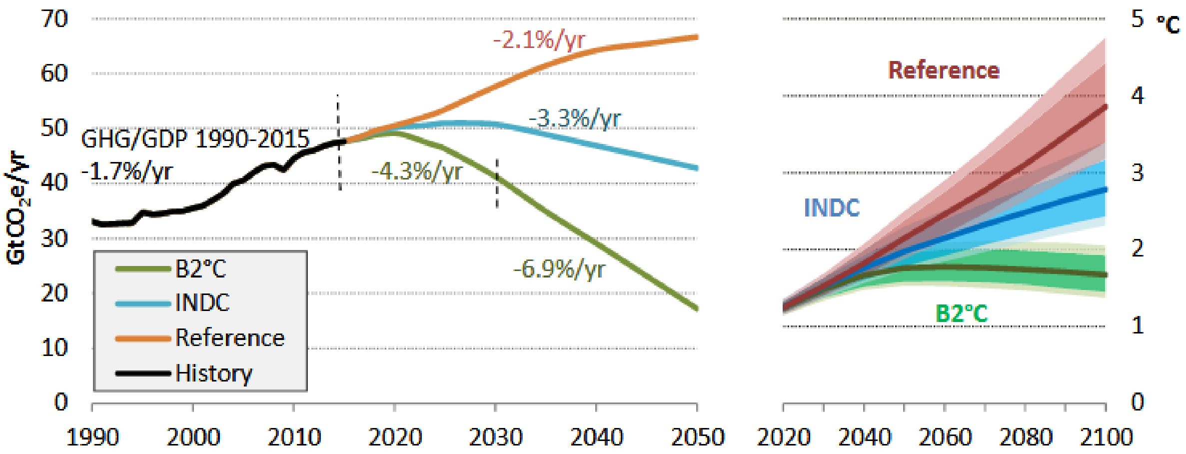


Figure 7: Left: world emissions (GtCO2e) and percent change in emissions intensity per unit of GDP. Right: global average temperature change. Source: POLES-JRC model

[73] See for example *The Emissions Gap Report 2017*, United Nations Environment Programme (UNEP) (2017), and *Aggregate effect of the intended nationally determined contributions: an update. Synthesis report by the secretariat,* United Nations Framework Convention on Climate Change (UNFCCC), 2016.
[74] http://publications.jrc.ec.europa.eu/repository/bitstream/JRC107944/kjna28798enn(1).pdf
[75] Both conditional and unconditional NDCs - and including achievement of the US NDC.
[76] Continuing the same level of effort assumes global GHG intensity of GDP continues to decline at the 2020-2030 rate

According to the UNEP Gap report 2017, most G20 countries require new policies and actions to achieve their NDC pledges. The EU has for instance recently adopted a set of policies that will allow it to achieve its NDC to reduce emissions by at least 40% GHG by 2030 compared to 1990. Recent data by the International Energy Agency[77] and Global Carbon Project's Global Carbon Atlas[78] furthermore show that, contrary to expectations, global CO2 emissions from energy and industry rose in 2017 after three years of flat emissions. Energy CO2 alone increased by +1.4% (460 million tonnes (Mt)) and reached a historic high of 32.5 GtCO2, while the total from energy and industry rose by +2%. This growth came after three years of flat emissions and contrasts with the sharp reduction needed to meet the goals of the Paris Agreement on climate change.

2.3 EU contribution to the Paris Agreement's temperature objectives

Section 2.1 discussed the global emission reduction pathways in-line with a well below 2°C and 1.5°C temperature objectives. The EU must reduce its own emissions to a level compatible with these goals, continuing to act as a leader by demonstrating how the transition to a sustainable, prosperous low carbon and resilient society can be achieved. The EU already has a strong record of considering the global picture when setting its own climate action targets. Our current target is to reduce domestic emissions of greenhouse gases to at least 40% below 1990 levels by 2030[79]. The EU policies that have been adopted to achieve this GHG target may lead us to outperform 40% GHG reductions (see section xxx).

Our objective for 2050 is to reduce emissions by 80-95% in the context of necessary reductions, according to the IPCC, by developed countries as a group[80]. It is now time to revisit the EU's contribution to global action, following the entry into Force of the Paris Agreement, the adoption of legislation to achieve the 2030 Framework (see Section 1.2) and the appearance of new scientific evidence, as synthesised in IPCC Special Report on 1.5°C. The 2050 Low Carbon Economy Roadmap[81] demonstrated that it is feasible and affordable for the EU to reduce domestic emissions by 80% by 2050 compared to 1990, with a milestone of -40% by 2030.

More recently, many studies have examined cost effective global pathways to well below 2°C and report results at global level. A much smaller number of studies reports results at regional level for different world regions that include a geographical scope similar to the EU. These tend to confirm that reducing EU domestic greenhouse gas emissions by at least 80% below 1990 levels would still be consistent with a global pathway for keeping warming well below 2°C. For

[77] International Energy Agency, Global Energy and CO2 Status Report 2017, p.3 http://www.iea.org/publications/freepublications/publication/GECO2017.pdf
[78] Global Carbon Budget 2017, Global Carbon Project, http://www.globalcarbonproject.org/carbonbudget/
[79] Climate and Energy Framework
[80] European Council conclusions, 29-30 October, 2009. The objective is based on the findings of the IPCC Fourth Assessment Report, which represented the best available science at the time of its adoption.
[81] Communication from the Commission, *A Roadmap for moving to a Competitive Low Carbon Economy in 2050*. COM(2011) 112 final

instance the Horizon 2020 projects LIMITS[82] and AMPERE[83] examined different below 2°C scenarios, comparing multiple models operated by different teams around the world. Their results are summarised in a 2018 report by the Netherlands Environment Assessment Agency, which selects only the well below 2°C scenarios where global cost-optimal mitigation begins in 2020 or later[84]. For the EU, the average reduction was found to be 74% below 2010 levels which is around 78% below 1990 levels. EU pathways for both well below 2°C have also been conducted by the Joint Research Centre (JRC)[85].

The JRC projects for a 2°C scenario that achieves globally 50% GHG reduction by 2050 compared to 1990, an EU reduction of around EU of 80% by 2050 while gradually moving by 2030 towards a global cost efficient mitigation scenario[86].

To achieve a 1.5°C pathway, global projections typically foresee the world reaching net zero emissions well before 2100, rather just before 2070 (see section2.1), including the use of net negative emissions both to compensate for remaining emissions from sectors that are hardest to decarbonise as well as to remove CO2 actively from the atmosphere after 2070. Analysis conducted by the JRC and Netherlands Environmental Assessment Agency for this report **Error! Reference source not found.** [87] projected similar global projections. These projections saw the EU reduce emissions by 2050 with 91% below 1990 levels and achieve net zero GHG emissions by 2070.

The main options for achieving net negative emissions typically involve the land sector, through some combination of reducing deforestation drastically, enhancing the forest sink by applying afforestation, and using biomass & CCS (BECCS) as an energy technology and provider of negative emissions. Regions with a large LULUCF sink, high biomass potential and/or high CCS potential are therefore typically assumed to achieve zero emissions first in cost-optimal modelling assessments. This means that the EU is typically not the first large emitter to achieve net zero emissions[88].

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[82] Kriegler et al., 2014, Making or breaking climate targets: The AMPERE study on staged accession scenarios for climate policy. Technological Forecasting and Social Change 90, 24–44.
[83] Riahi et al., 2015, Locked into Copenhagen pledges - Implications of short-term emission targets for the cost and feasibility of long-term climate goals. Technological Forecasting and Social Change 90, 8–23
[84] Xxx link PBL report. In this case, well below 2°C refers to scenarios associated with atmospheric greenhouse gas concentrations of around 450 parts per million CO2 equivalent. Scenario's that saw global peaking in 2010 were not retained, given that global emissions profiles of these projections were too higher with actual emissions.
[85] XXX link JRC/PBL joint report OR GECO_2018
[86] This is achieved by scaling the carbon price on the basis of GDP per capita. All countries are assumed to implement a carbon price from 2020, but the price for developing and emerging economies is lower. By 2030, advanced and emerging economies are assumed to implement the same carbon price, with a 'discount' maintained only least developed countries and India. By 2050 the carbon price is assumed to be global. [xxx include reference to GECO and confirm the differentiation setup]
[87] Xxx include reference
[88] Xxx link PBL report

These 1.5°C pathway scenarios rely on achieving net negative GHG emissions on a global scale after 2070. Projections that try to avoid the need for this net negative emission pathways towards the end of the century, achieve reductions on a global scale close to net zero GHG by 2050. Projections made by PBL and JRC[89] that try to reduce the need for these net negative emission pathways after 2070 confirm this and project for the EU the achievement of net zero GHG towards 2050.

The recent IPCC 1.5°C report has increased the estimate of remaining emission budget, which is not yet fully incorporated in these studies (see also Section 14). If these would be incorporated in the modelling projections the timing of net zero global GHG emissions may be delayed a bit, or reversely the need for negative emissions may reduce. But this will require additional scientific research over the years to come. What is clear is that by reducing GHG emissions as fast as possible, the need for negative emissions will reduce.

Wider considerations on the EU contribution

Many stakeholders have warned against the overly reliance on negative emission technologies. Many have underlined the need for the EU to achieve zero GHG emissions by 2050.

Scientific assessments, including those of the IPCC, have also reiterated several times that delaying action increases the likelihood of missing temperature goals, increases reliance on rapid emission reductions afterwards and increased the need for negative emissions, and is ultimately more costly than acting sooner.

There are therefore good reasons why the EU act in-line with the more prudent projections that try to limit net negative global GHG emissions in the 2nd half of the century.

This may be for a number of reasons, including as a precautionary measure, a demonstration of leadership and thus taking into account an equity perspective, a smart economic decision to develop new technologies and avoid lock-in to the status quo.

From a precautionary standpoint, there is a strong argument for the whole world to reduce emissions more quickly than the median scientific estimates suggest is necessary, and for the EU to take the lead in encouraging this.

Human-induced warming reached 1°C in 2017, and the best estimates of the remaining emissions compatible with 1.5°C are still subject to significant variation. Even though the recent IPCC 1.5°C report has increased the estimate of remaining emission budget, large uncertainties remain, including upwards ones such as earth-system feedbacks like the impact of permafrost thawing and uncertainties of the warming related to Non-CO2 emissions (see Section 14). Applying the precautionary principle it is better to show ambition early on if it would turn out that budgets are reviewed downward again.

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[89] Xxx include reference

From an economic perspective, acting early represents an opportunity for change and innovation. A net zero GHG world requires scale-up of a number of innovations in energy, transport and industry, but can also be accelerated by breakthroughs in General Purpose Technologies such as Information & Communications Technology, artificial intelligence and biotechnology[90]. While disruptive innovations are often difficult to predict and involve complex mix of socioeconomic interactions[91], the role of governments and policymakers in innovation is not trivial[92]. Looking at high ambition can therefore be a crucial part of creating this enabling environment. On the other hand, delayed action can increase the risks of lock-in to carbon intensive infrastructure, particularly if it means large capital-intensive investments are made in the meantime[93]. Planning for a zero GHG world will provide information on the related risks of carbon lock-in.

Finally, a number of studies[94] have attempted to measure different regions' contribution to global action using a number of potential metrics including purely equity based principles, which may have nothing to do with economic achievability of mitigation efforts.

Höhne et al (2018) distinguish for instance between approaches based on *technical necessity* (including cost optimisation and use of indicators such as emissions per capita, or per unit of GDP), and approaches based on *moral obligation* (such as measures that takes countries' income levels or historical emissions into account). Depending on which approach used, widely different objectives may be defined for the EU.

On emissions intensity metrics, the EU is already a strong performer. The EU has the lowest GHG emissions per unit of GDP of all major world economies[95] and is among the lowest in terms of GDP per capita.

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[90] OECD (2017). The Next Production Revolution: a report for the G20. http://www.oecd.org/governance/the-next-production-revolution-9789264271036-en.htm

[91] Geels et al (2017). Sociotechnical transitions for deep decarbonisation. *Science.* Vol. 357, Issue 6357, pp. 1242-1244. DOI: 10.1126/science.aao3760

[92] Mazzucato & Semieniuk (2017). Public financing of innovation: new questions. *Oxford Review of Economic Policy*. Volume 33, Issue 1, 1 January 2017, Pages 24–48, https://doi.org/10.1093/oxrep/grw036

[93] See for example Seto et al (2016) Carbon Lock-In: Types, Causes, and Policy Implications. *Annual Review of Environment and Resources* Vol. 41:425-452. https://doi.org/10.1146/annurev-environ-110615-085934 and
Luderer *et al* (2018) Residual fossil CO2 emissions in 1.5–2 °C pathways *Nature Climate Change* volume 8, pages626–633. https://doi.org/10.1038/s41558-018-0198-6

[94] Höhne et al (2018) Assessing the ambition of post-2020 climate targets: a comprehensive framework, *Climate Policy*, 18:4, 425-441, DOI: 10.1080/14693062.2017.1294046 ; Robiou du Pont et al (2017) Equitable mitigation to achieve the Paris Agreement goals *Nature Climate Change* **volume 7**, pages 38–43 ; Peters *et al* (2015) Measuring a fair and ambitious climate agreement using cumulative emissions *Environ. Res. Lett.* **10** 105004

[95] Series *GHG per GDP emissions* from EDGAR database v4.3.2. Available at http://edgar.jrc.ec.europa.eu/

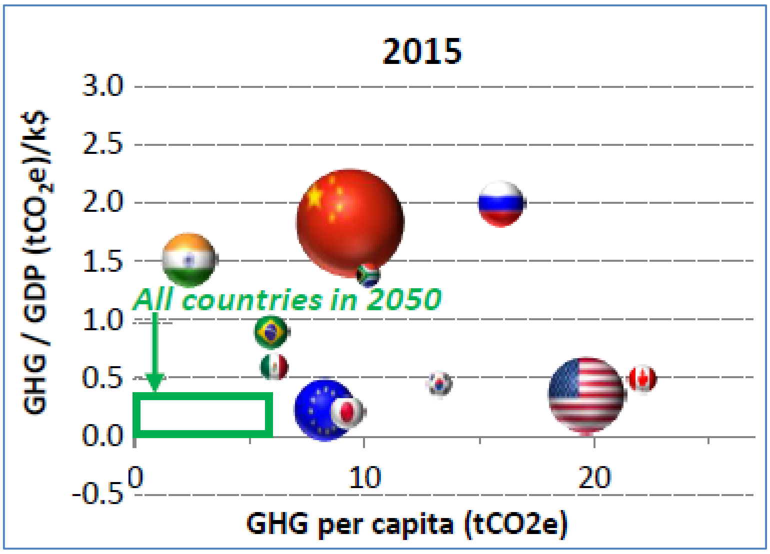

Figure 8:GHG emissions intensity vs GDP per capita for major economies
Source: JRC Global Energy & Climate Outlook (GECO) 2017

Robiou du Pont et al (2017)[96] estimated the necessary 2050 reductions for EU to achieve globally well below 2°, as well as the 1.5 °C. These were on average around -75% for the 2°C and -90% for the 1.5°) objective by 2050 compared to 1990, if the global allocation method was based on convergence towards equal annual emissions per person. The 1.5°C pathway used did allow for negative emissions later on in the century. If it would not allow for negative emissions later in the century, a per capita convergence would see required emission reductions converge towards -100% by 2050. Similarly if the global allocation method was based on the need for higher mitigation for countries with high GDP per capita a 1.5°C objective would typically see EU targets of little less than -100%. Only approaches that were taking into account the level of historical per capita emissions tended to allocate negative reduction targets (higher than 100%) for the EU by 2050, not taking into account the feasibility of such reductions.

In summary, there is a compelling case for the EU to reduce GHG emissions by at least 80%. Doing so is in-line, or even a bit more ambitious than projections that look at cost efficient global emissions reductions achieving the well below 2°C objective. It confirms the existing lower end of the EU target range of -80% to -95% by 2050. For 1.5°C significantly higher reductions are needed. While purely cost efficient projections may see -95% as in-line with the 1.5°C objective, such scenarios would rely heavily on net negative emissions later on in the century to remove actively CO2 emissions from the atmosphere. Such emission pathway clearly poses increased risks. If the aim is to avoid the need for large net negative emissions somewhere in the second half of the century, reductions in the order of magnitude of -100% by 2050 need to be considered. This would be a precaution to avoid to carbon lock-in and reliance on large scale negative emissions. By doing so the EU also confirms its leadership, to inform other countries on the challenges and opportunities ahead and catalyse the global transition in-line with a 1.5°C objective.

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Therefore the assessment presented in this report in support of the development of the EU's Long Term Greenhouse Emissions Reduction Strategy, will look at a range of GHG reductions, starting at -80% going up to -100% by 2050 compared to 1990.

2.4 Europe to lead in a changing world (mega-trends)

Climate change and a range of other "mega-trends" are global phenomena. Measures addressing climate change must necessarily apply across the world, and other global mega-trends will occur on a grand scale around the world. Concerted action by the EU is needed for several reasons. For climate change, it is clear that only the unanimous drive of EU policies and measures have maintained global action and awareness. Europe has clearly led the world in demonstrating how to meaningfully address climate change. For other trends, the industrial and technological challenges will be vast and will need concerted responses. This may be through research and innovation programmes large scale flagship technology projects, or the development of new industrial strategies and market designs. In a world of large trade blocks and large countries - Russia, China, the United States – competing as first movers and technology leaders, small, isolated unconnected countries acting alone will achieve nothing. A relevant example is the European drive to promote renewable energy technologies, which scaled up industrial effort, in the EU and around the world, bring costs down to the benefit of the entire world. A core virtue of EU action is bringing together resources, financing, markets and regulatory regimes to steer coherent policies and measures across a "domestic" setting of 500 million people – at scale, able to deal with the vast global challenges. This applies for all the trends and challenges discussed below.

Even if all emissions from human activities would suddenly stop, climate change would continue. And in a context of accelerating climate action, anthropogenic pollution and greenhouse gas emissions will further increase global warming, ocean acidification, desertification and changing climate patterns. As an example of the expected impacts, an additional 52 million people in 84 developing countries might be affected by coastal storm surges, by 2100[97]. Yields of most important crops in developing countries will decline, potentially exposing millions of people to malnutrition by 2050**Error! Bookmark ot defined.**. (Migration) The significance of migration as a social and political concern has intensified significantly in recent years, in the long term, the consequences of climate change can significantly increase the number of asylum seekers entering the EU.

Global demand for resources and materials has increased ten-fold during the 20th century and is set to double again by 2030, compared to 2010 [cit]. Demand for water, food, energy, land and minerals will continue to rise substantially, given the increasing purchasing power of a growing population. Since 1970, the world is in ecological deficit: humanity currently uses resources at a rate 50% faster than they can be regenerated by nature[98]. This trend is expected to continue in the future and could be further

[97] Bridlife 2015 on the impact of climate change, http://climatechange.birdlife.org/projected-impacts/climate-change-will-have-profound-consequences-for-people/

[98] See resources on Earth Overshoot Day website: https://www.overshootday.org/

aggravated by the consequences of climate change. If left unchecked, scarcity might increase the price of essential commodities with negative effects for vulnerable segments of the population. In Europe, lower income citizens might see their purchase power reduced by price inflation. Globally, scarcity might impair the efforts to provide everyone with food, clean water and energy. By reducing its resource footprint through early adaptation measures, Europe can mitigate the impact of resource scarcity. [Contribution by GROW and ENV on circular economy and scarcity]

Migration and climate change will happen in a context of changing demographic patterns. By 2030, the world's population is estimated to reach 8.5 billion, mostly getting older and more urban than today. By 2030, urban population share is expected to reach 60% and by 2050, the world's urban population is expected to nearly double[99]. The energy, transport and infrastructure needs of populations in future mega-cities will be different from those in contemporary European cities.

Change will be uneven across regions, with rapid population growth in many still-developing economies, while stalled — or even shrinking — in many developed countries. Shifts in demographics may affect business models, pension costs, social programs and the composition of the labour market.

The rise of the global middle class will lift millions of destitute people in developing countries out of poverty. Increasing demand for goods and services, the expanding middle-class could be a driver for global economic development However, changes in consumer behaviour and consumption patterns are expected to increase demand for food, water and energy by approximately 35%, 40% and 50% respectively by 2030 [cit]. Unless consumption patterns of the emerging middle class in developing countries change, they might cause bottlenecks in food and energy as well as increasing environmental degradation. Energy and resource efficiency will help mitigating the impact of rising consumer prices on European citizens. Early adoption of circular economy concepts will allow European industry to pioneer new business concept and products. Furthermore, the rise of a global educated middle class will have an impact on the distribution of jobs by skill level. This will affect employments and training needs in the European Union.

Developing economies and emerging markets are expected to continue growing relatively fast, given their increasing labour force and expanding markets potential, versus the advanced economies, which are mostly replacement markets. By 2030, over 70% of China's population could be middle class**Error! Bookmark not defined.**, onsuming nearly $10 trillion in goods and services and India could be the world's largest middle class consumer market, surpassing both China and the US.

The future of Europe will be significantly impacted by some global trends that are emerging today. Some of these trends, such as digitalisation and hyper-connectivity of products and processes, will transform the energy system and the way energy companies operate. Others trends, such as growing global consumerism and

[99] United Nations 2017, New Urban Agenda, http://habitat3.org/wp-content/uploads/NUA-English.pdf.

demographic imbalances, will have an indirect affect the energy system, but will still have a significant impact on Europe's decarbonisation strategy and on the wider economy. Digitalisation and communication technologies will enable integrating higher shares of decentralised generation in the energy mix. By 2030 at least 32% of final energy consumption and approximately 55% [check] of electricity will come from renewables, a big share of which will be connected to the distribution grid. Furthermore, electricity will be increasingly used in new sectors like transport, heating and cooling. This will changes the way electricity networks operate. Grids should be ready to connect new distributed energy resources (e.g. distributed generation, storage, and demand response), and be actively operated. Several business models are already emerging to deploy distributed demand response on a large scale. Electricity demand is normally highly inelastic on the timescales required to guarantee balancing of the power network. This will however change with large-scale deployment of smart meters and smart appliances able to respond to price signals from the electricity market. Large volumes of distributed demand response have the potential to reduce the cost of balancing the power network and integrating variable renewables.

The digitization of economic activities is perceived as an irreversible and accelerating process. It will transform the way of running business, but also create new business models that were unthinkable only a few years ago. The fact that the largest taxi company in the world does not own any vehicle or that the largest accommodation company in the world does not have any hotel are a clear illustration of such a tremendous development.

The interaction and cooperation between the energy and ICT sectors can increase the cost-efficiency of energy systems and create new benefits for consumers and new opportunities for European companies (see box below).

Impact of digitalisation on the electricity sector

- Tractebel (Dec. 2017), the estimated cumulative investments in EU during the period 2016 – 2020 is in the order of 50b€ (base-line scenario); this cumulative investment will generate a positive macro-economic impact in the sector, including the creation of additional 280. 000 jobs by 2020.
- McKinsey (2017), digitalisation can boost utilities profitability by 23%; the main impact of digitalisation is on the retail area by almost 9% (of the 23%) through the creation of new (individual) products and a better price-customer segmentation; followed by 6% on generation, through the optimisation of plant maintenance and fuel consumption.
- At global level, (Accenture, 2016), based on the ongoing investments in digitalisation of the electricity industry, it could reach €1,3 trillion worldwide from 2016 to 2025, from which 32% is expected to accrue from integrated customer services initiatives. In the same period, the value creation for society could globally overtake €2 trillion

Decarbonisation led by strategic vision can strengthen EU's leadership in low-carbon and energy-efficient technologies. Careful and flexible planning could reduce the cost of the energy transition as well as avoiding costs due to stranded assets. But transformation will not be limited to the energy system.

(By 2030, the global consumer class is expected to reach 5 billion people. This means 2 billion more people with increased purchasing power than today100. Most of this growth will occur in Asia: by 2030, China and India together will represent 66% of the global middle-class population and 59% of middle-class consumption**Error! Bookmark ot defined.**. The share of the European and American middle classes will decrease from 50% to just 22% of world's total101.

Other megatrends include diversifying economic inequality, the emergence of new governing systems and shifting health challenges.

These trends are largely independent from developments and policies in Europe.
Forward-looking decarbonisation, innovation and industrial strategies will reduce the costs of adaptation and allow reaping the benefits of new opportunities.

- **Studies**:

- Benchmarking smart metering deployment in the EU-28 (ongoing);
- Study on data format and procedures (ongoing);
- Other deliverables of Deliverables of the Smart Grids Task Force Expert Group 1, working group on data format and procedures[102];
- ASSET study (under HORIZON 2020) on format and procedures for data access and exchange: to appear under http://www.asset-ec.eu/.
- Smart Grid Lighthouse Projects, http://ec.europa.eu/docsroom/documents/27965
- Study on Barriers and Opportunities for Deployment of Smart Grids, http://ec.europa.eu/docsroom/documents/27964
- CEER report: "Smart Technology Development", 2018
- Eurelectic report: Blockchain in Electricity – A Call for Policy and Regulatory Foresight
- IEA report: Digitalization and Energy, 2017
- CEER report: "*CEER Advice on Customer Data Management for Better Retail Market Functioning Electricity and Gas*", 2015
- CEER report : "*Review of Current and Future Data Management Models*", 2016

[100] Brookings 2011 "The Emerging Middle Class in Developing Countries", http://siteresources.worldbank.org/EXTABCDE/Resources/7455676-1292528456380/7626791-1303141641402/7878676-1306699356046/Parallel-Sesssion-6-Homi-Kharas.pdf
[101] Brookings 2010 "The New Global Middle Class: A Cross-Over from West to East", http://asiapacifico.utadeo.edu.co/wp-content/uploads/2012/05/03_china_middle_class_kharas.pdf
[102] https://ec.europa.eu/energy/sites/ener/files/documents/tor_eg1_wg_on_data_format_procedures.pdf

3 OBJECTIVES: WHAT IS TO BE ACHIEVED?

3.1 Vision

This strategy will present a vision of the economic, technological and social transformations needed for the EU to meet its Paris climate objectives. It will explore the challenges and opportunities associated with delivering this transformation while generating jobs and growth and improving European competitiveness, climate resilience and living standards for all Europeans.

3.2 Specific objectives / Strategic dimensions

The Strategy will present the issues around delivering decarbonisation, carbon neutrality and other energy policy objectives. This involves specifying the range of different technological, commercial, economic, structural and social changes needed. The most relevant elements will be reflected in quantitative analysis and multiple scenarios. The implications across the economy will then be explored drawing on the results of the scenario analysis and other relevant literature.

Most sectors of the European economy will be affected, but the Strategy will explore the particular implications for the energy system (especially power and gas), housing stock, freight and passenger transport and mobility, industrial production as well as the provision of services, waste, agriculture, land-use and the use of natural resources.

The Strategy will also highlight the opportunities for economic growth, improved trade performance and job creation in new industries. The scope for the activation of consumers and behavioural change will be explored, and the implications regarding the security and adequacy of energy supplies and raw materials, other security issues and investment financing issues will be explored.

3.3 Guiding principles for the transitions required by the Long-Term Strategy

The multifaceted and complex nature of the transitions needed under this long term strategy mean that there are an almost infinite number of pathways to reach the objectives. Thus, principles guiding the strategic choices to be made are required. In line with the Commission's political priorities, the first such guiding principle for the low-carbon transition should be to follow pathways that are cost effective and that maximise the boost for growth, jobs and investment. Transforming the EU's economy into a low-carbon economy can make positive contribution to GDP and employment, stimulating new industries, processes, services and products. The low-carbon transition will require important changes in industrial production, and there will be a need to reinforce the EU's high-performing industrial base and to maintain its global leadership in strategic sectors with high-value jobs. This should involve reinforcing its global leadership in low- and zero-carbon technologies.

In view of the large investment challenge, EU measures under the transition will need to facilitate access to finance for the investments needed. The investment necessary and the financing for the transition should be mobilised mainly by private sources, with public support intervening where appropriate. Market-based incentives should be used to minimise loss of real utility and avoid stranded assets.

Having in mind the citizen's perspective, the strategic choices should also be guided by the need to improve the quality of life in the EU, maintaining living standards as those amongst the highest in the world. To this end, increasing consumer's choice and participation in the energy market are beneficial, while structural changes in employment due to the shift away from carbon-intensive activities should be adequately addressed ensuring socially fair transition. Collateral societal benefits (such as health) should also be reaped.

In addition to aiding certain sectors and regions in transition, attention is also needed to ensure competitive and affordable energy prices for EU industries and consumers as well as by improvements in security of supply.

The transition should be achieved while ensuring sustainable use and management of land and natural resources and enhance. The role of land use for balancing in removing emissions should be enhanced.

4 WHAT ARE THE OPTIONS TO BE CONSIDERED FOR EU?

4.1 Current decarbonisation trajectory

So far the illustration of the current EU decarbonisation trajectory has been the EU **Reference scenario 2016 (REF2016)**[103]. REF2016, elaborated with model PRIMES projected EU and Member States energy, transport and GHG emission-related developments up to 2050 taking into account global and EU market trends and the energy and climate policies already adopted by the EU and its Member States (with cut-off date of end of 2014). REF2016 projected achievement of binding 2020 targets but it did not achieve neither the 2030 targets as proposed by the Commission (40/27/30) or agreed in 2018 (45/32/32.5). It also did not achieve the decarbonisation objective in 2050. REF2016 was the benchmark (i.e. baseline) in the analysis underpinning the 2030 climate and energy targets and major Energy Union proposals (alongside so-called "EUCO scenarios" that built upon REF2016 but achieved 2030 targets and 2050 decarbonisation objective).

For the purpose of the EU Long Term Strategy, a new baseline was developed (hence forth "Baseline") - also with the model PRIMES[104]. It largely builds on the REF2016 but also presents an update on a number of key elements. The Baseline keeps the macro-economic projections, fossil fuels price developments and current MS policies as implemented in REF2016. On the other hand, it **incorporates an update of technology assumptions** as conducted under the ASSET project[105], **incorporates several major recently agreed pieces legislation as well as recent Commission proposals**:

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[103] The "EU Reference Scenario 2016 – Energy, transport and GHG emissions - Trends to 2050" publication report describes in detail the analytical approach followed, the assumptions taken and the detailed results, see: https://ec.europa.eu/energy/sites/ener/files/documents/ref2016_report_final-web.pdf

[104] Before the start of the work on the scenarios for the LTS, several improvements were performed on the PRIMES model:

- the extension of the time horizon to 2070
- improvements to the representation of car emissions
- improved representation of the buildings sector
- complete incorporation of (long term) market failures
- better connection of PRIMES with agricultural and biomass models
- represenation of technologies permitting storage, synthetic fuels and CCS/CCU

[105] Modelling scenarios for development of the energy system is highly dependent on the assumptions on the development of technologies - both in terms of performance and costs. While these assumptions have been traditionally developed by the modelling consultants, based on a broad and rigorous literature review, the Commission is increasingly seeking a review of these technologies by stakeholders to make them even more robust and representative of the current projects as well as experts' and stakeholders' expectations. This is why a dedicated project was launched by the Commission in early 2018 to ensure robustness and representativeness of the technology assumptions in model PRIMES by reaching out to relevant experts, industry representatives and stakeholders, who are in possession of the most recent data in the different sectors. The project run was concluded in July 2018 and its final report (including the finalised technology assumptions) is

- Regulations on CO2 from LDV[106] and HDV[107].
- ETS Directive[108] reflecting revision for Phase 4.
- Recast of Renewable Energy Directive[109] (notably the 2030 target of 32%, H&C RES obligation, mandatory national renewable fuels and advanced biofuels mandates (14%, 3.5% respectively) and a cap for food-based bio-fuels.
- Revision of Energy Efficiency Directive[110] (notably the 2030 target of 32.5% and continuation of Art 7 of EED in 2020-2030.
- Several transport-related measures such as the revision of the Eurovignette Directive[111], Clean Vehicles Directive[112], Combined Transport Directive[113] and the Regulation on electronic freight transport information[114].

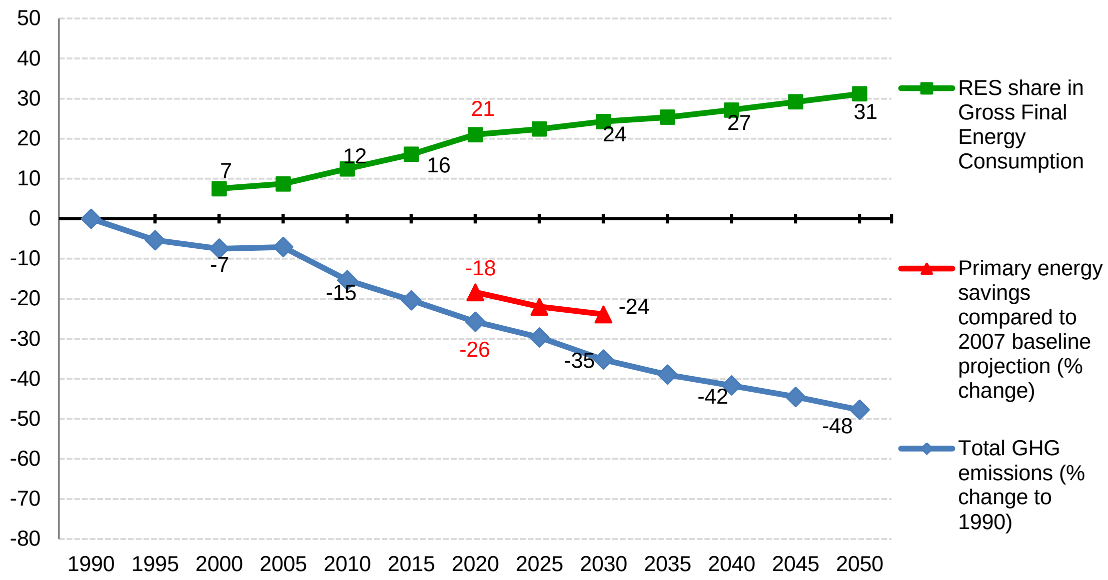
Most importantly, the Baseline also **projects the achievement of 2030 targets** as agreed in June 2018 (45/32/32.5). With this respect it is similar to EUCO scenarios in a sense that **2030 targets are achieved cost-effectively** by contributions of all MS taking into account the starting point created by the current policies. On the EU level and in 2030, the Baseline has very similar results to EUCO 32/32.5 with bigger differences on the national level explained by revised technology assumptions and revisions in PRIMES modelling suite

Finally, the Baseline **does not assume achievement of the decarbonisation objective in 2050**. In practice, it still achieves quite significant: -60% GHG emissions reduction.

Put an update of this REF 2016 graph:

available here: https://ec.europa.eu/energy/en/studies/review-technology-assumptions-decarbonisation-scenarios

106 Ref
107 Ref
108 Ref
109 Ref
110 Ref
111 COM(2017) 0275 final
112 COM(2017) 0653 final
113 COM(2017) 0648 final
114 COM(2018) 279 final

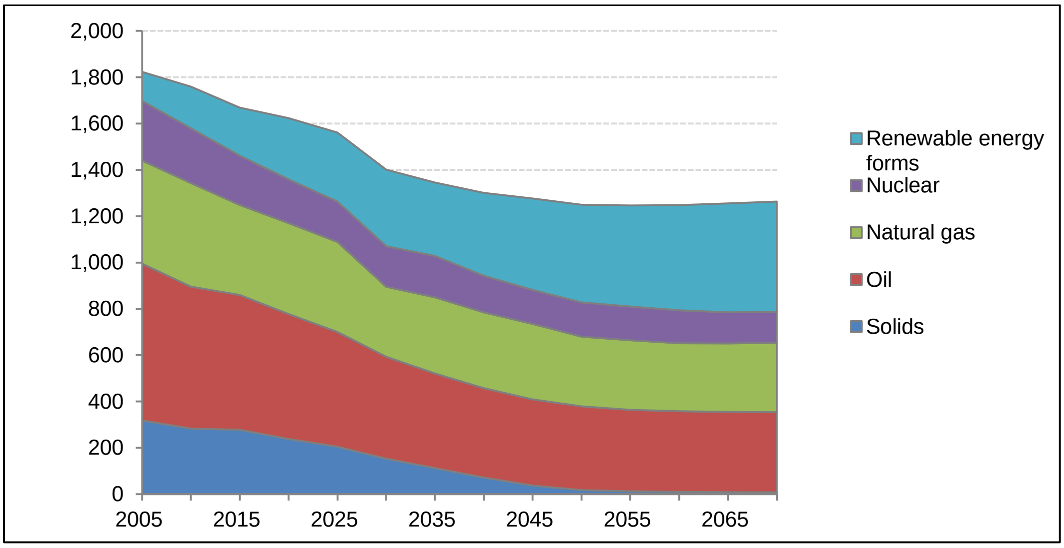


While the Baseline results are often described as a point of comparison for the decarbonisation scenarios (see Chapter 5), this chapter summarises the main results of the Baseline on its own, often comparing with REF2016 as the scenario set-up was fairly similar and yet the differences between the results are significant due to changes described above:

- Similar to REF2016, the **EU energy production is projected to continue to decrease** from some 760 Mtoe in 2015 to some 640 Mtoe in 2050 and 670 Mtoe in 2070. While the overall production volumes are very similar to REF2016, the **fossil fuels production declines faster** (due to higher decarbonisation ambition) and **renewable fuels production is higher** - pulled by the 2030 target and lower technology costs. In the Baseline, the nuclear energy production decreases compared to REF2016 as power generation responds to higher ETS prices mosty by renewables-based generation. While in the REF2016 biomass and waste had the largest share in the fuel mix of EU domestic renewable production, in the Baseline wind catches up with biomass and waste by 2055 and they remain on par till the end of projection period.
- As in REF2016, **in the Baseline net fuel imports will decrease**: from some 970 Mtoe in 2015 to some 680 Mtoe in 2050-70. This decline in the Baseline happens in a more pronounced manner than in REF2016 - by 2050, **the Baseline has 25% lower net imports than REF2016** because of **reductions in fossil fuels and renewable energy (biomass) imports**. While energy efficiency measures (obviously more ambitious in the Baseline) mostly target gas consumption, it is competitiveness of wind and solar technology which chiefly drive their higher penetration and thus reductions in the demand for biomass. As a result, while in the REF2016, the EU's import dependency slowly increased over the projected period, in the Baseline it even slowly decreases (from 56% in 2015 to 50% in 2070).
- As illustrated already on the case of imports, **energy efficiency plays much more prominent role in the Baseline** compared to REF2016 thanks to ambitious 2030 target and, for some technologies, more optimistic technology outlook (e.g. heat pumps). In case of primary energy consumption (PEC), higher penetration of renewables clearly boosts the energy efficiency performance. Compared to 2005, the Baseline achieves -

25% reduction in 2030 and -34% reduction in 2050, the PEC then stagnates at this level till 2070. Comparing between the two scenarios the overall GIC in the Baseline is reduced by 16% by 2050 compared to REF2016. The figure below illustrates both the overall GIC and energy mix evolution in the Baseline scenario.

Figure X: GIC in EU 28



- The **final energy consumption (FEC) displays similar reductions compared to GIC** between the REF2016 and the Baseline this thanks now uniquely to energy efficiency polices (that is case of heating electrification are also in close synergies with renewables policies). In 2050, the Baseline has the FEC reduced by 18% compared to REF2016. Comparing to 2005, the Baseline achieves in 2030 19% reduction and around 25% in 2050-70.

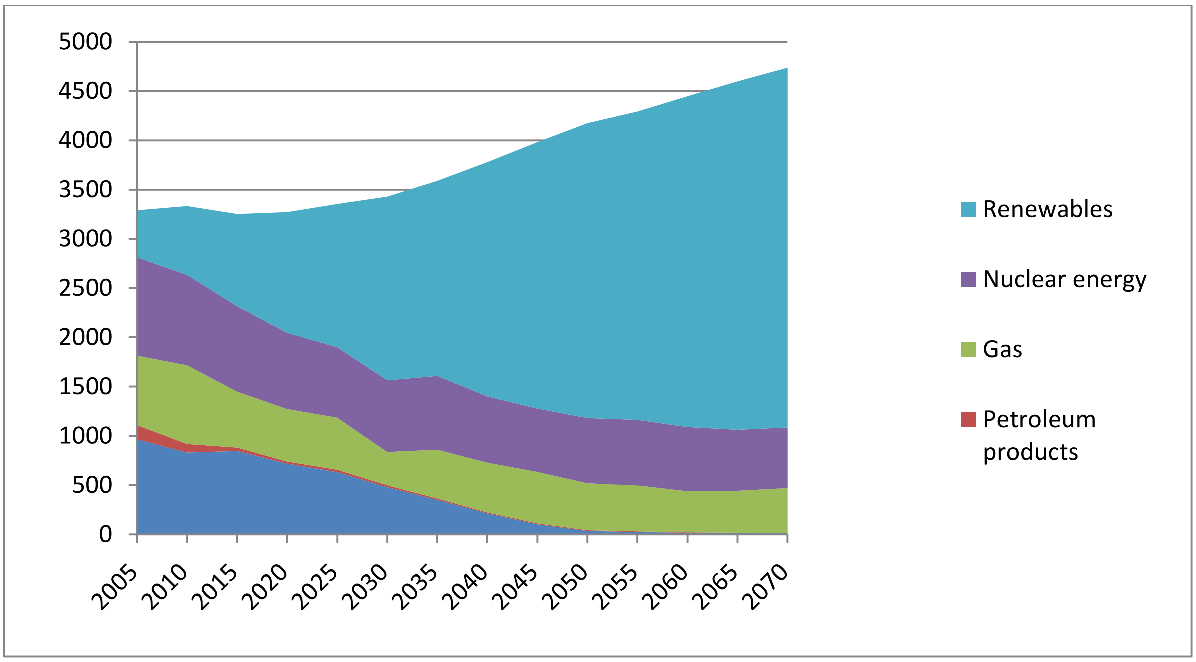
  Comparing between the two scenarios, the **reductions between sectors and fuels are uneven**. Among sectors, it is **residential, tertiary and transport sector which reduce the demand** by over 20% in 2050 (between Baseline and REF) whereas the industrial sector has very similar (even slightly higher in 2050) consumption. Consequently, unlike in REF2016, the share of industry slightly increases in the FEC while it decreases for other sectors. Concerning fuels in the Baseline FEC, the solids and oil are considerably reduced compared to the REF2016 (more than proportionally to overall demand reduction which is a **sign of fuel switch** taking place as a result of higher RES and decarbonisation targets). Gas and distributed heat reductions (targeted mainly by EE measures) are fairly proportional to overall FEC reductions. Despite overall FEC decrease, **electricity consumption increases** slightly till 2050 and then continues to grow very strongly till 2070.

- The overall **electricity generation** is very similar between the Baseline and REF2016, in both scenarios **growing strongly throughout the projection period** and in the Baseline also growing in 2050-70 period. The electricity generation is incrementally lower in the Baseline till 2030 (as energy efficiency 2030 ambition reduces slightly the demand) and higher post 2030 when slightly further electrification of demand is spurred by several more optimistic technology assumptions (e.g. for electric vehicles batteries) and recently implemented policies (e.g. CO2 for LDVs). More noticeably, in the Baseline, **the**

EU power generation mix changes even more considerably (compared to REF2016) in favour of renewables. In 2050, consumption of renewables in power generation grows by 34% compared to REF2016 with an **increase in wind being the most spectacular**). On the other hand, nuclear and all fossil fuels decrease - slightly in case of nuclear (i.e. -10% in 2050) and very significantly in case of fossil fuels (i.e. – 52% in 2050).

- Albeit in smaller quantities than in REF2016, gas maintains its role in the power generation mix. While it reduces its presence sharply till 2030, it shows a rebound effect post-2030 illustrating how increasingly it plays the complementary role to renewables by balancing the system.

Figure X: Power generation mix in EU28



- As in REF2016, **average retail electricity prices**[115] **in the Baseline increase up to 2030** (in both scenarios by about 18% relative to 2010 levels). In the Baseline, the prices then **stabilise around 2035-2055, after which they start to gradually decrease**. In REF2016 this stabilisation was happening slightly earlier and prices started to decrease already as of 2040. **It is the structure of the electricity costs that changes much more significantly between scenarios**. In both of them, the capital cost component (generation and grid costs) increasing significantly in the short term up to 2020, but decreasing afterwards in the longer term – this decrease is, however, much slower in the Baseline scenario. While in the REF2016, from 2030, the fuel cost component remains stable (and that despite the increase in fuel prices, due to a decreasing share of fossil-fuel combustion), **in the Baseline the fuel component visible decreases thanks to even higher participation of renewables**. In both scenarios, but more so in the Baseline, transmission and distribution costs increase significantly in the longer term, post-2030, partly linked to the need to cater for the increased presence of RES in the power generation mix.

[115] In the PRIMES model, prices differ per type of end-user.

- ETS prices – write about it or not? Perhaps at least a defensive why it is identical in 2050 to REF2016 despite PG and decarbonisation so different? As in REF2016, **the carbon price in the Baseline is projected to increase**, reflecting both the steadily decreasing ETS cap and the stabilising effect of the Market Stability Reserve. However, the increase in electricity prices due to ETS remains limited despite the significant increase in CO_2 price, as the share of carbon-intensive power generation decreases. Compared to REF2016, the ETS price is lower in 2030 because of much higher renewables penetration in power generation (34€/t vs 23€/t), it is, however, the same by 2050 because XX.

- (MOVE input) The **activity of the transport sector shows significant growth** by 2070[116], evolving similarly to REF2016 by 2050. The decoupling between energy consumption and activity is projected to continue and intensify relative to the projected trends in REF2016. **Electricity use in transport is expected to increase steadily as a result of further rail electrification and the uptake of alternative powertrains in road transport**[117]. Its share increases to 4% in 2030, 12% in 2050 and 14% in 2070 – at much higher levels than in the REF2016 (2% in 2030 and 4% in 2050), spurred by more optimistic technology assumptions and by the implementation of the Regulations setting emission performance standards for new light duty vehicles (passenger cars and vans) post-2020. The **uptake of hydrogen would be facilitated** by the increased availability of refuelling infrastructure and more optimistic technology assumptions relative to the REF2016, but its use would remain relatively limited in lack of additional policies (over 1% of energy use in 2050 and 2% in 2070)[118]. Liquefied natural gas becomes a significant energy carrier for road freight (over 15% of energy use in 2050 and 2070) and waterborne transport (over 8% post-2050), especially in the medium to long term[119]. Renewable energy in transport would represent about 15% in 2030, increasing to 54% by 2050 (70% by 2070), while the share of advanced biofuels is projected at 5.3% in 2030 going up to 13.7% in 2050 (15.4% in 2070)[120]. **Oil products would still represent about 80% of the EU transport sector needs (including maritime bunker fuels) in 2050 and 78% in 2070; although, significantly lower than in REF2016** (86% in 2050).

- As in REF2016**, investment expenditures for power supply** in the Baseline increase substantially until 2020 driven by RES target and then slow down. Unlike, however, in REF2016, they again **increase sharply in 2026-30 driven by 2030 RES target**. Interestingly, the **additional volume of investments needed** to reach 2030 target **is**

[116] Freight transport activity for inland modes is projected to increase by 76% between 2010 and 2070 (9% for 2050-2070); passenger traffic growth would be slightly lower than for freight at 51% by 2070 (6% for 2050-2070). Road transport would maintain its dominant role for both passenger and freight, although showing a decreasing share over time.

[117] Battery electric and plug-in hybrid electric vehicles are expected to see faster growth beyond 2020, in particular in the segment of light duty vehicles (LDVs). The share of battery electric and plug-in hybrid electric vehicles in the total stock of LDVs would reach about 18% by 2030, 55% by 2050 and 62% by 2070 – much higher levels than in the REF2016 (5% in 2030 and 12% in 2050).

[118] Fuel cells would represent about 3% of the light duty vehicle stock by 2050 and 5% by 2070.

[119] Similarly to REF2016, these developments are driven by the implementation of the Directive on the deployment of alternative fuels infrastructure and the completion of the core and comprehensive TEN-T network, which represent important drivers for the higher penetration of alternative fuels in the transport mix. However, the Regulation setting emission performance standards for new heavy goods vehicles plays an additional role in the higher uptake of liquefied natural gas in heavy goods vehicles relative to REF2016.

[120] The uptake of biofuels is driven by the mandatory national renewable fuels and advanced biofuels mandates, and the cap for food-based biofuels in line with the recast of the Renewable Energy Directive.

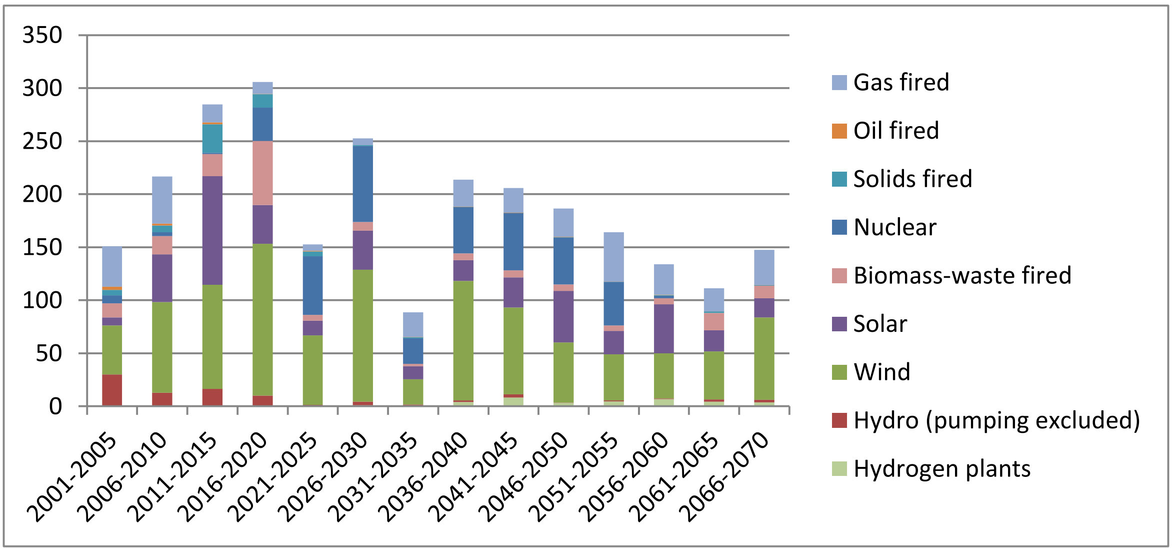
smaller than what was necessary to achieve the 2020 target (considering also that some installations built ahead of 2020 would need to be replaced by new ones/re-powered as they would have reached end of their technical lifetime). Shortly after the effort linked to achievement of 2030 target in the Baseline, the investments volume slumps to grow then again towards 2040 and then, slowly, declines throughout the projection period – while in the REF2016 the investments post-2035 where much higher and continuously growing.

In absolute numbers, the average annual investments in power plants amount to 42 bn in the period 2021-30, they decrease to 36 bn in the period 2031-50 and 28 bn in the period 2051-70. This can be partly explained by the fact that the **Baseline realises bigger renewables investments in the period 2021-30 and thus the power sector is already well prepared for the growing ETS prices** that used to spur investment post-2035 in REF2016. Also the capital costs in the Baseline for wind and solar are assumed to be lower and those technologies constitute the lion's share of investment (in both Baseline and REF2016) (anything else to explain this difference?).

As in REF2016, in the Baseline the nuclear investment mostly takes place via lifetime extensions until 2030 and in the longer term via new built but in absolute numbers the nuclear investments are lower than in REF2016 as renewables play even more dominant role. Finally and also as in REF2016, in the Baseline **new thermal plant investment is mainly taking place in gas-fired plants** but the magnitude of these investments is smaller compared to REF2016. It is only as of 2050 that gas investments start to grow again reflecting even higher need for renewables balancing in the electricity system. A significant part of gas investments are equipped with CCS.

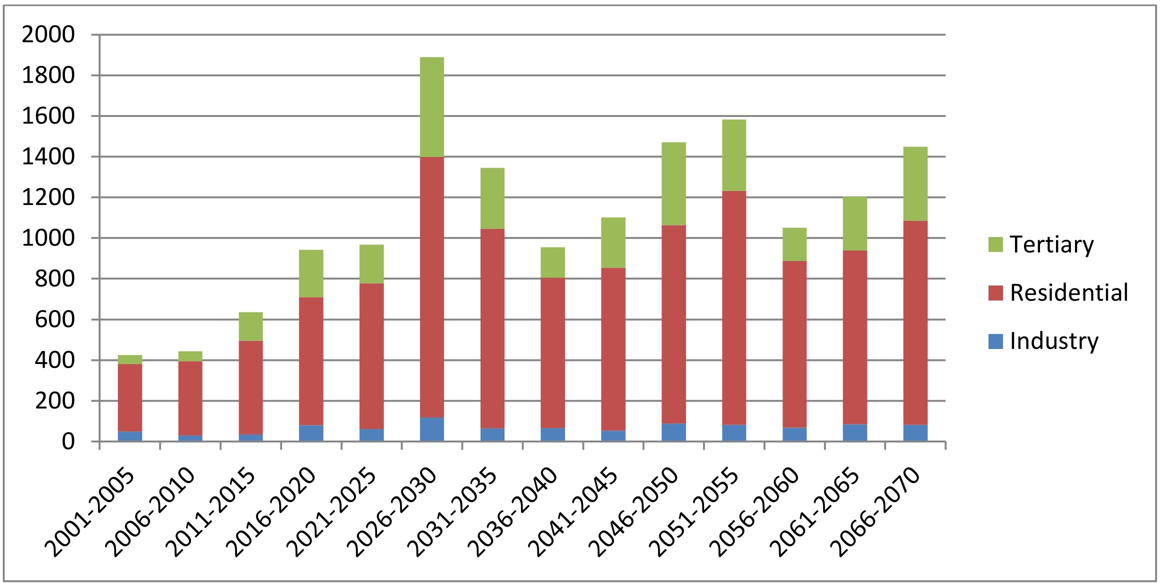
The investments in power plants are accompanied by **investments in power grid**, which are higher post 2030 than in the 2021-30 period reflecting the fact that the **grids have to reach increasingly remote locations of renewable power generation**.

Figure X: Net power capacity investments by plant type (MW – for five year period)



- As in REF2016, in the Baseline **investment expenditures in demand sectors over the projected period will be substantially higher than in the past and already in the Baseline represent a challenge in terms of financing**. In both scenarios, they spike in the short term up to 2020, particularly in the residential and tertiary sectors, as a result of energy efficiency polices. Immediately, post-2020 these investments slightly decline in both scenarios. The major difference is that **while in REF2016 the investments then slightly increased only as of 2035, in the Baseline ambitious 2030 targets make the investment peak in the years up to 2030** and afterwards investments remain at relatively high level, higher than in REF2016. Throughout the projection period, the investments are higher in the Baseline than in REF2016 and by over 120% higher in the period 2026-30. The **biggest differences are in both residential and tertiary sector** which are those mostly targeted by energy efficiency policies but which represenation was also thoroughly revised in the new PRIMES building module and where new costs assumptions were used. Looking at the Baseline on its own, its average annual investments on the demand side amount to 978 bn in the period 2021-30 and then slightly increase in the period 2031-50 to 1.060 bn and finally to 1.131 bn in 2051-70 period.

Figure X: Investment expenditures (5-year period) - demand side, million €'2013 (excluding transport)



- **Decarbonisation of the energy system progresses much more substantially in the Baseline than in REF2016** as 2030 target of 40% is overachieved (45% reductions compared to 1990 are achieved mostly because of ambitious EE and renewables targets for 2030) and further progress is achieved by 2050 (-61%) without, however meeting decarbonisation objective. In the REF2016, GHG emissions were projected to be 35% below by 2030 and 48% by 2050. As in REF2016, **in the Baseline, most of the GHG emissions are energy related** (73% in 2030 and 63% in 2070), **and this part also determines the overall trends**. Non-energy related CO_2 emissions mainly relate to industrial processes, and remain rather stable and non-CO2 emissions that mostly relate to agriculture also remain stable. Land-use related CO_2 emissions are discussed below in the LULUCF section (do you now count them in line 65 of VCLIMA or they come on the top?). Both ETS and ESR targets are over achieved in 2030 (respectively – 47% and -34% GHG emissions reductions are achieved and, as in REF2016, emission reductions in the ETS sectors are larger than those in sectors covered by the ESR throughout the projection period as current legislation implies a continuation of the reduction of the

ETS cap with 2.2 % per year over the projected period leading to a carbon price driving long term emission reduction. In the ESR sectors there are no further drivers beyond market forces (e.g. rising future fossil fuel prices, more competitive renewable sources) and the continued impact of adopted policies such as CO_2 standards for vehicles or energy performance standards for new building to further reduce energy and consequently emissions.

- Non-CO_2 emissions - does CLIMA want to describe them?
- **The system costs are very similar between REF2016 and the Baseline**, overall energy system costs increase up to 2020 but whereas they have been stabilising afterwards in REF2016, they **continue to grow till 2030 in the Baseline and only post-2030 stabilise reaping the benefits of investments already made**. Large investments are undertaken driven by current policies and measures as well as 2020 and 2030 targets but the costs are also driven by projected rising fossil fuel prices (to large extent in the Baseline moderated by energy efficiency policies). The overall system costs are surprisingly similar between REF2016 and the Baseline as, on one hand, **Baseline has higher costs related to 2030 targets but more optimistic technology assumptions and greater benefits due to moderation of demand for fossil fuels –** compared to REF2016**.** Overall energy system costs increase in the Baseline from 12.5% of EU GDP in 2020 to 12.7% of EU GDP by 2030 and drop to below 10% post 2050. In absolute numbers, average annual system costs of the Baseline in 2021-30 period amount to 1.975 bn, they increase to 2.174 bn in 2031-50 and to 2.347 bn in 2051-70.

4.2 Description of available options

4.2.1 Energy supply side: production/imports and networks (ENER: AK; CLIMA: KS)

The energy system is currently responsible for almost 75% of GHG emissions in the EU.

This is due to declining but still significant dependence on **fossil fuels**, which in 2016 met 67% and 72% of the EU's final and primary energy demand respectively. Clean energy transition in line with the Paris objectives requires energy system emissions to radically decrease by 2050. This is particularly important for the power generation which is bound to grow significantly both in the EU and globally in the decades to come[121].

Without breakthrough technologies, decarbonisation leaves fossil fuels with two options: either their emissions are captured by the deployment of **carbon capture and storage or utilisation** (CCS/CCU) technologies, or they are replaced in the energy system by carbon-free energy sources.

CCS

The global power system is seen to grow to 1.7 to 3.2 times its size in 2015 as measured in annually generated energy by the IEA ETP B2DS and Shell Sky scenario respectively.

In fact, even some very ambitious decarbonisation scenarios see natural gas and oil in the energy mix for decades to come, providing between a quarter and a third of primary energy in 2050 [122] [123]. This is due to the role of natural gas as a transition fuel and the use of gas and oil in sectors where alternatives are not yet mature (see section 4.2.2 on transport, or as feedstock in some industrial processes – see section).

Large scale deployment of CCS/CCU technologies would allow these fossil fuels to remain in the energy mix without generating GHG emissions, in particular as fuel for flexible power plants or for large industrial sites [source]. The valorisation of captured CO_2 as raw material for carbon-based products or fuels/feedstock could also contribute to a cost-effective transition in the industrial sector (see also section **Error! Reference source not found.**). Global itigation studies with ambitious decarbonisation goals[124] see up to half of the captured CO2 in the power generation sector, followed by industry sector being responsible for 25%-40% of emissions captured. CCS becomes particularly important for 1.5°C scenarios where negative emissions would be needed[125] (see sections **Error! Reference source not found.** and **Error! Reference source not und.**). Yet the deployment rate of CCS/CCU technology observed so far is slow and insufficient for ambitious climate scenarios[126] due to economic viability and low public acceptance.

Carbon-free energy sources

Three carbon-neutral technologies have been deployed during the 20th century: hydroelectricity[127], nuclear fission and, with a much smaller installed capacity, geothermal energy.

Hydropower is currently responsible for 16% of the global electricity production. Ambitious decarbonisation scenarios estimate a doubling of the installed capacity by 2050 allowing the technology to maintain its share in the global power mix[128]. Its growth potential in Europe is however limited apart from small hydropower. [Reference & numbers on potential]. Also, the long-term reliability

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[122] IEA ETP, B2DS scenario
[123] Shell Sky scenario
[124] E.g. IEA ETP 2DS and IEA ETP B2DS as well as the Shell sky scenario
[125] Negative emissions could be obtained by using bioenergy125 with CCS ("BECCS"): see Luderer et al., Residual fossil CO2 emissions in 1.5–2 °C pathways, *Nature Climate Change, V*olume 8, pages 626–633 (2018), https://doi.org/10.1038/s41558-018-0198-6
[126] IEA ETP, page 74
[127] Ref that large dams can actually release CH4 emissions
[128] IEA ETP 2DS and B2DS

of hydropower as an energy source will depend on the evolution of climate conditions in the different parts of Europe where dams are located[129].

Hydropower can also play a role in energy storage. Pumped-hydropower storage (PHS) could be a key source for flexibility in the future power system[130] though its development depends on how competing options for power system flexibility will develop.

The other established large scale carbon-neutral technology is **nuclear fission** currently responsible for 11% of global electricity generation. Nuclear power plants have traditionally been used as a source of baseload power, because of the high upfront investment costs and relatively low operational costs. With increasing shares of renewable energy, nuclear power plants might more often operate in load following mode[131]. The economics of nuclear energy are also affected by nuclear safety regulations, which evolve over time taking global operating experiences into account [132].

Maintaining nuclear energy requires a strong regulatory expertise as well as solutions for the management of long-lived nuclear waste and a long-term access to nuclear fuel. New technological options are being explored, however with no large scale deployment expected before the mid of the century.

However, due to public acceptance issues related to safety or waste, nuclear energy is not considered a key option in a number of countries and phase out policies have been implemented in several EU Member States. Scenario studies reach different conclusions: the installed nuclear capacity globally could double by 2050 and maintain the current market share[133] or decrease to about 4%[134].]

Geothermal energy represents less than 1% of global electricity output. The technology usually generates baseload electricity but is fully dispatchable. The availability of this energy source entirely depends on geological conditions,

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[129] Comment on climate variability impact, eg Brazil droughts + PESETA study for EU?
[130] eStorage project Deliverable D4.2, Overview of potential locations for new Pumped Storage Plants in EU 15, Switzerland and Norway, http://www.estorage-project.eu/wp-content/uploads/2013/06/eStorage_D4.2-Overview-of-potential-locations-for-new-variable-PSP-in-Europe.pdf

[133] IEA ETP, IEA WEO, Shell sky
[134] IRENA Remap case 2050

which strongly vary around the globe. Estimates of the global potential are above 200 GW [135] [136] , 15 times the current capacity installed yet far below the potentials estimated for wind and solar energy (see below). Potential in the EU?

The generation of electricity from **biomass**, though conceptually established for a long time, has only recently developed significant growth, roughly tripling between 2000 and 2015 and currently generating about 2% of the world's electricity demand. Different technologies are being developed using biomass for conversion in power generation, residential heating, transport or as industrial feedstock.

Biomass fired power stations have the advantage of being fully dispatchable. Studies see the global electricity generation from biomass 4[137] to 10 [138]times as high in 2050 as compared to 2015. In combination with CCS energy from biomass can also produce negative emissions (see section 4.2.7). The use of bioenergy raises questions on the possible trade-offs with other SDG dimensions related to land use, in particular food security or biodiversity, and on air pollution and health (see sections **Error! Reference source not found.** and **Error! ference source not found.**). There are also concerns about the potential in Europe and the sustainability of imports[139].

Solar and wind energy accounted for virtually nothing of the energy system until recently but have shown the highest growth rates of all generation technologies in recent years. In 2017, solar PV and wind accounted for 76% of all new capacity additions in Europe (with only 9% of other renewables added[140]).

Electricity generation from **solar energy** has grown 170 fold between 2000 and 2015, now being responsible for 1% of the world and more than 3% of the EU electricity production. Scenario studies in line with the Paris goals see the global share solar generated electricity to reach one fifth[141] to one third[142] of generated electricity. The potential for solar electricity in the EU is significant[143]. Solar

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[135] World energy Council, world energy resources, geothermal 2016, https://www.worldenergy.org/wp-content/uploads/2017/03/WEResources_Geothermal_2016.pdf
[136] IRENA Remap case 2050
[137] IEA ETP REF scenario
[138] Shell Sky scenario
[139] Climate Paths for Germany, Study for the Association of German Industry,
[140] WindEurope (2018) Wind in power 2017
[141] IEA ETP 2DS scenario
[142] Shell sky scenario
[143] Report on PV and CSP potential in Europe

energy can also contribute to the energy system through low enthalpy heat production for buildings (see section **Error! Reference source not found.**).

The global electricity generation from **wind** in 2015 was 25 times that of 2000, meeting 3% of the worldwide and 9% of the EU's electricity demand. On-shore wind farms were responsible for 95% of the wind electricity. According to decarbonisation scenario studies, the global contribution could reach one fifth[144] to one quarter[145] of the world electricity supply by 2050.

The available potential for wind energy in Europe strongly depends on competing land use and planning restrictions. Yet, even under pessimistic assumptions, on-shore wind farms could meet almost twice the current European electricity demand[146].

[Offshore?]

In addition to these fast growing renewable energy sources, other longer-term carbon-neutral options are being explored. With 71% of the globe surface and regular tides and currents, **oceans** constitute a possible future energy resource. Wave energy, tidal stream, tidal range, ocean thermal conversion or salinity gradient devices could generate important quantities of electricity.

The EU benefits from 68000 km of coastline[147] and the largest Exclusive Economic Zone (20 million km^2) and is thus well positioned to make use of this resource, with an estimated potential of about 100 GW[148]. Ocean energy technologies include: wave energy, tidal stream, tidal range[149], ocean thermal conversion or salinity gradient. Apart from the mature tidal range technology, ocean energy concepts are still in the demonstration phase[150]. Although announced projects sum up to about 1 GW for the early 2020s, gearing up these technologies will require overcoming a number of barriers, in terms of costs decrease but also anticipating potential conflicting uses of sea, seabed and coastal areas with biodiversity conservation policies, tourism, fishing industry, maritime transport activity or military uses.

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[144] IEA ETP sceneario

[145] Shell Sky scenario

[146] Wind potentials for EU and neighbouring countries, JRC report, EUR 29083 E

[147] https://ec.europa.eu/maritimeaffairs/sites/maritimeaffairs/files/docs/body/eu-and-international-ocean-governance_en.pdf

[148] Ocean Energy Forum (2016): Ocean Energy Strategic Roadmap 2016, building ocean energy for Europe. https://webgate.ec.europa.eu/maritimeforum/en/frontpage/1036

[149] Like the La Rance tidal power plant (about 250 MW capacity)

[150] JRC Ocean Energy Status Report 2016 Edition, EUR 28407 EN

Finally, a number of countries have engaged, sometimes collectively, into scientific programmes on **nuclear fusion**. One of these major initiatives is the International Thermonuclear Experimental Reactor (ITER)[151] which is also the European Union's main contribution to fusion research. It will constitute the last step before the construction of a demonstration unit by the mid of the century [152]. As the availability of a commercial nuclear fusion reactor is not forseeable, nuclear fusion is actually not considered in most of the prospective mitigation assessments[153].

Deployment of carbon-free energy sources in power generation would allow further expansion of electricity use offering a high value and versatile energy form without GHG emissions.

*Infrastructure*The anticipated electrification of heating, transport and industry and increasing geographical dispersion of renewable energy generation will require **reinforced and smarter electricity networks**. This will need to happen both between countries to make the best of the renewable resources allocation over the European territory[154], but also within countries in order to accommodate for an increase of decentralised electricity generation. In Germany, citizens and energy cooperatives alone contributed to 42% of the renewable energy installed in 2017[155]. Special attention will have to be paid to transporting electricity produced in a more decentralized way.

However, important segments on both energy production (e.g offshore wind farms which can reach capacities comparable to conventional sources) and the consumption side (e.g. energy intensive industries) are likely to remain centralised and will require high voltage power lines, gas or oil pipelines.

Increased interconnection capacities will be needed if electricity networks are to match renewable energy supply and demand over ever larger geographical distances. High Voltage Direct Current (HVDC), which generates less transport losses, could play an increasing role in the connection of offshore wind farms and help establishing a pan-European electricity 'super-grid' [add references].

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[151] https://www.iter.org/ , gathers the EU, China, India, Japan, South Korea, Russia and the USA

[152] Fusion Electricity A roadmap to the realisation of fusion energy, https://www.euro-fusion.org/fileadmin/user_upload/Archive/wp-content/uploads/2013/01/JG12.356-web.pdf

[153] References on recent mitigation exercices_A noticeable exception is: Cabal et al. (2017), https://doi.org/10.1016/j.esr.2016.11.002

[154] Reference to 3rd PCI list that focuses on interconnection objective of 15% by 2030

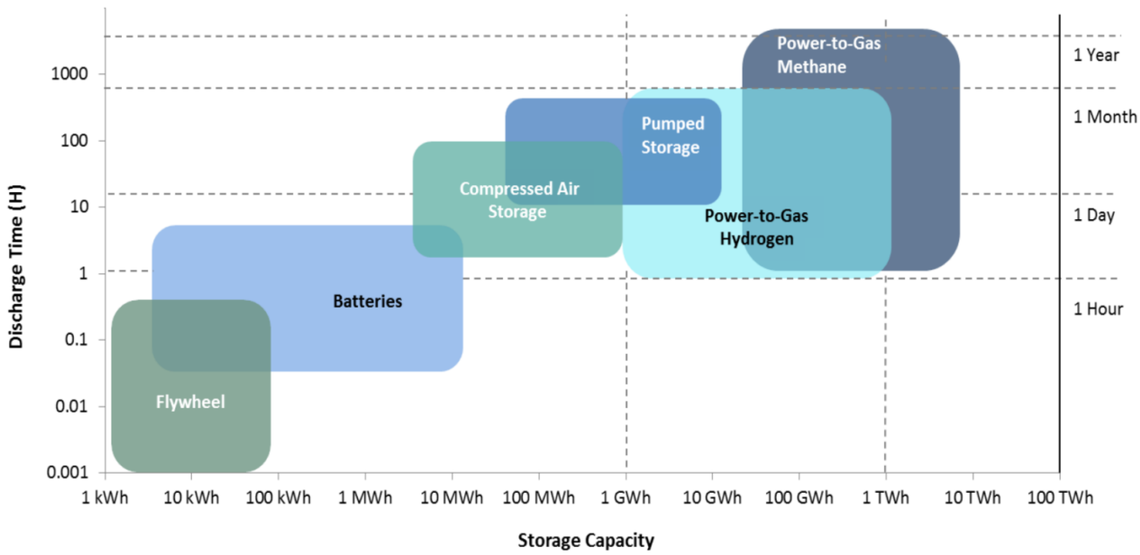
[155] https://www.weforum.org/agenda/2018/04/how-europe-s-energy-citizens-are-leading-the-way-to-100-renewable-power/

Integration into the electricity system of meteorologically driven sources, such as wind and solar energy, requires **flexibility** of the rest of the system. This includes fast reacting generation sources on the supply side, storage or demand response. The ongoing digitalisation of the energy grids can help activating decentralised flexibility resources[156] (see sections **Error! Reference source not ound.**, **Error! Reference source not found.**, **Error! Reference source not found.**).

These challenges are to be anticipated ahead in the capacity planning process, and will require more co-ordinated and complimentary approaches across the entire energy system, in particular towards "sector coupling" with other energy vectors, that will be able to act as storage and flexible resources.

Electricity **storage** solutions are developing fast both in laboratories but also on the market. The global installed storage power capacity in 2017 was about 176 GW, 96% of which was **pumped-storage hydro** (PSH) (IRENA, 2017). [Add Europe figures]. Different technological solutions compete for storing electricity over timeframes between fractions of seconds and seasons (see Figure 9).

Figure 9. Overview of different electricity storage technologies



Source: California Hydrogen Business Council (2015), Power to Gas: The Case for Hydrogen White Paper. Los Angeles, CA, USA, 2015.

The most noticeable recent evolution is the rapid improvements of **batteries**, in **particular of** lithium-ion type, that were originally developed for ICT products (mobile phones and laptop computers) in the late 1990s and have become a key

[156] 3rd PCI list, smart grid projects

option for electrifying transport. Although more than 90% of the production is likely to be used for e-vehicles in 2030 [add source] (see section **Error! eference source not found.**), Li-ion batteries are increasingly penetrating the power sector. Li-ion batteries can be found both behind the meter, storing PV electricity for several hours, as well as in the form of larger centralised units providing frequency control.

Batteries made significant progress in terms of cost reduction, with a drop of 70% from 2007 to 2014[157]. Considering the expected developments of electric mobility (see Section 4.2.2), batteries are likely to keep experiencing cost reduction and performance improvement in the future (another reduction of 70% is forecasted towards 2030[158]).

Fluctuations of electricity production at the level of days, weeks and seasons require technologies that can balance the electricity system beyond short-term daily timeframes. The current power system relies on either storing fossil fuels or seasonal hydropower storage where available. A range of alternatives are being developped, including Power-to-Heat stored in in aquifers[159], Power-to-Ammonia[160] that can be stored and used as a fuel in power plants, Power-to-Hydrogen that can be stored in dedicated reservoirs and retransformed into electricity or used directly as a fuel, or even Power-to-Gas and Power-to-Liquid technologies with much higher usability than hydrogen but at the expense of production process losses.

Storage options are discussed at greater length in the Commission Staff Working Document "Energy storage – the role of electricity" SWD (2017) 61 final[161].

4.2.1.1 New fuels

In addition to electricity, **new fuels** are being considered in energy and industrial applications where it is difficult to replace fossil fuels, in particular because of the chemical and physical properties sought. Hydrogen and its carbon derivatives obtained by reaction with CO_2 possibly recovered from CO_2 emitting activities [References] like e-methane and e-liquids [References + further definition] are considered as possible options for decarbonisation of transport or

[157] Björn Nykvist & Måns Nilsson (2015), Rapidly falling costs of battery packs for electric vehicles, *Nature Climate Change* 5,329–332
[158] *Fuel Cells and Hydrogen Joint Undertaking* (2015) Commercialisation of Energy Storage in Europe
[159] Aquifer thermal energy storage: https://www.sciencedirect.com/science/article/pii/S1876610217359763
[160] http://www.ispt.eu/media/ISPT-P2A-Final-Report.pdf
[161] https://ec.europa.eu/energy/sites/ener/files/documents/swd2017_61_document_travail_service_part1_v6.pdf

industry. These new fuels will themselves rely on important consumption of carbon-free electricity.

Below is the summary of definitions used to describe new forms of gas as well as the schema that illustrates different production pathways, which are consistently used throughout the SWD.

Box X: Types of gas

For the sake of this SWD, the term “gas” is not limited to natural gas, i.e. of fossil origin. Rather, the term “gas” is used for gaseous energy carriers, including

- **Natural gas** (mainly CH_4) from fossil sources; in full decarbonisation by 2050 only relevant with CCS, e.g. natural gas power plant with pre- or post-combustion CCS.

- **(Renewable) synthetic gas** (e-CH_4), synthetic methane produced from H_2 from (renewable) electricity through water electrolysis and CO_2 obtained from organic processes, or captured from air by elevated temperature processes. "e" prefix indicates the use of electricity in the production of synthetic methane.

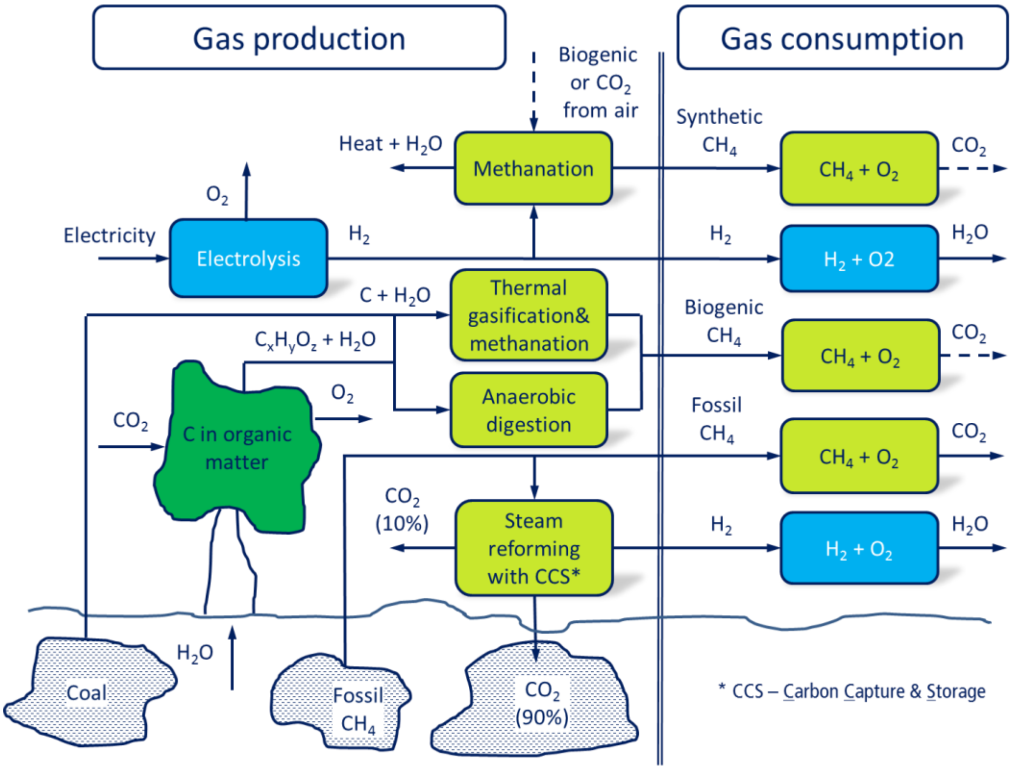
- If H_2 is obtained from steam methane reforming (not relaying on electricity) then we refer simply to synthetic methane, such methane cannot be renewable.

- **Biomethane** (bio-CH_4), i.e. methane from organic matter (purified biogas), produced by anaerobic digestion or thermal gasification.

- **(Renewable) Hydrogen** (H_2): either fossil-based hydrogen in combination with CCS, e.g. from steam methane reforming of natural gas, or produced through water electrolysis from (renewable) electricity.

Source: Gas in 2050 study and other studies

Box X: Schema of different gas production pathways



Hydrogen can take the role of an energy vector beyond its potential role as a chemical storage of electricity. In a transition towards a decarbonised energy system, hydrogen could replace natural gas as an energy fuel per se and as feedstock for industrial applications (e.g. steel industry, refineries, fertilisers - see section **Error! Reference source not found.**). In combination with CO_2, ydrogen could serve as a building block for the production of "e-fuels", both in gaseous and liquid form, to be used as an energy fuel or feedstock.

Hydrogen is already a common input to some industry processes, with a consumption of 43 Mtons in 2010 globally, including 7 Mt in the EU[162]. Chemicals represent 63% of the total in the EU (ammonia alone representing most of it, with 50% of the total), followed by the refinery sector (30%) and metal processing (6%). Currently, it is produced via steam reforming using fossil fuels as input (mostly natural gas).

In a power system largely based on variable renewable sources (wind and solar), hydrogen could be produced by water electrolysis, in particular at times of low demand providing additional flexibility. This carbon-free production route would entail the development of large capacity of electrolysers, viable when operating

[162] CertifHy project, deliverable 1.2 "Market Segmentation" (2015): http://www.certifhy.eu/images/D1_2_Overview_of_the_market_segmentation_Final_22_June_low-res.pdf

at low capacity factors and/or rapidly changing operational conditions which may prove challenging.

There are already 1600 km of hydrogen pipelines in Europe to carry hydrogen across industrial sites[163]. To transport potentially higher volumes of hydrogen towards new consuming centres, it can be blended with natural gas so as to make use of the existing gas transport infrastructure up to 15% by volume[164]. An upgrade of the network would be needed to accommodate for higher levels of hydrogen, even more so for pure hydrogen[165]. A regulatory framework guaranteeing safety will also be necessary for a large deployment of hydrogen transportation and storage facilities to avoid possible accidents likely to affect public acceptance[166].

Hydrogen could also be "upgraded" to synthetic hydrocarbons by reacting, using electricity, with CO_2. The sustainability of such **"e-fuels"** will depend on the source of electricity and the source of CO_2.

Despite high current production cost estimates[167] (close to 2500 €/t for e-methane to well above 3000 €/t for e-petrol, i.e. more than 5 times the fossil fuel alternatives) they could benefit from reduction of electricity price (which represents more than half of the production cost estimate) and further technological improvement. Such fuels could be considered for decarbonisation of sectors where better alternatives do not exist, for instance in aviation.

Finally, an interesting option is the processing of hydrogen to ammonia, which is a versatile product, easier to transport and to store, that could be used in industry or as energy carrier or storage.

As is the case today for oil and natural gas, hydrogen or e-fuels could be imported from regions with comparatively cheaper, abundant renewables[168]. If these fuels were to develop as large contributors to our future energy needs in a

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[163] https://hydrogeneurope.eu/hydrogen-transport-distribution#PIPELINES

[164] See the FP6 EC research project NaturalHy: https://cordis.europa.eu/project/rcn/73964_en.html

[165] See NREL report (2013) "Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues" https://www.energy.gov/sites/prod/files/2014/03/f11/blending_h2_nat_gas_pipeline.pdf

[166] The JRC HIAD database registers hydrogen-related events since 1985: https://odin.jrc.ec.europa.eu/giada/Main.jsp
See also Galassi et al (2012), HIAD – hydrogen incident and accident database, International Journal of Hydrogen Energy, Volume 37, Issue 22, November 2012, Pages 17351-17357 https://doi.org/10.1016/j.ijhydene.2012.06.018

[167] https://www.transportenvironment.org/sites/te/files/publications/2017_11_Cerulogy_study_What_role_electrofuels_final_0.pdf

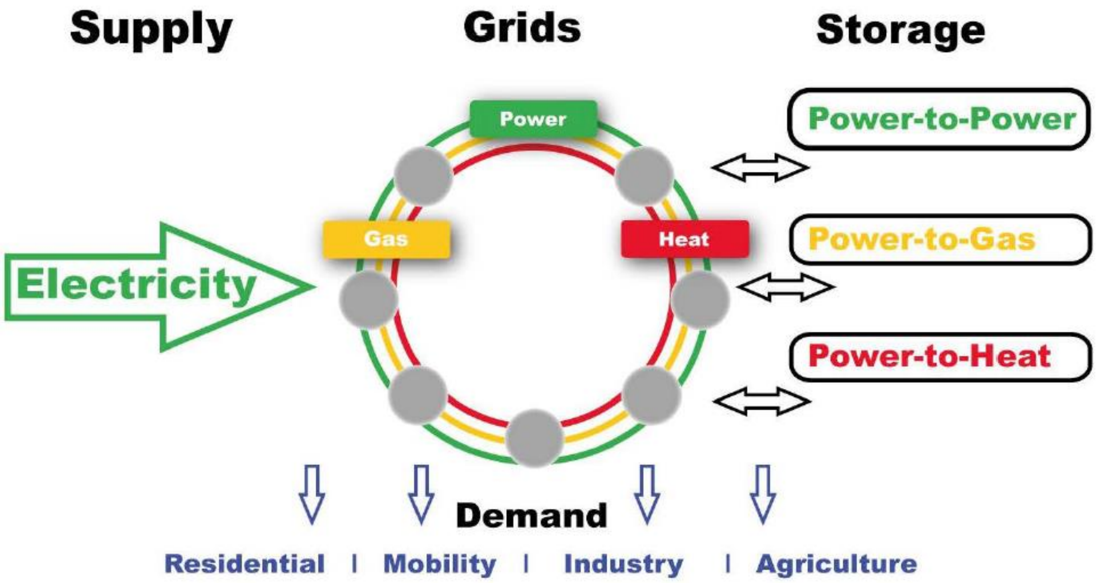
[168] Climate Paths for Germany, Study for the Association of German Industry

decarbonised economy, such option could help reduce the cost of the transition as well as possible pressure on domestic resources (land, sea) linked to large scale use of renewables. However, it would also affect EU's energy security.

Sector coupling

Integration of renewable energy sources can be facilitated by coupling of different energy vectors that have historically been separately managed[169] (see Figure 7). With the availability of e-fuels, flows between the power and the gas grid could become bidirectional. Further flexibility can be provided by lining both power and gas grids to heating networks.

Figure 10. Energy system integration



Source: "Energy storage – the role of electricity". *SWD (2017) 61 final*[170]

Most of today's energy network infrastructures (electricity, gas, heating and cooling, liquid fuels) will still be operational in 2050. There is clearly a rationale of making use, during the transition, of the large existing gas infrastructure that is able to carry and store substantial amounts of energy, including by potentially upgrading it for the use of hydrogen or bio-methane. In the longer run, however, managing simultaneously multiple networks will have to be evaluated against operating a sole extended power grid[171].

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[169] ETIP SNET Vision 2050 – p. 29 (some direct quoting will need rephrasing or more precise referencing)

[170] https://ec.europa.eu/energy/sites/ener/files/documents/swd2017_61_document_travail_service_part1_v6.pdf

[171] http://www.poyry.com/news/articles/fully-decarbonising-europes-energy-system-2050

Role of energy efficiency

Speed and levels of decarbonisation of the energy system will also depend on the future level of energy demand. Energy-efficiency measures across the energy system help achieve higher GHG emissions reductions.

Also, deployment of supply-side emissions abatement options does not depend only on technology developments. Levels of future final energy demand will also influence the composition of the energy mix. With low level of energy demand, it might not be possible for technologies at lower Technology Readiness Levels to reach the scale required to reduce costs. On the other hand, with high level of demand, the technologies available on the market might be required to exceed their maximum economic potential. In this case, costs might increase and it will be necessary to develop technologies that are not yet on the market.

The technical potential of the main low-carbon technologies described in this section (e,g, renewable or nuclear energy) is estimated to be very high; however, the economic potential of each single option is limited compared to task of decarbonising the energy system [ref needed]. The cost effective decarbonisation pathway will consist of combination of several supply-side and demand-side decarbonisation options. As it is not possible to foresee technological development, it is not possible to determine the exact decarbonisation pathway. However, it is possible to explore different decarbonisation scenarios on the basis of the best estimates for costs and potential currently available.

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4.2.2 Transport

For all transport modes, deep long term reductions can be explored through combinations of improvements at 4 levels: (1) low or zero carbon fuels (decarbonised electricity, hydrogen, sustainable biofuels) , (2) vehicle efficiency, (2) systemic efficiency gains (such as modal shift, efficiency of logistics to reduce overall transport demand) as well as (4) behavioural change impacting transport demand

The magnitude, pace and interaction of these options will vary between subsectors (passenger or freight, road, rail, aviation, or shipping) depending on technological and resource potential, costs, infrastructure and institutional factors. The analysis will therefore explore potential pathways for the sector as a whole and the different subsectors.

For *cars, vans*, *and buses,* various technologies can be considered: electrification , hydrogen fuel cells, the use of biofuels, as well as intermediate technologies such as hybrids, plug-in hybrids, range-extender electric vehicles, and more efficient ICE's. In order to reach zero emissions, the vehicle fleet will gradually shift from more efficient internal combustion engines, to using hybrids, plug-in hybrids and finally zero-emission vehicles such as battery electric and fuel cell vehicles. It is important to understand the speed at which such shift need to occur to achieve certain levels of emissions reduction, which in itself will also depend on technology cost developments. The Commission has published in-depth studies in the Staff Working Documents on Low Emissions Mobility[172], for the CO2 and Cars Proposal[173] and its background technical study[174], and the proposal on Low-Emission Vehicles[175].

However, beyond vehicle technology itself, other elements are of importance, including for instance the availability of recharging/refuelling infrastructure, acceptability of new technologies, and the need for a transition in the automotive industry to reskill workers for new technologies.

Digitalisation and the gradual development of autonomous 'mobility as a service' could provide systemic efficiency gains, if the average occupancy rate of road vehicles is thereby increased, but likewise might also result in increased mobility demand (see discussion of options in section 4.2.6 on Lifestyle and consumer choices).

For *heavy duty vehicles*, in the short-medium term battery electrification is more challenging due to the power and range requirements of lorries. Advanced biofuels are traditionally seen as a solution to allow for full decarbonisation but also the application of hydrogen fuel cells will have to be explored. If the infrastructure is deployed, a train-trolley style charging system on main highways could also overcome the limitations of batteries. Systemic efficiency gains could be had through the internalisation of externalities and the deployment of C-ITS technologies which could lead to more increased loads in trucks and associated efficiency gains .

For *rail* low-carbon electricity will provide a sustainable fuel in all scenarios but might still require infrastructure work. For sectors, such as road freight or air transport, which are harder to decarbonise than the power sector, a modal shift to rail can reduce emissions.

For *shipping,* a variety of options exists for reducing emissions. Operational measures, such as reducing max speeds[176], weather routing, and improved scheduling, can reduce emissions. A variety of technical measures (hull design, engine optimisation) and vessel size can increase the energy efficiency of ships. Finally, novel propulsion technologies, capable of using low carbon fuels, like biofuels, bio-LNG, hydrogen and ammonia, as well as hybridisation notably for coastal and inland shipping, can transform the shipping sector.

For *aviation* improvements in aircraft fuel efficiency, and work on optimizing Air Traffic Management itself are important to limit emissions but will not be sufficient to meet the required overall emission reductions, also taking into account the expected continued growth in air travel demand. Technology options that can be explored are the development of *sustainable alternative fuels.* These can include advanced biofuels but also drop-in e-fuels. Electric

[172] SWD (2016) 244 final
[173] SWD (2017) 650 final
[174] Ricardo Energy and Environment (2016) Improving understanding of technology and costs for CO2 reductions from cars and LCVs in the period to 2030 and development of cost curves
[175]
[176] Slow steaming does not per definition improve the intrinsic technical energy performance of ships, but it does reduce ship resistance in the water. As such speed optimisation is one of the measures that have the largest mitigation potential in the short term, estimated in the range of 10-30% for reducing emissions.

hybridisation of aircrafts will contribute to further fuel efficiency improvements. Full electric aircraft are being developed, and the first small planes are operating, though achievability of large full electric aircraft is yet untested. Beyond technology options behavioural changes may also be important to impact aviation emissions. Modal shift towards high speed rail for short/medium distances can be considered[177]. Advances in digital communication technology (video-conferencing; webinars etc.) can impact business travel. It is less clear to what extent they can impact demand for travel to family and friends or tourism (see discussion of options in section 4.2.6 on Lifestyle and consumer choices).

In terms of *alternative fuels* for all modes, the Commission has already communicated that food based biofuels must play a limited role[178] and should not receive public support after 2020. Such biofuels should be gradually phased out and replaced by advanced biofuels, including cellulosic ethanol and algal fuels, as well as renewable electricity based fuels.

For all modes, *Systemic Efficiency Gains* are possible through the deployment of digital technologies, such as Co-operative Intelligent Transport Systems. These technologies can enable improved logistics across transport modes, which are more responsive to supply & demand as well as the current traffic conditions. Also improvements to spatial planning could increase the use of more efficient modes of transport.

4.2.3 Industry

EU Industry has steadily contributing to the emission reductions in Europe. Since 1990, the chemical sector’s emissions have reduced by almost 60%, while the cement and steel sector’s emissions reduced by about 40%. To further reduce its emissions, especially in line with Europe’s ambition for 2050, major changes need to be made in the way industry consumes energy and produces its products. There are a plethora of deep decarbonisation[179] options for industry, but neither a single silver bullet for all subsectors. During the 2017 expert consultation for the Innovation Fund, 85 pathways and technologies were identified in the main sectors under the ETS[180]. The industrial sector is composed by many diverse subsectors, each with its own particularities. Differences arise from a variety of reasons, most notably by the different energy and material needs resulting in different types, mixture, volumes and concentration of industrial effluents containing greenhouse gases. These aspects are also closely linked to the location of each industrial plant, possibly offering access to different infrastructure and resources.

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[177] High-speed rail is considered competitive with aviation only for relatively short to medium distances (e.g. < 1 000 km) (European Commission, 2011)

[178] Com 2014 (15) A policy framework for climate and energy in the period 2020 to 2030

[179] The term decarbonisation is defined as reducing the amount of gaseous carbon compounds released in air as a result of economic activity and not the complete disappearance of carbon in the industrial production process, which for example is vital for the chemical industry. This is why, the chemical industry prefers to use the more precise term fossilisation.

[180] Climate Strategy & Partners, 2017, Summary report: Finance for Innovation: towards the ETS Innovation Fund, https://ec.europa.eu/clima/events/articles/0115_en

Fuel switching and efficiency improvements

A large part of the GHG reductions achieved up to date are a result of energy efficiency improvements. Further energy and process optimisations, for instance through the reduction of heat losses, recovery of process released heat and re-use of energy containing gaseous effluents are achievable, but will be in themselves insufficient to achieve the long term GHG reduction goals.

On the energy related emissions side, the most commonly discussed options relate to fuel switching. Industrial processes heating operations represent about two thirds of the sector's energy demand. They are critical operations aiming to transform raw material into steel, plastic, concrete, glass, ceramics, paper etc. For this purpose energy is supplied from a diverse range of sources in the forms of fuels, electricity and steam, with fossil fuels having the major share. Therefore an obvious option for the industry is to switch from the highly emitting fossil fuel based heating processes to carbon free ones, like electricity[181], biomass[182], but also hydrogen and synthetic gas using electricity produced by renewable sources. Innovative solutions for providing direct heat from concentrated solar energy are also under exploration.

Innovative low carbon processes

Process related emissions are the inherent result of the chemical transformation of materials, the most notables one being cement production and the oxidisation of coke to produce pig iron. Alternative process technologies that use different chemical reactions for the production of the basic (or substitute) material, avoid the emission of such process related CO2 emissions. Such break-through innovations therefore constitute a completely new production system that would replace production processes that have been used and optimised since many decades. As an example, in the iron & steel sector the Hybrit[183] project aims using hydrogen to completely bypass the use of coal for the production of primary steel. For the cement sector, new binders – replacing clinker – can substantially reduce emissions, while at the same time allow for lower demand of heat.

An alternative way to reduce process emissions is by substituting currently used materials based on fossil fuels by ones with less carbon content or with biomass. The chemical sector is a prime example where either biomass feedstock or hydrogen based[184] chemical production can significantly reduce process emissions.

Carbon capture and storage

Carbon capture and storage technology (CCS) brings strong emission reductions potential, and is technically feasible for most large point sources (power and CO_2- intensive industry). In

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[181] Assuming the power sector is decarbonised in the future, thus the indirect emissions are almost zero.
[182] Considering the limited supply potential of biomass and its importance also for other hard to decarbonise sectors like transport.
[183] http://www.hybritdevelopment.com/
[184] Hydrogen as a reactant with CO2 to produce chemicals, with the CO_2 being re-used.

combination with methane steam reforming it can also supply low carbon hydrogen (as an alternative/complement to hydrogen from renewable power transformed through electrolysers). Its actual potential depends on different factors such as cost, public acceptance and infrastructure, and competition with alternative options such as fuel switching and innovative processes.

Carbon capture and use

CCU could allow CO_2 utilisation into one or several cycles, avoiding the use and emissions related to an equal carbon amount of fossil based resources provided that the energy used in capturing and converting the CO2 is zero carbon. Its applications can be quite wide, ranging from materials (chemicals and minerals) to fuels.

Regarding CCU fuels, they have the benefit that they can be used in existing energy infrastructure. As such they reduce combined emissions across the concerned sectors. Given that CO2 is still released when the CCU fuel is burned, these fuels can only be seen as climate neutral if the re-used CO_2 is coming from sustainable biomass or direct air capture. They also have a high primary energy footprint given the energy needed to produce them. For instance if used to reduce emissions in cars, they have a significant larger primary energy need than battery electric vehicles.

CCU based materials, in contrast to CCU fuels, have the advantage that they can be recycled at the end of life so the carbon can be again captured and used. Materials under advanced development are various types of plastics and building material substitutes. Their lifespan depends on the end use of the CCU product. Examples would be the application in the automotive sector (e.g. polyurethane car seat cushions) or in the construction sector (e.g. concrete building blocks). Other CCU materials are still at basic research stage, such as carbon fibres, but have the potential to displace carbon-intensive materials such as steel, aluminium and cement and reduce emissions from their production.[185] Materials in general are suited for integration to the circular economy, as the overall lifespan can be elongated via material recycling.[186]

Resource efficiency

Resource efficiency in industry mains reduced raw material needs, minimisation of waste, increased recycling and material substitution. As such it is a key part of the Circular Economy. Industrial and manufacturing processes can be redesigned so that material loss in the production and between the different lifecycles phases of each product or material are minimized. Improved waste management allows materials to go back into the economic cycle, thus, reducing the input of raw materials and the need to treat waste. The quantities of virgin material used as feedstock will reduce, part of it replaced by increased recycled and re-used

[185] ICEF (Innovation for Cool Earth Forum), 2017, Carbon Dioxide Utilization Roadmap 2.0

[186] *Identification and analysis of promising carbon capture and utilisation technologies, including their regulatory aspects,* 2018, Ramboll

material, which requires with high quality waste streams much less energy and carbon intensive processes for its processing, and part of it from the cascading use of material and reduced material loss during the processing phase. Cascading use of material will lead to a diversified reuse across the value chain, for example cotton clothing first reused as second hand apparel, then as fibre-fill in upholstery in the furniture industry and later in cotton wool insulation for construction[187].

Product and business model development

Many of the changes required to achieve the kind of resource efficiency gains in the context of a circular economy will require some changes to product design or business model of the involved industries. Industries may also be able to develop genuinely new products, with similar functionality for end consumers but lower emissions associated.

Industrial symbiosis

Finally, the partnership of industries across sectors, sharing their infrastructure and their material inputs and outputs in the context of industrial symbiosis, is another way to optimise resource use and thereby reduce emissions. CCU can be an example of such symbiosis. Such structures are greatly enabled by the megatrend of digitalisation, which is already increasingly penetrating industry. Taking advantage of the strong interlinkages of the different industrial sectors and their exchanges of material, energy and services, can enhance environmental sustainability and achieve economic benefits for all partners at the same time[188].

The above options may be applicable to all industrial subsectors, to only to a few or even to selected industrial sites in Europe which fulfil possible requirements of infrastructure and access to specific resources. Many of them will require technology breakthroughs due to their low technology readiness level or even product innovations and new business models. Some may be economic in the long run or only be able to survive with a variety of strong public support - from economic incentives, to building the needed infrastructure and partnerships to adaptations of the regulatory framework for instance related to waste streams. For the scope of this document, the aim is to identify which combination of technologies and actions can create pathways that can lead to the required emission reductions in industry and what impacts would be on industry, assuming all the necessary prerequisites are met.

4.2.4 Buildings

The energy use in buildings is influenced by major societal trends such as urbanisation, decrease in a number of residents per household or increasing comfort levels (i.e. more surface, higher indoor temperature/higher need for air conditioning, no longer accepting that part of the

[187] Example taken from the 2013 report "Towards the Circular Economy" by Ellen McArthur Foundation.
[188] For more information see "Cooperation fostering industrial symbiosis: market potential, good practice and policy actions", Trinomics, 2018.

dwelling would not be heated). These trends are not only due to increasing welfare but also evolving lifestyle and ageing. As for the tertiary sector[189], the major trends are economic growth and the fact that many of the services offered are increasingly energy-intensive (e.g. computing power that consumes very high amounts of electricity). In absence of policy or economic calculation (spending on heating and electricity for operation of appliances represents a considerable share in household's/businesses/public authorities budgets), this would lead to a steady increase in energy consumption of dwellings even in the case of stabilising population numbers - as is the case in the EU.

Buildings, including residential and services, currently represent approximately 40% of energy consumption and 36% of CO2 emissions in the EU since majority of buildings' energy needs is still covered by fossil fuels. Energy consumption in buildings serves very different purposes. Heating represent the largest end-use, with about 60% of the total[190] (65% in residential buildings and 50% in services). Importantly, large part of the energy serving this purpose is wasted because of the poor insulation and poor performance of the heating equipment. Heating is followed by appliances with slightly more than 20% of end-use consumption on average (15% in the residential but much larger in services with 35%), water heating with 10% (13% in residential, 5% in services), then cooking and cooling with about 5% each.

Different options can be foreseen to lower energy use and/or reduce emissions of the building stock.

Thermal insulation

Given the importance of temperature-related energy needs, the importance of fossil fuels in providing heating (gas and oil represent about 62% of the total inputs to heating) and the amounts of wasted energy due to insufficient thermal insulation in the EU, the role of thermal insulation has already since a long time[191] been considered as crucial in the future evolution of energy consumption in buildings and fulfilling GHG emissions reduction objective. At the same time, renovations have a very diverse as well as scattered nature and encounter multiple market failures, which make it difficult to address and shift towards steady decarbonisation pathway.

Performant equipment

Right after the thermal insulation, the uptake of **performant energy consuming equipment** in buildings (for heating/cooling, for water heating and cooking and all domestic and tertiary

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[189] Tertiary sector covers both services (private and public) and agriculture

[190] http://www.odyssee-mure.eu/

[191] In EU, 2010 has been in this respect a turning point when the EPBD was adopted on one hand and the Global Financial Crisis put the housing sector and in particular the renovation of the existing stock at the center of political concern because of its growth-enhancing role, see: Housing Europe position paper: http://www.housingeurope.eu/resource-1096/decarbonisation-of-the-building-stock-a-two-front-battle. Also, already the 2011 Roadmap gives a key role to the energy performance improvements in the building stock.

sector appliances) has been for a long time identified as a powerful driver in reduction of the energy demand. The first eco-design regulations that act precisely on the performance levels of equipment date back to XX and nearly all of those early have been already revised to introduce more ambitious performance standards while the new categories of product are being constantly added. The eco-design regulations are facilitated by other policies that ensure accurate and useful consumer information and address the remaining market barriers and behavioural biases.

Fuel switch

Reduction of the energy consumption being represented by the first two types of action is already well under way in the EU pushed by strong policy instruments, the more junior option of buildings decarbonisation is the **fuel switch, most often to renewable fuels and in some cases, more broadly to low carbon fuels**. Today, the most common technologies using renewable sources to deliver heating and cooling services in the buildings are solar thermal, biomass boilers, and high Coefficient of Performance heat pumps. These technologies can be used in individual units of small capacity or in district heating and cooling in larger capacities[192,193,194]. Their penetration in the EU is very low, currently standing at XX despite being promoted by both energy efficiency and renewable policies (that increasingly focus on heating and cooling via dedicated policy measures).

The specific options for the fuel switch must be looked into detail as they vary in terms of complexity and the repercussions they would have on the entire energy system. While some are having relatively simple impact such as **complementary use of renewables** (conversely renewables would have a complex impact if the building go for a **decentralised system** or **sell the surpluses of electricity** to the grid). **Electrification of heating in buildings** for its part would need to relay on sectoral integration (i.e. electrification will only be a viable route if electricity supply decarbonises, increases its output, strengthens distribution networks, and adapts to consumption patterns of buildings), switch to district heating would require dedicated infrastructure and again sectoral integration (DH sector would need to decarbonise and develop the output). The most complex changes would be required should buildings use the **new alternative fuels,** whose supply challenges and opportunities are described in chapter XX: H2 and e-CH4.

Hydrogen

Already today, H2 can play a role in heating when blended with natural gas and as such delivered for heating purposes. As described in chapters devoted to supply side options, hydrogen can be injected in natural gas grids up to the maximum technical feasibility (defined today at 15% and 15-20% in the long term). Today such hydrogen blending for the purpose of

[192] IEA (2018) Renewable heat policies. https://www.iea.org/publications/insights/insightpublications/Renewable_Heat_Policies.pdf
[193] Vad mathiesen (2018) Heatmap Europe
[194] Example of solar heating distric grid?

residential heating is performed for isolated projects (e.g. Nord-Pas-Calais XX describe it a bit here) but could become more frequently used throughout Europe as H2 production technology matures and its costs decrease because no infrastructure adaptation is necessary.

As investigated in detail in the study "Sectoral integration"[195], hydrogen-based heating technologies have not been in focus much of the European debate on the decarbonisation of the heating sector until now. However, there exist multiple technologies that have been applied in international – mostly Asian – markets. Four main hydrogen-based technologies could be suited for use in households (Dodds et al., 2005[196]):

1. **Fuel cell micro-CHP:** The most established hydrogen utilisation is in the form of fuel cell CHPs. Currently, the fuel cells micro-CHP run most often on natural gas, which is reformed to hydrogen within the device (thus not offering much of decarbonisation potential) but it the future could use pure hydrogen. While fuel cells are usually known for their highly efficient electricity production, they do also provide heat[197]. Since fuel cells are modular existing small-scale applications can easily be scaled up.
2. **Direct flame combustion boiler:** Direct flame combustion boilers powered with hydrogen, which are functionally identical to European natural gas boilers.
3. **Catalytic boilers:** Hydrogen can be used in catalytic boilers, which produce heat that can be used for domestic heat supply.
4. **Gas-powered heat pumps:** Hydrogen can be combusted in gas heat pumps to generate the phase change instead of an electric compressor which is used in electrical heat pumps. Besides this, the concept of both heat pump types is the same.

In Europe, fuel cell programmes have led to first installations in multiple countries as demonstration projects started in 2008 with the goal to install 50 000 systems with a subsequent commercial roll-out until 2020[198].

Apart from the potential for the decarbonisation of the heating sector and the improved integration of renewable energies by using excess electricity for hydrogen generation, the ability of fuel cell micro-CHPs to operate during black-out times makes them favourable in certain regions. However, the relatively high investment costs are still a challenge for this technology today. In the future, hydrogen-fuelled heating could play a bigger role, especially in **off-grid areas**, where there are a limited number of flexibility sources that can ensure the balance in the heating system.

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[195] Ref to ASSET study with PRIMES modelling

[196] Dodds et al. (2015): Hydrogen and fuel cell technologies for heating: A review, International Journal of Hydrogen Energy, Volume 40, Issue 5, 9 February 2015, pp. 2065-2083

[197] Protone-exchange-membranes fuel cells (PEMFC) are the most developed fuel cell technology suitable for decentral residential heating and account for 90% of total fuel cell systems sold. Solid oxides fuel cells (SOFC) are also used in household heating system sizes. Currently, SOFC and PEMFC have total electrical efficiencies of 80-90% and 95% respectively.

[198] In other markets, ambitious goals and support programmes led to a large-scale implementation of fuel cells. Technology deployment of fuel cell micro-CHPs for domestic use was supported in particular in Japan and South Korea. The Japanese support programme with about € 200 million per year for more than 10 years has led to a strong growth and a decrease of prices of 85% in Japan over ten years.

The large-scale use of hydrogen in end-uses would imply the development of a (**pipeline-based) distribution system**, similar to the gas distribution infrastructure. Due to technical reasons, the currently available gas infrastructure is not fully appropriate for hydrogen and needs adaptations of significant investment cost. The system also requires hydrogen storage at a large scale, e.g. in salt caverns and other facilities, similarly to the storage of natural gas. Another possibility for the distribution system of hydrogen is the use of trucks[199] this is so-called **"decentralised distribution"**. The considerations concerning upstream supply of H2 are presented in chapter XX.

e-CH4

While production of e-CH4 has many challenges (and opportunities) on the supply side, amply described in chapter 4.2.1, **once it is produced** (and in a manner compatible with decarbonisation objectives), **it is exactly the same molecule as natural gas, and can be distributed via existing distribution system and used by existing installations**. So from the final consumer perspective the only difference will be most likely the cost that will reflect the complex, energy-intensive nature of e-CH4 production that also requires (in the context of decarbonisation) supply of carbon-neutral CO2. From the final consumer perspective, it would have to be discussed how the price of e-CH4 should reflect all the costs borne on the way and if still some emissions are attributed to its production where they should be attributed. Interestingly, the end consumer has only a limited choice of fuel that is distributed to the building. Gas heating is currently a predominant option but without the choice of type of gas used (similarly to electricity supply only some form of "green certificates" could be envisaged) and only switching for heat pump or own production of renewable electricity is implemented without a need for bigger investment in infrastructure (as would be required e.g. for direct heat). Consequently, any policy to incentivise the uptake of e-CH4 would have to target gas distributors and such option is explored in some PRIMES scenarios analysed in Chapter 5.

Smart buildings

Technological innovation beyond the material use has the potential to drive the market further with new services and solutions which will accelerate decarbonisation The newest tool in the buildings decarbonisation are the measures that can be collectively labelled under **"smart buildings"** and whose potential is increasingly growing because of **digitalisation meta trend**. Buildings are indeed "smartening up", thanks to the development of building automation and control systems[200] (BACS), that will help optimise their operation, notably in terms of energy

[199] More precisely hydrogen tube trailers, which transports compressed hydrogen (180-250 bar) in steel tubes. Each trailer can transport about 280-720 kg of hydrogen

[200] "System, comprising all products and engineering services for automatic controls (including interlocks), monitoring, optimisation, for operation, human intervention, and management to achieve energy – efficient, economical, and safe operation of building services. The use of the word 'control' does not imply that the system/device is restricted to control functions. Processing of data and information is possible. If a building control system, building management system, or building energy management system complies with the requirements of the EN ISO 16484 standard series, it should be designated as a building automation and control system (BACS)." (Source: EN ISO 16484-2:2004, 3.31)

consumption and maintenance of their technical systems and appliances. Such systems will, as a complement to building insulation and access to low-carbon energy sources, capture energy saving potentials offer possibility of demand-side response and provide to their users a more efficient energy service and at the same time guaranteeing comfort and environmental quality. For instance they will enable highly energy efficient operation of heating and cooling technologies depending on a better knowledge of temperature and solar insulation profiles. It has thus been estimated that the use of building energy management systems alone may reduce the energy consumption for space heating between 2-30% and for space cooling between 37-73% by 2030 with very rapid payback[201]. Importantly, apart from energy demand reduction, "smart buildings" have the potential to respond to a number of societal challenges such ageing, increasing number of single-person households or the need to empower the consumers to make more informed choices.

In addition to advantages for buildings, BACS will also interact dynamically with the rest of the energy system through communication with the grid by offering flexibility in its demand patterns thanks to generalised smart-metering, access to local on-site production from PV panels and storage batteries, both stationary and embedded in appliances and vehicles. Buildings thus become an active, manageable part of the energy system in transition, offering more flexibility options.

Finally, smart buildings will also ease the integration of electric vehicles (see section), including private cars but also smaller personal devices like electric bicycles or scooter, by ensure buildings' readiness to connect to electric vehicle charging.

To unlock this potential, user devices, smart metering set-ups, home/building energy management systems, but also platforms of service providers and grid operators must be able to inter-connect, communicate and understand one other in order to finally inter-operate. To ensure that data is seamlessly flowing as and when needed, minimum requirements for interoperability and specific procedures for access and exchange of data must be in place. This will facilitate the development and market uptake of new services and products enriching consumer choices and helping competition as new businesses will be entering the scene.

Behavioural change/circular economy/city planning

The last lever available for buildings decarbonisation is behavioural change with options such as accepting lower indoor temperature, partial heating of the house and therefore abandoning the comfort levels that consumers have been so far accustomed for. Other types of behavioural change relate to "circular economy" family of measures and they relate to sharing office space, reducing the surface of private dwellings (because of sharing some common spaces) or reducing the number of appliances (because, again, of sharing). Finally, different urban planning while it would have the biggest impact on mobility (reducing the trajectories in daily commuting) could have also an impact on reduction of surface per dwelling and there are already examples of that

[201] Impact assessment of the EPBD revision: SWD(2016) 414 final: https://ec.europa.eu/energy/sites/ener/files/documents/1_en_impact_assessment_part1_v3.pdf

(e.g. some Swiss cities, describe it a bit here). This option is the newest and not without controversies as it affects the lifestyle rather than exploiting the potential of technology like all the others. So far it has inspired some consumer awareness campaigns and resulted in pilot projects only.

Combination of decarbonisation options

The combination of the levers described above, except the behavioural change, is the concept of near zero energy buildings[202] (or version of it: "passive building"). The fact that this concept is already mandatory in the European legislation, reflects that the EU has been at the forefront of buildings decarbonisation policy. Thanks to EPBD (even before the revision)[203], all new buildings in Europe will be **near zero energy buildings** from 2021 onwards. These buildings will be fully insulated, and make use of their shell (rooftops, walls and also windows[204]) and soil occupancy to produce renewable electricity from solar PV, solar heat or geothermal heat pumps.

However, these new buildings will only represent 10-25%[205] of the total stock in 2050 and, even if near zero energy consumer, they will not be enough to achieve our decarbonisation objectives.

The overall behaviour of the stock will be largely determined by the **capacity to renovate and (significantly) improve the energy performance of the existing buildings** and this is what other articles of EPBD incentivised (and even more so and with a longer time horizon after the revision[206]). It has been estimated[207] that up to 97% of this existing stock (i.e. all buildings built before 2010, two third of which having been built even before energy performance standards existed) needs partial or deep renovation to comply with the long term strategy ambition. That will imply a **more than doubling of the renovation rate** of the building stock, from the today observed 1% -1.5% yearly rate to at least 3%, increasing **the depth of renovation** as well as **targeted solutions towards the worst performing segments** of national building stocks (including demolition, and replacement by new and thus near zero buildings).

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[202] https://ec.europa.eu/energy/sites/ener/files/documents/nzeb_full_report.pdf

[203] Energy Performance of Building Directive (EPBD) https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings/nearly-zero-energy-buildings

[204] http://www.sciencemag.org/news/2018/01/new-smart-windows-darken-sun-and-generate-electricity-same-time

[205] http://bpie.eu/wp-content/uploads/2017/12/State-of-the-building-stock-briefing_Dic6.pdf

[206] The main novelty in the revised EPBD is contained in article 2 which provides that *Member States shall establish a long-term strategy to support the renovation of the national stock of residential and non-residential buildings, both public and private, into a highly energy efficient and decarbonised building stock by 2050, facilitating the cost-effective transformation of existing buildings into nearly-zero energy buildings*. First strategies should shed a light on combination of levers envisaged by MS to achieve the decarbonisation objective.

[207] Ref from Alban

The acceleration of clean energy investments in buildings will require initiatives aiming at facilitating the **access to financing**, correcting market failures and improving the perception of the economic rational of strengthened insulation.

4.2.5 Land use: Agriculture and Forestry

Agriculture non-CO2 emissions have declined since 1990. But with current technology and management practices, agriculture emissions cannot be fully eliminated, because of the biological processes involved in growing food, feed, fibres.

Given the more restricted mitigation potential of agriculture and the multiple demands including food security, this sector would become one of the main remaining sources of EU GHG emissions after 2050 in case of deep decarbonisation. To achieve a GHG balance, these residual emissions would need to be *offset* by negative emissions technologies or compensated by sink in the LULUCF sector in EU. Therefore there is benefit in trying to reduce agriculture's GHG emissions as much as possible

The EU's methane and nitrous oxide emissions from agricultural activities amount to 430 $MtCO_{2\,eq}$ in 2016, about 10% of EU GHG total emissions. The GHG emission profile of the so-called agriculture sector reported under UNFCCC (which excludes energy consumption related emissions) is very specific, with only 2% of emissions derived from carbon dioxide (from liming of acid soils and urea applications), whereas 55 % of emissions being methane (from enteric fermentation and manure management) and 43% nitrous oxide (from soil and manure management).

These *non*-CO2 emissions from agriculture have reduced by over 20% since 1990, mainly through the reduction in livestock numbers and overall efficiency improvements in EU agriculture such as the more efficient use of inorganic fertilizers.

Agricultural activities may also emit CO2 from soil and biomass, but these emissions are reported separately in the land use, land use change and forestry (LULUCF) sector[208] of the UNFCCC inventories.

This LULUCF sector in the EU today is a *carbon sink*, i.e. it sequesters annually more biogenic[209] carbon than it emits as GHG. According to the information reported by Member States to the UNFCCC[210], the 2016 net balance amounted to 314 Mt of CO2 absorbed in the LULUCF sector as a whole, with 424 MtCO2 removals from forest land offsetting the emissions of other land cover types, in particular from cropland and settlements and smaller net emissions from grassland and wetlands.

[208] The land use, land use change and forestry (LULUCF) sector covers the emissions of biogenic and removals of atmospheric carbon through land use activities related to forest, cropland, grassland and wetland management, or resulting from land use change between these managed lands.

[209] Xxx Definition biogenic a product made by or of life forms (https://en.wikipedia.org/wiki/Biogenic_substance)

[210] EEA data viewer, not including N20 indirect emissions

Carbon tends to be lost when *converting* grasslands, forest or other native ecosystems to croplands, or by draining, cultivating or liming highly organic soils. Soil organic carbon tends to increase when *restoring* grasslands, forests or native vegetation on former croplands, or by restoring organic soils of wetlands to their native condition.

Mitigating large amounts of emissions related to production in the agriculture sector is recognised as challenging from an economic and technical perspective[211]. Similarly changing land use is not always that easy to be achieved. Nevertheless, policy and technical options exist to reduce emissions and increase sequestrating in the agriculture and land use sectors.

Broadly speaking, four strategies can be envisaged to contribute to reducing GHG emissions through land use in the EU:

a) Increase productivity. To meet growing and changing food demand without encouraging land conversion to agriculture will require productivity increases – the amount produced per animal or unit of land – on current agricultural land to be increased sustainably. By using less land, fewer animals and fewer fossil-based inputs (such as fertilizer and fuel) to produce the same crop, dairy and meat production, the GHG efficiency of the agricultural system is improved and overall emissions reduced;

b) Adopt innovative technology and practices that aim to reduce GHG emissions. Non-CO2 emissions can be reduced through the application of a number of technical options and selection of management practices that favour climate outcomes. The main source of emissions that could be targeted this way are enteric fermentation, management of agricultural soils and manure management. All together, these sources comprise more than the 95 % of the total non-CO2 GHG emission in agriculture;

c) Take actions to sequester carbon directly as biomass and thus increase the EU sink or store carbon in goods. Biogenic carbon stocks can be increased in agricultural soils and forest biomass, again through the adoption of specific management practices and policy choices. Carbon from biomass can also be permanently stored (bioenergy with carbon capture and storage, biochar), temporarily stored as wood for construction, or biomaterial substitution in general.

d) Finally biomass produced by the forestry and agriculture sector can be used as alternative to fossil fuels, or as input to the bio-economy, reducing emissions in the energy system and in EU industries. Depending on the amounts needed and the source of this biomass, this can impact both negatively and positively the EU sink. The impact on the EU sink from increased biomass needs to be included in any assessment looking at economy wide mitigation pathways.

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[211] Xxx More information can be found in [References to EcaMPA, GAINS, Others See with AGRI if we can include in annex their comprehensive list of “20170906 Assessment of Mitigation Actions”. (or do they have a reference to it?

The approaches can provide substantial synergies that create virtuous drivers; for example, sequestering soil carbon improves soil fertility, increases productivity, and is also associated with innovative management practice that reduces soil erosion and increases sustainability. However, if an ecosystem currently acts as a sink, its possible lack of adaptation to the future climate combined with other drivers may decrease its mitigation potential and turn it into a carbon source. Adaptation benefits are likely to emerge from many such actions and mitigation practices, too.

As such, “win–win” or "no-regret" strategies should be prioritised to the greatest extent possible. Mitigation measures that also improve food security, profitability and resilience, would be more favourable than those that have no economic or agronomic benefit, or that could hinder the application of long-term adaptation actions. For example, even a modest increase in the soil carbon pool can provide a significant contribution to improving soil fertility, water retention and agricultural productivity, which in turn fosters the availability of land for other policy needs.

4.2.6 Lifestyle and consumer choices

It is unlikely that technology deployment alone can achieve a net zero GHG emission society. Ambitious mitigation objectives requires making use of all available options, and demand-side solutions are often needed too. These relate to consumer choices.

Behavioural changes in lifestyle matter and can have a significant impact on the level of GHG emitted by our society[212] with potential co-benefit on health or other environmental aspects. Mobility, housing and food consumption are all sectors where consumer choices and preferences can have a direct impact on the GHG emissions. Reversely urban and spatial planning can influence consumer choices in term of mobility and housing needs as well as business needs for offices.

Mobility

The geometry of the city and the topology of its road network influence urban and short distance travelling habits. Compact urban settlements with smaller city blocks, where buildings are close together, building size is small, and streets are narrow, promote walking and other non motorized travel. Moreover, a system of smaller city blocks enables pedestrians to change direction easily, a factor that promotes convenience and accessibility. In contrast, a coarser-grained urban fabric with larger city blocks, where buildings are large and streets are wide, encourages fast-moving vehicular traffic and discourages pedestrian activity[213].

Taking into account external costs on health (pollution, accidents) or on productivity (time spent in traffic congestion) could also reduce demand for energy-intensive modes of transport and favouring modal shift towards increasing demand for public transport and active modes such as cycling and walking with health co-benefit.

[212] Xx Include more precise reference to IPCC 1.5C SR
[213] Creutzig et al 2016

The development of autonomous vehicles could see the development of mobility as a service, relying less on private cars and more on the sharing of the car fleet. If mobility as a service is done exclusively by zero-emission vehicles, greenhouse gases would reduce. If mobility as a service is achieved in a way which increases the occupancy rates of the average vehicle (currently very low at 1.5 passengers per car), this increases energy efficiency. If mobility as a service reduces the amount of time cars are not used, it reduces the amount of cars needed and thus improves materials efficiency throughout the whole supply chain of the road transport system. However, there is also a risk that autonomous transport is seen as a very convenient transport mode that will increase demand for mobility or willingness to spend time in traffic jams, with adverse environmental effects as a consequence.

GHG emissions from medium and long distance transport are also a matter of concern. Aviation is a sector particularly challenging to decarbonise with a limited number of technological options relying mainly on fuel switching towards advanced biofuel (with constraints on availability of biomass) or e-fuels (energy intensive to produce and relying on direct air capture or biomass feedstock to become carbon neutral). Rail and low carbon coaches could replace short distance flights (<1000 km) to reduce GHG emissions in this sector, but it would need an appropriate incentive since flights, with its low amount of taxation applied, are often cheaper and faster than their alternatives currently.

Digitalization and information technology can potentially contribute to reduce the demand for transport. For short distance transport this relates to the deployment of solutions for telebanking, teleworking, teleconferencing and online shopping. However, there is also a risk that this may decrease incentives to live close to work and encourage urban sprawl.

For mid to long distance travel, video-conferences clearly offer scope to reduce business travel. For travel to see family and friends it is less clear that what extent this can be a substitute and to what extent social media and communication technologies not actually increase demand for travel. For tourism they certainly do not offer an alternative and more direct and conscious choices would be needed by consumers to reduce travel demand. Nevertheless if people would be better informed of the externalities of aviation and the impact of their long distance travelling on the environment, potentially a shift in less frequent but longer travel periods may well be a consumer choice that reduces overall transport demand without reducing the utility provided by such type of tourism [references xxx].

Housing

[text, examples/reference needed from DG ENER! xxx]

Compact urban form tends to lessen building energy consumption and GHG emissions due to lower per capita floor areas, reduced external building surface-to-volume ratio, increased shading, more opportunities for district heating and cooling systems[213]. It would also reduce demand for building material.

Beyond building typology, individual choices that can save energy use of buildings are many and can have a very significant impact when cumulated: reducing the thermostat a few degrees can have a significant impact on energy demand. Applying fans instead of air-conditioning in regions with limited heatwave occurrences is much more energy efficient than permanent application of air conditioning system. Other behavioural changes, such as replacing long showers and bath with short showers, washing clothes at lower temperature, dishwashing at full load only, using clothes line instead of dryers, using low volume refrigerators, adapting cooking practices can cumulatively have a significant impact on energy demand.

Food consumption

Changes in food consumption patterns would significantly impact agriculture activities and therefore GHG emissions in the sector, both those related to CO2 emissions from land as well as non-CO2 emissions from agriculture. Diets that are more reliant on meat tend to have significant higher overall greenhouse gas emissions than diets that are more plant based. Ruminants with enteric fermentation are particularly GHG intensive, with beef having typically a significantly higher GHG footprint compared to pig meat, and poultry having the lowest[214].

Nationally recommended diets are a prominent method for informing the public on dietary choices and their impact on health. Comparing the environmental impact of average dietary intakes and a nation-specific recommended diet show that following a healthier nationally recommended diet in high-income nations results in a reduction in greenhouse gases, eutrophication, and land use[215]. Reducing the consumption of ruminant meat (beef and sheep), and to a lesser extent dairy products, has the biggest GHG reduction potential with poultry, vegetable and cereal alternatives having a much lower impact in term of GHG emitted per calorie or protein provided[216].

New products with lower GHG footprint such as artificial meat or vegetarian burger reproducing accurately the taste and consistency of meat could disturb the food market in the future, and the associated emissions, if accepted by the consumer and if having the same nutritional value.

Another approach to reduce emissions through change in the food consumption habits is to limit the food wastes generated at consumer level. In 2015, the objective to halve per capita food waste generation at the retail and consumer levels by 2030 was agreed as part of the 2030 Sustainable Development Goals adopted by the United Nations Assembly[217]. The Commission is also in the context of the Circular Economy Action plan working on a common EU methodology to measure food waste and define relevant indicators. Options to reach this are further improvement of processing and distribution of food, including information campaigns to better inform final consumers of the impacts of food waste as well as the establishment of distribution channels for formally expired but still edible food to be made available to low-income households at low costs.

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[214] Poore, Nemecek, 2018, Reducing food's environmental impacts through producers and consumers, Science 01 Jun 2018: Vol. 360, Issue 6392, pp. 987-992
[215] Berhens et al 2017
[216] Bryngelsson et al 2016
[217] Ref SDG

4.3 Levels of ambition considered

The sector specific options described above can be combined to create economy wide options meant to address different levels of ambition, covering the potential range of reduction needed in the EU to contribute to the Paris Agreement's temperature objectives of between the well below 2°C, and to pursue efforts to achieve a 1.5°C temperature change. As explained in section 2.3 this is assumed to be a reduction for the EU in 2050 compared to 1990 anywhere between -80% and -100% (or achieving net zero GHG emissions).

Based on a common baseline, reflecting current policies and objectives, as well as their continuation towards 2050, the various sectoral options are grouped together in different pathways towards meeting the desired levels of ambition.

Although these pathways tend to have certain elements stronger than others, they are not examined as extreme options (e.g. the hydrogen economy, the synthetic fuel economy, etc) but as feasible options for the projected future. Due to the inertia of the energy system and the economy as a whole, the differences start becoming more visible closer to 2050 and even stronger thereafter.

The lower level of ambition assessed, corresponding to meeting the well below 2°C ambition, is set at -80% GHG emission reductions in 2050 compare to 1990, excluding the LULUCF sector. The impact on the sink is also projected. After 2050 emissions continue to decrease but no net zero GHG emissions are achieved.

Five different options are assessed for meeting -80% GHG emission reductions in 2050, with an increased focus on different decarbonisation technologies. Three of these options concern an increased focus on supply side action and examine the impacts of switching to low carbon fuels, namely electricity, hydrogen and e-fuels, in order to meet the prescribed level of ambition. The other two options take the viewpoint of the demand side, examining how stronger energy efficiency measures or the transition to a more circular economy can deliver the desired emission reductions.

All of the above options are assumed to share similar no regret options, like growing energy efficiency and increasing penetration of RES. Moreover all technologies and fuels are assumed to be available in each option, but the specific pathway and technology considered in each option is assumed to have certain advantages facilitating its uptake based on economic criteria, e.g. in the circular economy standardisation of recyclable material and improved systems for collection and in the hydrogen scenario enabling infrastructure available to transport as well as produce hydrogen from renewable energy sources.

For the intermediate level of ambition, the above five options are combined into a sixth option, where all pathways are assumed to be available. With more choices being available, a higher level of ambition can be achieved. This should result in higher emissions reduction in 2050 (without sinks) and being closer to GHG emissions neutrality in 2070 (including sinks). This option serves also as a bridge between the low and high ambition options, aiming to identify how far we can go in emission reductions using a combination of solutions as identified in the projections achieving -80% GHG emission reductions, but without application of significant negative emissions technologies and/or changes to consumer preferences.

The highest level of ambition assessed requires net zero GHG emissions by 2050 (thus including sinks), while in 2070 emissions should be mildly negative, i.e. negative emissions should be higher than remaining GHG emissions.

One option, building on the combined option, aims to further increase the ambition level of all the technology options, but also introduces application of BECCS and specific additional actions to enhance the land use sink, this to enhance the economies negative emissions, The aim is to have the relevant negative emissions balancing the remaining emissions by 2050 and surpassing in a limited manner in the period afterwards.

The alternative option assessed combines and intensifies all technical options to reduce emissions, but also reduces the need for negative emissions to balance emissions, by assuming significant changes in consumer choice that are more beneficial for the climate, including dietary changes, the sharing economy in transport, and reduced demand for aviation.

The modelling tool set used for this exercise is the PRIMES-GAINS-GLOBIOM model set up. For more detailed information related to this modelling set up, as well as the assumptions related to the scenarios, see section 13. The next chapter focusses on interpretation of the modelling results made for this report, as well as other studies that have undertaken similar assessments at sectoral and economy wide level. Furthermore it also includes stakeholder contributions.

5 RESULTS: ANALYSIS OF OPPORTUNITIES AND CHALLENGES

5.1 Greenhouse gas reductions

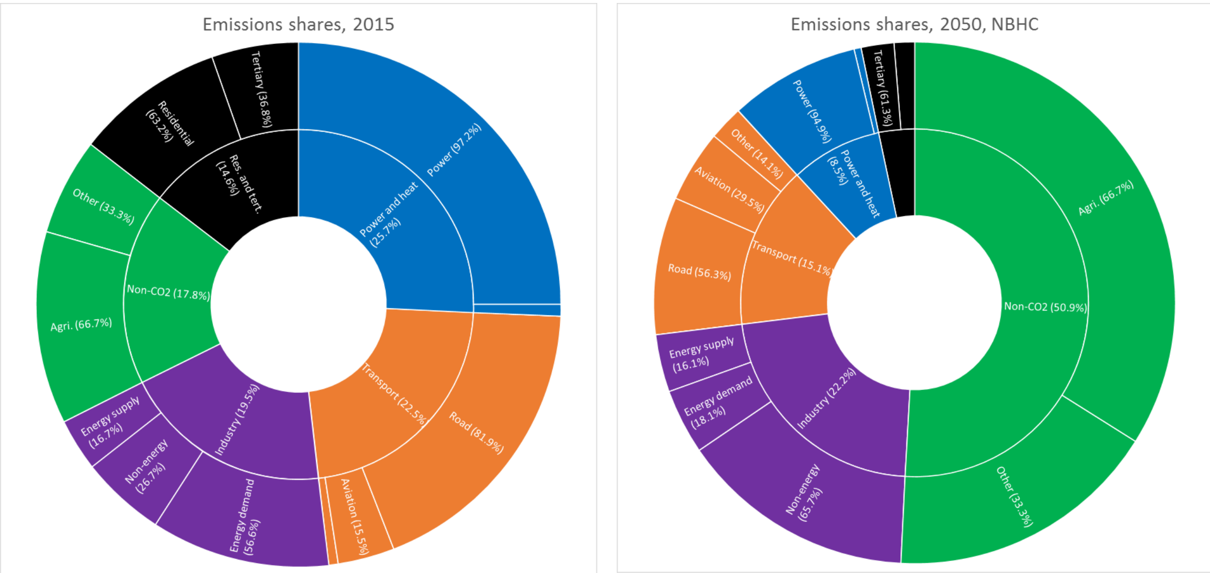
[xxx to consider placing this section at the end of chapter 5, rather than in the beginning] Efforts to decarbonise EU economies in the past decades have affected the composition of GHG emissions as progress has been faster in some sectors than others (section 1.2.4). While emissions can be reviewed in a number of more or less detailed ways, a straightforward and intuitive way to consider them focuses on a sectoral approach. On this basis, emissions are first categorised between CO_2 and non-CO_2 emissions. CO_2 emissions arise principally from the burning of fossil fuels for energy and to a smaller extent from non-energy uses, i.e. mainly from industrial processes. Non-CO_2 emissions arise mainly from agriculture (mostly related to enteric fermentation, manure and use of fertilizers), but are also generated by the energy sector, industrial processes and waste.

The below figures relate to GHG emissions as represented by the PRIMES-GAINS-GLOBIOM set-up. For 2015 these emissions are very similar to the emissions as reported in the EU GHG inventory. For 2050 it represents projections of emissions.

In 2015, power generation and district heating accounted for about one quarter of total GHG emissions. Transport, including aviation (but excluding international maritime transport) whose emissions have yet to be put on a firm declining trend, was the second largest emitting sector with a share of emissions of 22.5%. Non-CO_2 emissions and industry represented close to 20% of total emissions each.

Regardless of the decarbonisation pathway that is envisaged, the sectoral shares of residual emissions, excluding the LULUCF sector, in 2050 will be significantly different from 2015, reflecting varying challenges and technology options available for decarbonisation (*Figure 11*). For projections achieving -80% and higher emission reductions, the share of non-CO_2 emissions is likely to reach at least 30% of the total remaining GHG emissions in 2050 in a scenario that achieves -80% GHG reduction and is higher than 50% in scenarios that achieve net zero GHG emissions (as represented in the right hand side of the below figure). [xxx to be updated, the scenario results did not yet achieve zero GHG, thus higher emission reduction need to be achieved and higher rates of non-CO2 can be expected for these scenarios]

Figure 11: sectoral shares in total emissions, 2015 and 2050 (NBHC scenario)



Source: PRIMES, GAINS.

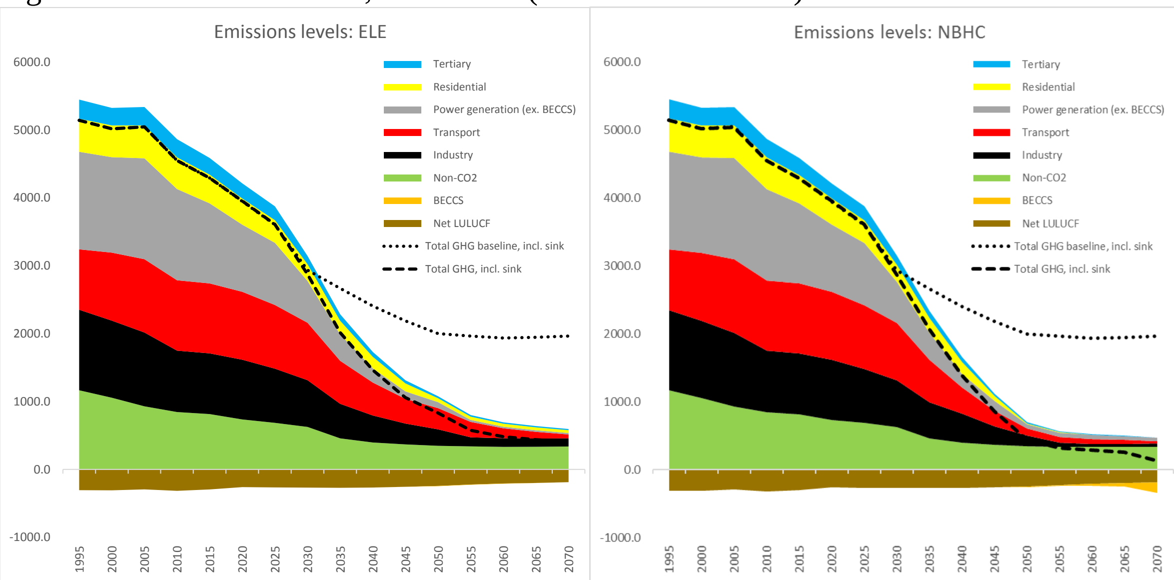
The evolution of these shares reflects decarbonisation pathways that vary across sectors, including in terms of timing of emissions cuts. All pathways nevertheless show that major progress will be required early on and in all sectors (*Figure 12*). Under the baseline, total net GHG emissions (including sinks) are reduced by around [60%] in 2050 (relative to 1990). No sector would achieve full decarbonisation and most progress would be achieved in power generation and district heating because of the falling cost of renewable electricity sources. Also industry sectors included in the ETS see significant reductions, though certainly no full decarbonisation.

Instead in the highest decarbonisation pathways (the NBHC scenario is the one that achieves zero GHG and does so with the use of technology options, including BECCS) all energy and CO2 related emissions strongly decrease towards full decarbonisation. Non-CO_2 emissions will be the most difficult ones to reduce and become a critical factor in the achievement of zero GHG emissions and the corresponding need to materialise negative emissions. Even with consumer choices going towards more climate friendly options, non-CO_2 emissions would be a multiple of the cumulated emissions of all other sectors.

As a result, the size of the carbon sink and the deployment of negative emissions technologies (BECCS or direct air capture with storage) will be a determining factor in achieving GHG neutrality and negative net emissions (see below).

[xxx the below figure will require updates once scenarios are updated to truly achieve a zero GHG emission profile. Higher emission reductions will be needed, probably via increased use of CCS which in turn delivers BECCS. Furthermore the sink function will decrease more, due to increased use of Biomass].

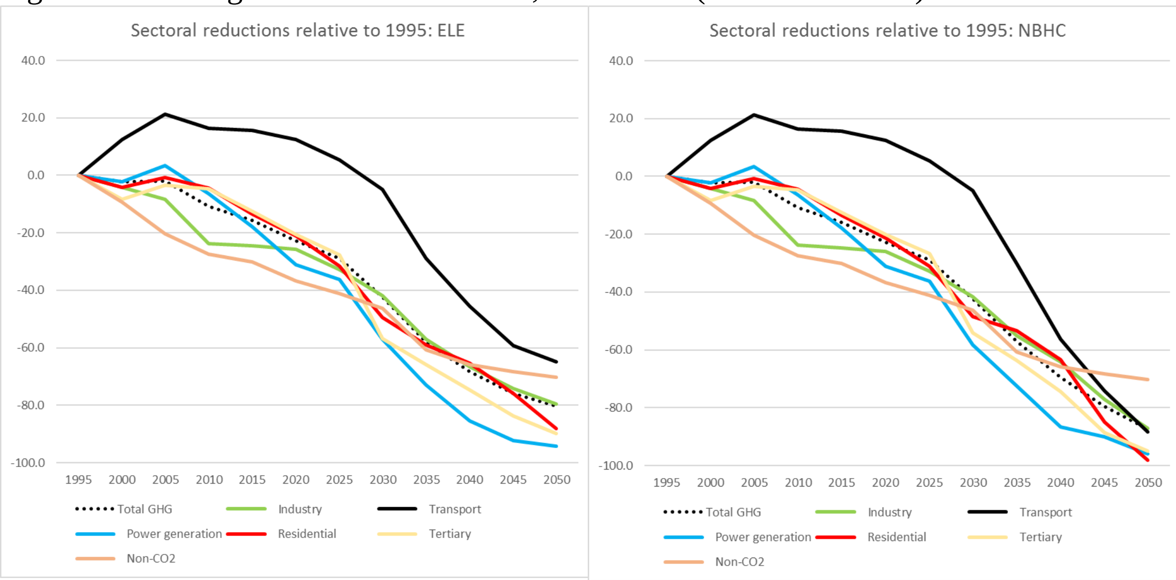
Figure 12 sectoral emissions, 1995-2050 (baseline and NBHC).



Source: PRIMES, GAINS, GLOBIOM.

Under the various decarbonisation pathways, the energy related emissions, are typically required to reduce emissions by an above-average proportion in order to compensate for constraints in cutting non-CO_2 and transport emissions (Figure 13). Emissions in these sectors become very small towards 2050 to achieve net zero GHG emissions, with lowest emission in the build environment and the power sector. In the power sector they even become at some point net negative, though the application of BECCs. Instead, in industry (including process CO2 emissions), and transport reductions are somewhat lower. This is most notably for transport, with emissions remaining above 1995 levels until 2025 and only reducing to around -60% for a scenario achieving economy wide 80% reductions (left hand side below figure). Nevertheless under deep decarbonisation pathways achieving zero GHG by 2050, also this sector will also have to achieve sharp emissions of more than 80%, in a relatively short period of time towards 2050 (right hand side below figure).

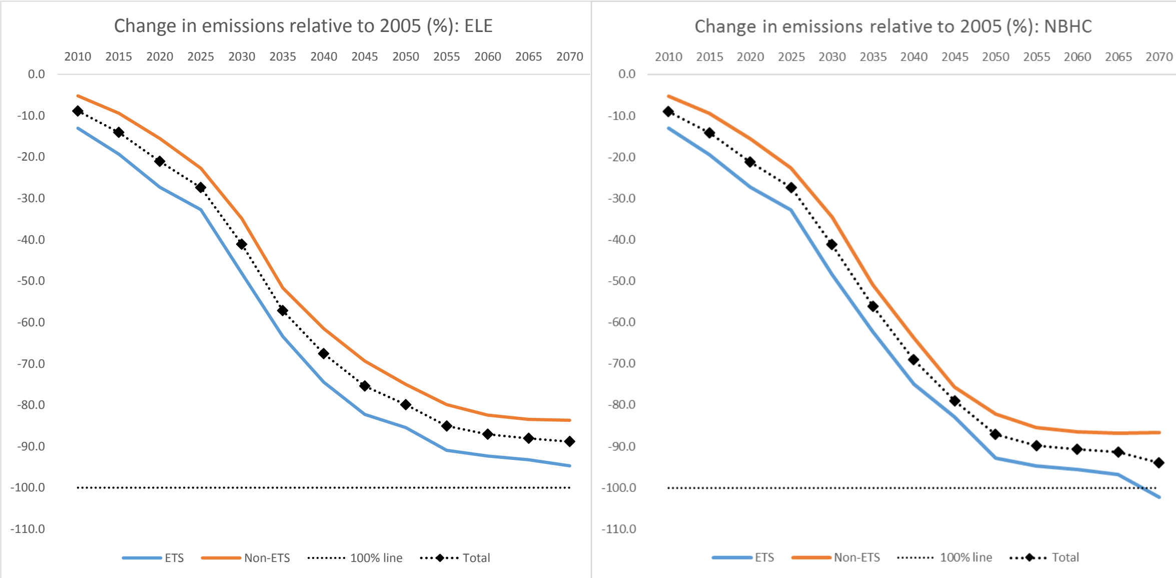
Figure 13 % change in sectoral emissions, 1995-2050 (ELE and NBHC)



Source: PRIMES, GAINS

Sectors encompassed in the EU ETS have so far seen higher reduction compared to historic emission levels. This is set to continue in the long-term under all pathways with the ETS reducing more than the Non ETS sector. Though the differentiation is less pronounced as in the past and these sector reductions move relatively in tandem. Only with the introduction of BECCs in ETS sectors to achieve net zero GHG emissions, and non-CO2 emissions remaining in the non-ETS, does this differentiation enlarge again towards the end of the period.

Figure 14 reductions in ETS and non-ETS emissions.



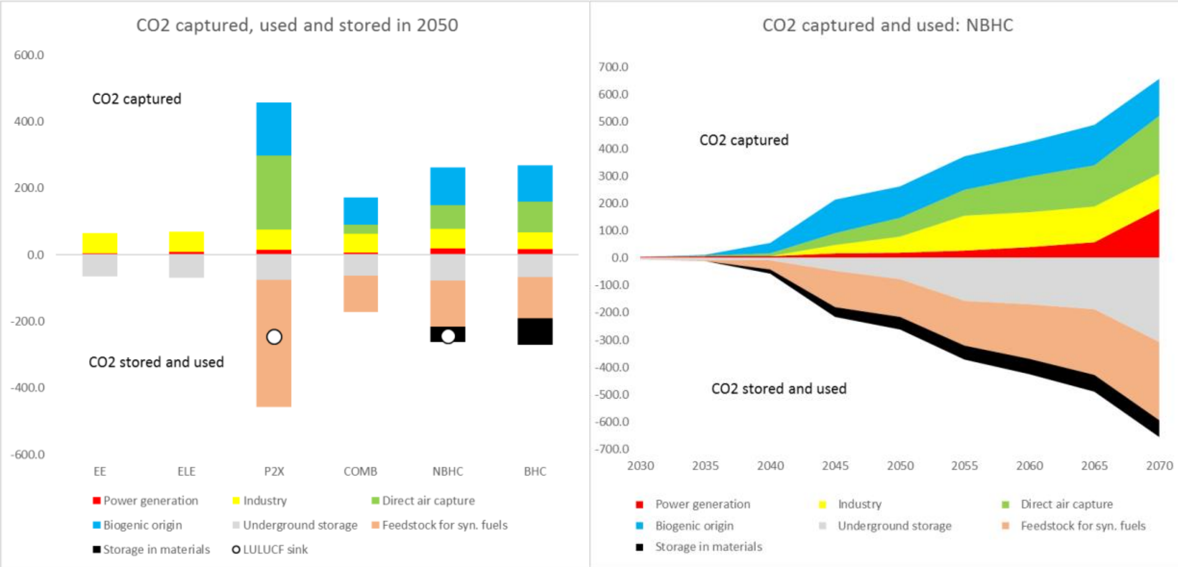
Source: PRIMES, GAINS

Optimising the natural sink and deploying carbon capture and storage at a significant scale are therefore necessary not only to achieve negative emissions, but also to attain net zero emissions.

The different pathways indicate limited variability in terms of the natural sink, which is estimated at to vary between around 220 and 275 million tonnes CO2 in 2050. Though important in this context will be how different increasing levels of biomass are produced, with pathways using woody crops and high afforestation having least impact on the sink, though seeing highest impact on changes in land use.

The pathways envisaged vary more significantly in terms of the deployment of capture, use and storage technologies (*Figure 15*). Capture of CO2 molecules for use or for storage, including through direct air capture and capture from biomass sources varies strongly for different scenarios, though is large under any 1.5°C scenarios. Carbon capture, storage and use technologies are likely to pick up slowly before 2040 and accelerate only subsequently. . For the scenarios achieving -80% reductions, the P2X scenario requires highest capture rates, well above 400 million ton CO2 by 2050, given the significant levels of synthetic gas. Underground storage (CCS) is envisaged under all pathways, with the deployment in projections achieving -80% by 2050 seeing levels at around 50 mega-tonnes. This is much smaller than what was projected for the 2050 Low Carbon Economy and Energy Roadmaps, notably because increased penetration of renewable energy as well as other reduction technologies in the industrial sectors. [xxx to double check!]

Figure 15 CO2 captured, stored and used



Source: PRIMES, GAINS

[xxx To be updated once new scenario with higher reductions are modelled]

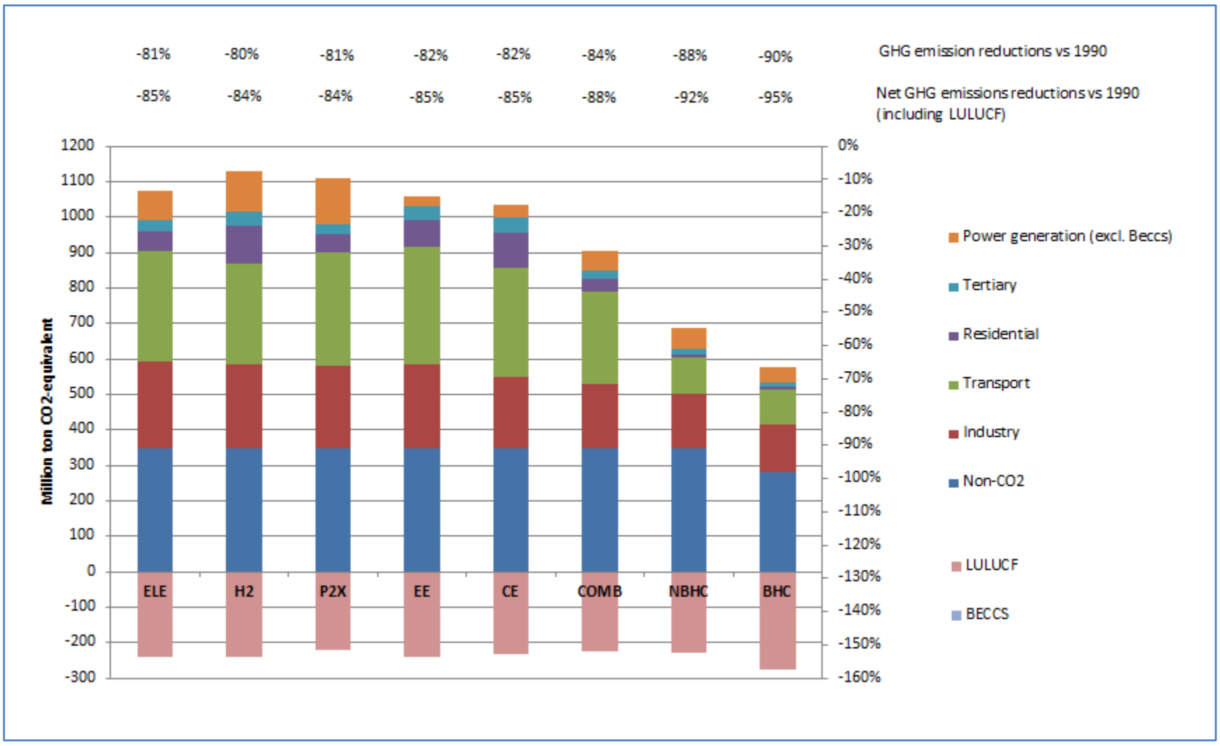
Overall, GHG emissions (excluding sinks) are projected to fall by around 61% under the baseline in 2050 (relative to 1990).

The Electrification, Hydrogen, Power to X, Energy Efficiency and Circulare Economy Projections all achieve between -80% and -82% GHG reductions by 2050 compared to 1990 excluding LULUCF. Including LULUCF these projections perform a bit better, with reductions between -84% and -85%. On average the additional reduction in percentage terms when LULUCF is included is 3.3%, though smallest in case of the P2X scenario which only sees an additional reduction of 3.1% when including LULUCF, related to the higher biomass needs for this scenario as feedstock for the P2X.

These results underline that if the EU reduces its GHG emissions with 80%, its net GHG emissions (including negative emissions from LULUCF) reduce with a bit more in percentage points.

The scenarios in-line with the 1.5°C objective [xxx to be updated once new projections available] reduce with around 90% emissions, and including LULUCF emission reductions are as high as -95% in case of the projections that includes changes in consumer choice, which notably in the agriculture sector results in land availability that allow to increase the LULUCF sink, resulting the largest difference in achieved emissions reductions when comparing emission reductions excluding and including LULUCF.

Figure 16 : sectoral emissions levels (2050) and percentage change in total emissions.



Source: PRIMES GAINS GLOBIOM.

5.2 Energy demand

Final energy demand will be analysed in detail in each of the sectors: buildings (comprising residential and tertiary sector), transport and industry in the subchapters below. However some general observations can be done for the entire level of final energy demand (FEC).

Already in the Baseline FEC is substantially reduced. In 2030, a 19% reduction is achieved compared to 2005 levels which correspond to the 2030 target (of 32.5% reduction compared to 2030 levels as projected in 2007 Baseline). By 2050 the FEC is then further reduced to achieve 25% reduction compared to 2005 levels. It then remains stable till the end of the projection period.

Looking at decarbonisation scenarios, they achieve the **FEC reductions (compared to 2005) ranging between 31 and 48% in 2050 and the consumption then remains stable till the end of the projection period**. The lowest reductions are achieved in scenarios with alternative fuels (ELEC, H2 and P2X) as those fuels are by 2050 nearly zero-carbon and thus enable reaching decarbonisation objectives without the reduction of the demand. EE and CRIC scenario achieve higher (and similar between them) reductions while even higher reductions are achieved in COMBO (that combines all demand-side measures) and the highest in 1.5C B which on the top of solutions of COMBO scenario activates the behavioural change.

Comparing among sectors, the **residential has the sharpest reductions** (in 2050 compared to 2005) in all scenarios except in H2 where it is transport that is even having incrementally higher reductions. After the residential (and in some scenarios with a very small difference) it is transport sector which has the highest reductions. **Industrial sector has in most cases the lowest reductions** (or equal to reduction in the tertiary sector).

5.2.1 Buildings

Buildings sector (both residential and tertiary) display significant differentiation in the scenario results as both supply side changes (i.e. use of alternative energy carriers) and demand-side adjustments (energy-efficiency and behavioural change) make impacts on this sector.

Today, the residential and tertiary sectors combined have the largest final energy consumption (FEC). In all the decarbonisation scenarios their consumption is reduced (albeit to a different degree depending on scenario design). The residential sector, in 2050 reduces FEC compared to 2030 between 18 (specify scenario) and 40% (specify scenario) and only incrementally more in 2070 (this is due to population growth and increase is average surface of dwellings). The 1.5C B scenario achieves the highest reductions as it builds on all technological options and couples them with behavioural change (notably XX). In tertiary sector: XX These figures are significantly higher than the reductions seen in the 'Paris compatible' scenarios by the IEA Energy Technology Perspectives (B2DS scenario) and the Shell Sky studies which report buildings' FEC savings of 21% and 13% respectively between 2030 and 2050.[add more studies]

The reductions of FEC are due to both reduction of H&C demand (driven by renovations and proliferation of BACS) and an improved appliances performance. The reductions in useful H&C demand[218] compared to the Baseline range between 11 and 37% in 2050 and 19 and 46% in 2070. This clearly shows the impact of renovations (and in some cases behavioural) on existing buildings which are the highest in EE, COMBO and 1.5 C scenarios. [add studies with specific information on individual EE measures as this level of detail is not reported by main energy scenario studies] On the other hand, the use of alternative energy carriers enables in other scenarios to maintain higher energy consumption while fulfilling the decarbonisation targets. But even in those scenarios, energy efficiency plays an important role keeping the demand for these fuels (which are zero-carbon but fairly expensive) in check. This illustrates that "energy efficiency first" remains the key principle across all scenarios.

As for appliances, there is no change in the useful energy demand as exactly the same level of services are sought across all scenarios (e.g. cooking, laundry or washing) but there is a visible reduction in final energy consumption in EE, ELEC and COMBO and 1.5 C scenarios as more ambitious performance requirements are sought (e.g. via more stringent eco-design standards or in case of ELEC by very high penetration of heat pumps that have very high energy efficiency performance). In tertiary sector XX…

[218] Better to show because excluding impact of the fuel choice.

The reductions in H&C demand can be very well confirmed looking also at energy demand per m2 of the dwelling (thus isolating energy efficiency measures from slightly countervailing effects of population and comfort levels growth). The average final energy consumption per m2 in 2050 is at between 44 and 61% higher compared to 2030 and up to 32% higher in 2070. These dramatic reductions in energy consumption are mostly due to the renovation of existing building while the energy consumption of new buildings is only incrementally improved in EE, COMBO and 1.5 C scenarios because of XX.

The main driver of reduction in H&C demand are renovation of existing building stock[219] and to lesser extent application of BACS. The renovation rates (average annual rates for respective 20-year periods) across the decarbonisation scenario depend on the assumptions: they are the highest in 2031-50 in CRIC scenario (1.86% because of what???) and in EE scenario (1.77%) and then remain on this level in COMBO and 1.5C scenario that relay on these developments to achieve ambitious decarbonisation targets. Interestingly, in 2051-70, the EE scenario has the highest rates followed by COMBO and 1.5 scenarios (explain why?). Beyond the share renovation rate, the assumptions and thus performance of the scenarios differs in terms of depth of renovations pursued. The EE, (slightly less so CIRC), COMBO and 1.5C pursue most in-depth renovations (i.e. walls, windows and roof) that represent some ¾ of all renovations. Other scenarios have not only lower renovation rates but higher shares of them are light renovations (e.g. simply changing the windows). Such different structure of renovations results in differing energy savings achieved from refurbishment. These savings vary from 53 to 63% in 2050 while lower spread and savings are achieved in 2070 (most of the buildings have been then to some extent at least renovated already). Surprisingly, the CIRC scenario has the highest savings in 2050 and EE scenario the lowest – please explain but rather correct sth in modelling.

Beyond renovation rates, the buildings automation, control and smart systems (BACS) also contribute to the demand reduction. While the results in PRIMES have been fairly conservative (quote here), there are multiple studies and demonstration projects that indicate a higher potential for energy consumption reductions. Certainly a "smart building" does not dispense from renovations but a smart building could at least partially reduce the need for very stringent renovation standards that might bring only marginal improvement and this at very high costs. It is also an opportunity to further implicate the consumers – especially if "smart building" is coupled with management of own production (from renewables) and possibly storage.?

Finally, behavioural change, while in PRIMES still modelled in fairly conservative manner, can have a significant impact on the heating/cooling needs. The assumptions in PRIMES revolved around sharing office space, different organisation of blocks of flats, XX, YY, ZZ and in 1.5C A scenario contribute further into the reduction of energy demand from buildings. Other studies, however, indicate much higher impact but also then requiring behavioural change that would have higher impact on lifestyle and thus perhaps lower acceptability such as substantial

[219] It could have been also demolition and new constructions but these are unchanged across the scenarios.

lowering of indoor temperature, sharing of common spaces in blocks of flats, upper limits to the size of dwellings.

Also, the fuel mix shows significant differences. The share of gas that in 2030 would be a dominant fuel standing at 45%, declines to between 15 (ELEC, COMBO, 1.5) to 28% (P2X) in 2050 and between 11 to 28% in 2070. This is similar to the IEA ETP B2DS and the Shell Sky scenarios which see the natural gas share of in residential final energy use at 21% and 11% respectively in 2050 [add more studies]. While P2X scenario has the highest gas shares, more than half of it is e-CH4 and thus does not generate emissions. In H2 scenario, hydrogen partly substitutes methane as its shares in FEC stand at 13 and 17% in 2050 and 2070 respectively. This is the highest share among all scenarios as high H2 penetration in residential sector proves capital intensive (because of infrastructure or costs of fuel itself?). Neither the Shell Sky nor the IEA ETP B2DS scenarios see hydrogen in the residential sector in 2050. The shares of electricity grow in spectacular manner in all scenarios. While they stood at 32% in 2030, in the decarbonisation scenarios the shares increase to between 46 and 62% in 2050 and 48 and 74% in 2070. The highest shares can be of course found in ELEC scenario and also only slightly lower in COMBO and in 1.5C scenarios. This is comparable to the Shell Sky scenario, in which the share of electricity in the residential sector reaches 74%. The IEA ETP B2DS scenario in more pessimistic on electrification and does not see its share rise above 35% residential final energy demand. To illustrate the magnitude of household electrification, one can look at the ELEC scenario, where the electricity provided by heat pumps in both residential and tertiary sector grows by 51% in 2050 and 77% in 2070. Another manner to look at this development is checking the number of households that would be equipped with electric heating[220]: in ELEC scenario their number would quadruple between 2030 and 2050. Importantly, electricity produced by heat pumps is also considered as renewable energy in heating & cooling.

Biomass and waste are a "gap-filling" zero carbon fuel but they increase their share only marginally in the decarbonisation scenarios (compared to the Baseline) with the only exception of the H2 and P2X scenarios that increases biomass shares because of XX. Most of this biomass (TBC) is the bio-CH4 which is perfectly fungible with natural gas (as it is purified form of the bio-gas). Higher penetration of bio-CH4 is only limited by the limited production/import potential. The remaining biomass and waste are pellets stoves which, however, generate pollution issues (Particulate Matter) and might not be a feasible solution for modern urban dwelling. They thus remain marginal in all decarbonisation scenarios. Interestingly, distributed heat which is more energy efficient and creates less GHG and pollutant emissions (often having CHP plants at the source) does not further develop in decarbonisation scenarios and its share decreases in time and compared to the Baseline as for it to be competitive in decarbonisation pathways only biomass and large scale HP remain a valid options, the first option is problematic pollution-wise and the second is not yet commercially mature. The Shell Sky scenario does not see a significant role of biomass with less than 10% of final energy in the residential sector in 2050 while in the IEA ETP B2DS, biomass meets a fifth of the demand [add more studies].

[220] There would be small part here which represent traditional electric resistance heating.

As a result of such significant fuel switch, the CO2 emissions in residential sector decrease substantially and CO2 emissions are in 2050 reduced nearly to zero (compared to 2005/1990?). The outstanding emission would represent some remote locations that do not have the full menu of heating options. The technology options and technology-based demand management aspects (energy efficiency, circular economy) enable buildings to fit in -80% GHG by 2050 decarbonisation pathways and their combination even enables to reach slightly beyond -80% GHG reductions. But it is only with behavioral change that buildings can fulfil the necessary effort for the net-zero ambition in 2050 without other sectors having to shoulder a higher effort or the need for an offset by negative emissions.

Furthermore, the sector becomes mainly based on renewable energy sources the RES H&C shares (which also comprise industrial heating) that in 2030 stood at 36% grow to between 55 to 79% in 2050 and between 61 to 85% in 2070. Such performance is certainly helped by overall reduced energy demand but also supply development play a key role as electricity and large shares of H2 and eCH4 are of renewable origin (see chapter on gas supply). The highest shares of RES H&C among 2C scenarios can be found in the P2X scenario because the e-CH4 is largely renewable and then COMBO scenario maintains those shares (albeit via more cost-effective mix of electricity, H2 and e-CH4) and 1.5 C scenarios achieve even higher share thanks to higher reductions in the overall demand.

Both the energy efficiency policies and the fuel switch in the magnitude presented in respective scenarios have significant costs. In terms of necessary investments they cover both capital outlays into the equipment and in buildings renovations (and new constructions). Compared to the Baseline, the average annual investments increase between 6 and 44% in 2031-50 and between 4 and 18% in 2051-70. The highest investments happen in EE, COMBO and 1.5C scenarios and are the direct consequence of deep and high renovation rates. As to the fuel expenditure, the results are less varied. Most of the scenarios has lower fuel expenditure than the Baseline albeit for those scenarios that relay on the alternative fuels, the expenditure reduction is the smallest. In case of 1.5 C B scenario the expenditure in 2050 is even incrementally higher than in the Baseline – explain why or correct modelling. Combining capital outlays and fuel expenditure system costs in the residential sector, the system costs represent the overall costs borne by the sector. In all decarbonisation scenarios and both in 2050 and 2070 the system costs are higher than in the Baseline. It is the H2 scenario that comes as the most expensive since relatively low amounts of H2 do not reduce significantly the need for renovations and H2 remains an expensive fuel. The lowest costs are found in EE, CRIC and ELEC scenarios and in general the costs increases are lower in 2050 than in 2070 (compared to the Baseline) as it is in 2031-50 period that more ambitious renovations are pursued. In the tertiary sector… XX (similar developments probably). The magnitude of investment depicted above will certainly be challenge but the sectors which are solicited (construction, engineering, IT) are mostly domestically located and thus this investment challenge can be a great stimulus to growth and jobs creation in the EU economy (see chapter on macro-economic developments).

5.2.2 Mobility

ENER/MOVE contribution:

For transport, a reduction of GHG emissions that is consistent with the long term vision of a low-carbon society in 2050, together with a drastic reduction of the oil dependency, would be required, while maximising co-benefits in terms of reduced costs of air pollution, congestion, noise pollution and accidents. ***Sustainable mobility*** entails the integration of all transport modes within the vision of more efficient, cleaner, smarter, safer, competitive, accessible, user- and citizen-friendly transport system. Behavioural change need to be better accompanied, to support sustainable transport usage.

Strong action on vehicle efficiency, accompanied by appropriate policies to support innovation, the deployment of recharging/refuelling infrastructure and alternative fuels and powertrains will need to contribute towards this vision. Stronger integration of transport with the energy system and progressive change of the transport fuel mix will also be essential for low-emission mobility. The substantial increases of OEMs investments into alternative powertrain technologies will lead to faster innovation cycles, both for hardware (e.g. battery technology, lightweight materials, sensors etc.) and software (digital services). New market players will arise, from within and outside the EU.

In this time perspective, new societal developments and behaviour changes have large potential for improving mobility and contributing to decarbonisation. Integrating the sharing economy and connected, cooperative and automated mobility in the existing transport institutional and technical set-up, and making full use of digitalisation, mobility as a service and the potential of active modes, will be an essential part of the transport agenda.

As vehicles, infrastructures (recharging, refuelling, grids), services and users will be connected; increasingly, value will be generated through services and platform provision, with an increased focus on data, data management and security. Shared and automated forms of mobility will transform mobility (both urban and long-term), enabling full optimisation of transport in urban environments, where space is becoming increasingly constrained. Seamless mobility in a low-emission environment will benefit both passenger and freight transport. Particularly the logistic sector might change profoundly (Internet of things).

A completed core and comprehensive Trans-European Transport Network by 2050 will allow for the optimal use of transport modes, with high-speed rail and waterborne transport being attractive means for medium distance trips respectively for passenger and good transport between cities in the EU. Making full use of the benefits of digitalisation and low- and zero-emission alternative energies will enable the transport sector to provide seamless, resilient and sustainable mobility solutions to citizens and industry, and thus mitigate the impacts of energy use and emissions. Data will have become almost like a “new mode of transport”: they enable highly innovative, seamless door-to-door mobility across modes, integrated logistics and value added services using data from transport.

When addressing negative externalities in transport, existing initiatives would need to be stepped up; notably as regards integrated planning, intelligent and smart traffic management, promotion of sustainable urban mobility planning etc. Moreover, in future we must aim at a more consistent application of the polluter-pays and user-pays principles. This means more pricing based on the internalisation of the external costs.

At the same time, the challenge of shifting towards low-emission mobility and reducing other negative externalities of transport remains intertwined with the outstanding challenges of creating a well-functioning Single European Transport Area and connecting Europe with modern, multi-modal and safe high-performance transport infrastructure networks. A functioning low-carbon transport system thus also supports EU competitiveness – as facilitator of EU trade and services and incentive to global technology leadership.

Generally, the EU's long term goals regarding sustainability, competitiveness and socially inclusive growth require significant investments in new mobility models, renewable energies, energy efficiency, research and innovation, digitisation, education and skills, just to name a few.

As the Commission recalls in the Communication on a European Strategy for Low-Emission mobility[221] "*by mid-century greenhouse gas emissions from transport will need to be at least 60% lower than in 1990 and be firmly on the path towards zero. Emissions of air pollutants from transport that harm our health need to be drastically reduced without delay*". The main elements of the strategy are to (i) increase the efficiency of the transport system (ii) speed up the deployment of low-emission alternative energy for transport and (iii) move towards zero-emission vehicles.

This Staff Working Document aims to refine and extend this vision for each transport sector. It will consider each of these main elements in road transport (cars, vans, buses, coaches and lorries) as well as rail, aviation and shipping. The SWD will update knowledge on vehicle technologies and alternative energy carriers. It aims go beyond earlier analysis in clarifying the land use demands of biofuels used in transport. Systemic efficiency gains, enabled by digitalisation, internalisation of externalities, and spatial planning, will be explored in all scenarios, at different levels of ambition.

5.2.2.1 Activity Results: PRIMES

[XXX to be rewritten, shortened and less focus on PRIMES results only, increased use of additional material discussing similar topics]

In the Baseline scenario, passenger transport activity (including aviation) rises with 36% by 2050 and 44% by 2070, driven by increased wealth. Very large increases are seen in aviation, which doubles over the period, as well as in the use of rail, due to infrastructure build and policies supporting modal shift. Private car transport increases by 27% by 2050 and 33% by 2070.

Passenger transport activity growth compared to 2015 (Gpkm % increase)	**2030**	**2050**	**2070**
Passenger transport activity	17%	36%	44%
Public road transport	9%	18%	24%
Private cars	13%	27%	33%
2wheelers	15%	39%	53%

[221] COM(2016) 501 final

Passenger light duty vehicles	15%	29%	34%
Rail	35%	72%	81%
Aviation	42%	94%	115%
Inland navigation	18%	31%	35%

Freight transport activity grows by half by 2050 compared to 2015 and by 66% by 2070, with rail seeing the largest growth. The 45% growth in rail freight by 2030, 87% by 2050 and 107% by 2070 is due to supporting policies on the development of TEN-T networks, and the internalisation of external costs. Meanwhile, heavy and light duty freight vehicles transport grows by around 50% by 2050 and 60% by 2070. Inland navigation also sees significant continued increases.

Freight transport activity growth compared to 2015 (Gtkm % increase)	**2030**	**2050**	**2070**
Freight transport activity	29%	52%	66%
Heavy duty vehicles	26%	46%	58%
Freight light duty vehicles	26%	52%	62%
Rail	45%	87%	107%
Inland waterway navigation	28%	46%	62%

In most policy scenarios that assumes no specific demand changes, impacts on transport activity due to cost impacts is small compared to the Baseline scenario. Passenger transport activity increases or decreases by at most ~3% by 2050 depending on the scenario. The Circbio scenario sees the largest increases, due to [CHECK] lower prices for biofuels as these become more available for the transport sector. By contrast, fuel prices are highest in the high PX scenario, which sees the largest decreases in activity.

The scenario in-line with 1.5 °C, that assumes that consumer choices will take more climate impact into account, sees an increase in activity by 2050 as measured by means of passenger kilometres, due to the convenience of autonomous public private transport as well as overall lowest energy prices. Simultaneously however this type of transport is assumed to increase the average occupancy rate of cars from 1.55 to 1.83 persons per car, leading to a decrease in vehicle kilometres.

Furthermore, environmental consciousness in this scenario leads to significant reductions in air travel, partly due to video conferencing and telepresence replacing business travel, as well as a modal shift towards high speed rail for regional travel. As a result, aviation increases by only 61% by 2050 and 52% by 2070 compared to 2015 instead of a double and 115% increase in the baseline. Passenger rail sees growth of 81% by 2050 and 95% by 2070, a full 10 percentage points more than in the Baseline scenario.

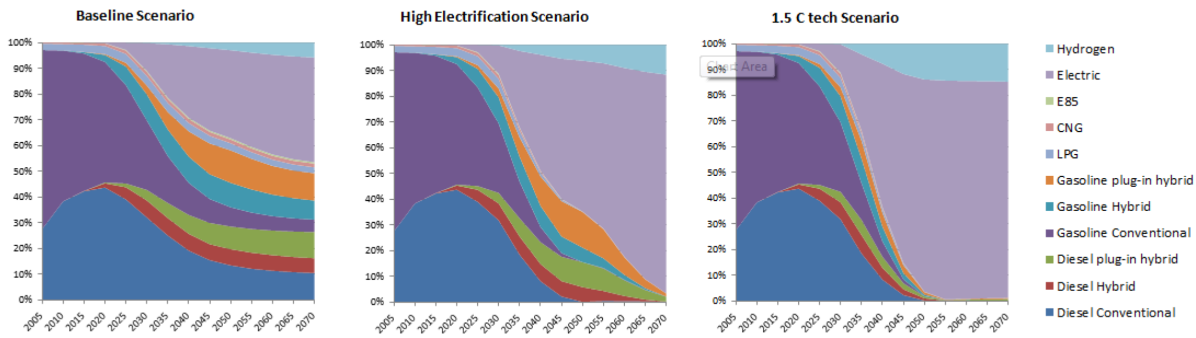
Similarly impacts on freight activity relative to baseline are limited to plus or minus 2% around 2050 in the most extreme scenarios and below 1% in most policy scenarios modelled.

5.2.2.2 Vehicle Technologies

In the baseline scenario, alternative drivetrains are increasingly used in road transport, but do not dominate fully. In cars, conventional diesels decline from 42% of the total stock in 2015 to around 13% by 2050. Conventional gasoline declines from 59% of the total stock in 2015 to around 7% in 2050. These drivetrains are replaced by a variety of hybrid and plug-in hybrid drivetrains. In the long run, battery electric vehicles become increasingly important, reaching 34% of the stock by 2050 and 41% by 2070.

It should be emphasised here that long run uncertainties around the success of technologies are very large. Baseline and 2C / 1.5C scenarios are precisely that: scenarios. Technological progress, consumer choices and regulation can lead to different results. In terms of regulation, note that the Baseline scenario keeps CO2 and Cars standard constant at 2030 levels. Further evolution is driven naturally by technological progress and the divergent modelled preferences of consumers.

Chart: Example of propagation of different drivetrain technologies in cars in the Baseline Scenario, the high electrification scenario and the 1.5°C technology based scenario



By contrast, the high electrification scenario shows a transition towards the full electrification of passenger car transport. In this scenario, electric vehicles are 11% of the stock by 2030, nearly 60% by 2050 and 85% of the stock in 2070, with hydrogen fuel cell cars making up 12% of the stock at that point in time. The Comb1p5 scenario, in-line with a 1.5°C objective, shows the need for a much more rapid and full transition to zero GHG mobility for passenger cars in the two decades after 2030. Once BEVs and hydrogen cars reach the market introduction stage, they need to dominate newly sold vehicles in order to rapidly replace the entire existing fossil fuel based car fleet:

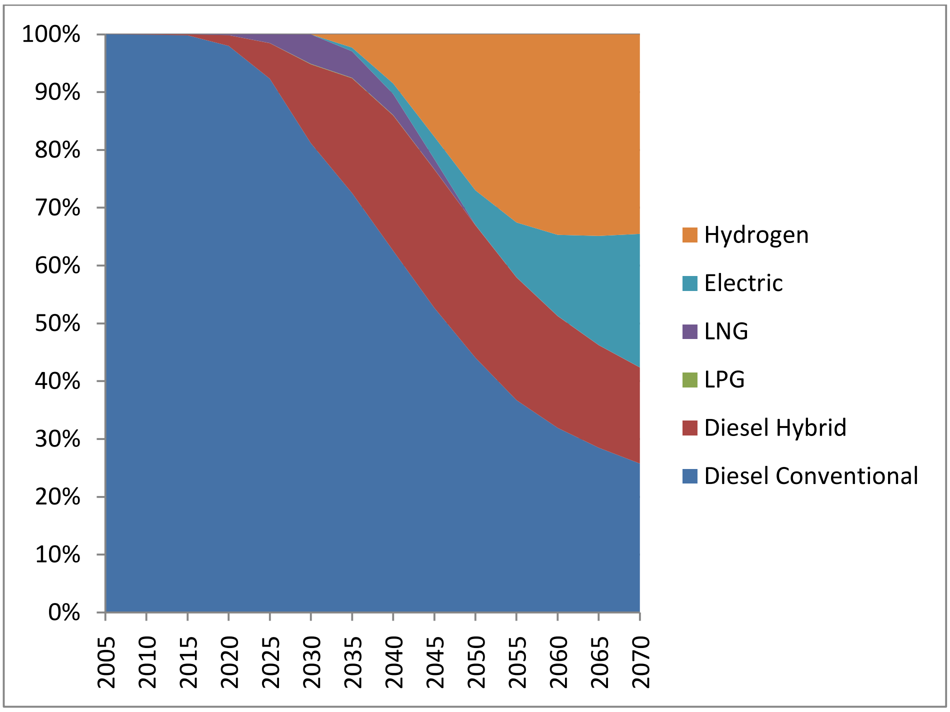
All decarbonisation scenarios show a similar transition to low emissions mobility. While technology uncertainties exist for cars and vans, the current conventional wisdom regards electrification (with a more limited share of fuel cell vehicles) as a viable long term option to decarbonise the sectors

For buses and LDV's, the storyline is similar but for heavy duty vehicles, no such technology has yet emerged. Batteries still have limitations in terms of energy density for long distance heavy goods transport. Trolley or rail systems on highways could solve this issue, but infrastructure costs might be high and would still require significant amounts of batteries for the part of the journey where this infrastructure is not available. The cost of fuel cells is still high, although in the future hydrogen could be made available without large infrastructure investments, by building electrolysis plants, powered by electricity near to logistic hubs. Investments and R&D are needed to further develop advanced biofuels, which do have the potential to power heavy goods transport on road, at the energy densities required, and using current infrastructure. But also aviation will have strong demand for this scarce resource.

The scenarios investigated thus show a variety of technologies being used in different circumstances, depending on the distance travelled, the load, and the infrastructure choices which are available in a given locale.

The high electrification scenario consistent with a 2C Scenario has 20% electric trucks by 2050 and 43% by 2070. These trucks can be battery electric or, in addition, driven by trolley-like systems. The high H2 scenario shows a similar propagation of fuel cell trucks instead of electric trucks. The high PX scenario shows LNG trucks increasing from 35%-41% of the fleet between 2050 and 2070. However, in all of these scenarios conventional diesel trucks remain important, forming around 36% to 51% of the stock in 2050 and around 30% in 2070.These trucks then reduce emissions by using advanced biofuels. As an illustration, the combined scenario is shown below.

Chart: Propagation of different drivetrain technologies in the heavy duty vehicles fleet in the Combined Scenario



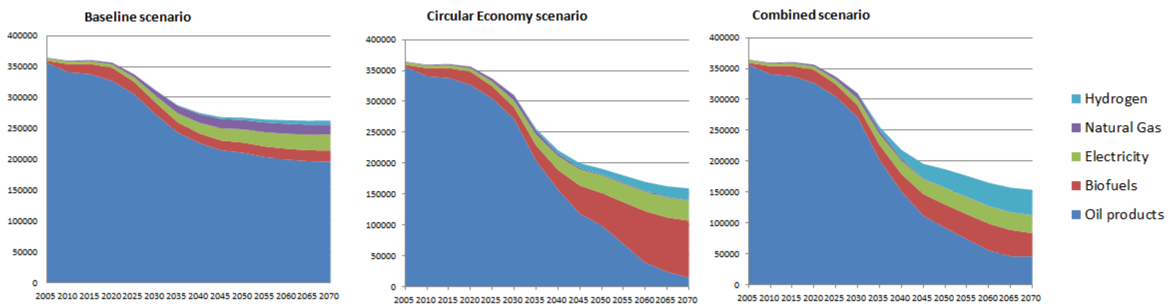
Given the uncertainties, care should be taken with interpreting these scenarios. It is not yet known which option, if any, will win out, or whether a variety of technologies will remain needed.

For *rail* all scenarios show electrification as the main option. In the Baseline scenario, around 85% of rail energy demand is electric by 2050, as is around 80% of rail stock. In a 2C scenario such as the high EE scenario, the transition to electrified rail happens more completely, leading to a fully electrified rail system (in terms of energy demand) by 2070.

5.2.2.3 Fuels: PRIMES modelling

The Baseline Scenario shows transport energy demand decreasing by 26% by 2045 compared to 2015 and roughly stabilising thereafter. Oil products remain dominant, providing 75% of energy demand even in 2070, down from 80% in 2045 and over 90% currently. In the longer run, fuels such as electricity and LNG become visible, but have a niche scale of between 5% and 10% after 2030. Without incentives, biofuels share in the long run is similar to today.

Chart: Fuel mix in the Baseline, circular economy scenario, combined scenario



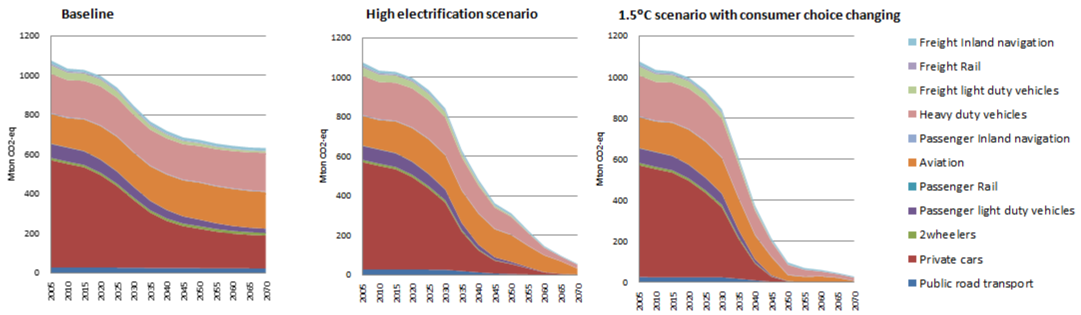
In the decarbonisation scenarios, total energy demand in transport drops 50% to 60% compared to 2015 and around 60% in the 1.5C scenarios. In all scenarios, biofuels are projected to increase significantly, most prominently in the circbio scenario, where there is a 220% increase by 2050 and a 462% increase by 2070. [xxx let's discuss if we want to keep this extreme, the scenario was meantto show that more biofuels are available for transport, but this may be criticised]. Biodiesel for HDVs and biokerosine for aviation are the two dominant applications with biokerosine becoming gradually the most important.

It is only in the combined scenario where there is a more moderate growth in biofuels, by pushing hydrogen in heavy duty vehicles, electrification in cars and sustainable biofuels as well as some P2X for aviation [xxx CHECK] This scenario shows an increase of biofuels of only 130% by 2050, 164% by 2050 and 130% by 2070. [xxx interesting to see what happen on the side of LULUCF, primes did not yet report biomass data for this scenario!]

5.2.2.4 Results: CO2 emissions and transport

The Baseline Scenario shows CO2 emissions from transport, including aviation but excluding maritime emissions, reducing by -18% in 2030, -30% by 2040, and -37% by 2060. As can be seen from below chart, CO2 standards and technological developments lead to a large reduction of CO2 emissions from private cars, by half around 2040, and by two thirds by 2070. Aviation and heavy duty vehicles then become equally or more important sources of CO2 emissions.

Chart: Reductions in CO2 from transport for different scenario



The 2C scenarios show a reduction of around 70% in transport by 2050 compared to 2015 and of 90%-96% by 2070. Private cars electrify and rapidly reduce emissions to -90% by 2050 and 100% beyond. By 2040, private cars have only a 23% share in emissions, having been overtaken in importance by heavy duty vehicles (29% share) and aviation (33% share). However, already in 2030 the combined share of the latter two sectors is comparable to that of private cars. By 2035 it is significantly larger.

In the 1.5C scenario, private cars are zero-emitting by 2050. The rapid penetration of all technologies, fuels and consumer action, as described in the previous sections, leads to a rapid decrease of emissions from heavy duty vehicles and aviation as well. Total emissions are around 10% of 2015 emissions by 2050, and drop to near zero beyond.

5.2.2.5 Aviation

PRIMES scenarios show very large increases in aviation activity, which nearly doubles by 2050 and rises by 115% by 2070. Only in the 1.5 °C scenario where consumers choices increasingly take into account climate impacts, due to shift to high speed rail and videoconferencing, does aviation increase by only 61% by 2050 and 52% by 2070 compared to 2015.

In the PRIMES modelling for the aviation sector, energy efficiency and a shift to biokerosine are the most important drivers of decarbonisation. Energy efficiency here is a combination of factors, relating not just to vehicle technologies, but improved occupancy rates and logistics due to initiatives such as the Single European Sky. Energy Efficiency of air travel in this broad sense, measured as toe/Mpkm, increases significantly already in the Baseline Scenario, by 25% in 2030 compared to 2015, and by 40% in 2050 and 45% in 2070.

In the PRIMES scenarios, electric flights remain a niche [CHECK] though hybridisation can help with efficiency improvements and there are even developments on full electrification of aviation ongoing. Norway has activities to electrify all short haul flights by 2040[222]. Airbus, Rolls-Royce and Siemens are developing[223] a hybrid-electric demonstration aircraft.

[xxx PM RTD/MOVE to add about Clean Sky 2 Joint Undertaking under Horizon 2020]

Once energy efficiency measures have been taken, remaining energy demand needs to be met through low-carbon fuels. Biokerosine and E-fuels are the most important options with the required energy density to provide for longer distance flights. In the circbio scenario, biokerosine grows from 27% in 2050 to 89% in 2070 as biomass becomes available from other sectors not requiring it, notably the industrial sectors [xxx to check with Kostis]. In the high P2X scenario instead, biokerosine remains very limited as e-fuels are used. The combination scenario applies both, thereby limiting biokerosine share to23% by 2050 and 44% by 2070.

In the Baseline Scenario, aviation CO2 emissions grow by 17% by 2050 compared to 2005. In the highEE, circbio, highH2 and highELE scenario, emissions drop by -12% to -16% in the same timeframe. The highPX scenario shows a more significant reduction of 36%. Both 1.5C scenarios show a reduction of over 80% compared to 2005, implying a rapid penetration of all low carbon fuels.

[PM Insert Graph: Decomposition Analysis Comparison of each PRIMES Scenarios, showing contribution of EE, Fuel shift and Activity? Requires P2X data]

A study commissioned for the European Parliament's ENVI Committee[224] determines that to stay below 2°C, the target for EU aviation for 2030 should not exceed 39% of its 2005 emission levels (50% below the baseline) and should be -41% compared to 2005 emission levels in 2050. The PRIMES results do not attain such reductions in most 2C scenarios, but go well beyond them in the 1.5C scenarios. The target from this study implies the need for modal shift and citizens action, a fast penetration of biokerosine/e-fuels, or the more implementation of novel technologies.

Analysis by EUROCONTROL and EASA has identified the most likely scenario of influences on future traffic across ECAC States[225] and modelled these assumptions out to future years. On the basis of traffic forecast, fuel consumption and CO_2 emissions of aviation have been estimated for a theoretical baseline scenario **without** any mitigation action. The results neither include cargo and freight traffic[226]. Whereas in 2010 CO_2 emissions stood at 120 Mt according to this study, in 2040 they are projected to climb to 238.38 Mt.[227] Therefore under the baseline assumptions of traffic growth only and fleet rollover, with 2010 technology applied throughout the projection, CO_2 emissions would almost double for passenger flights departing ECAC

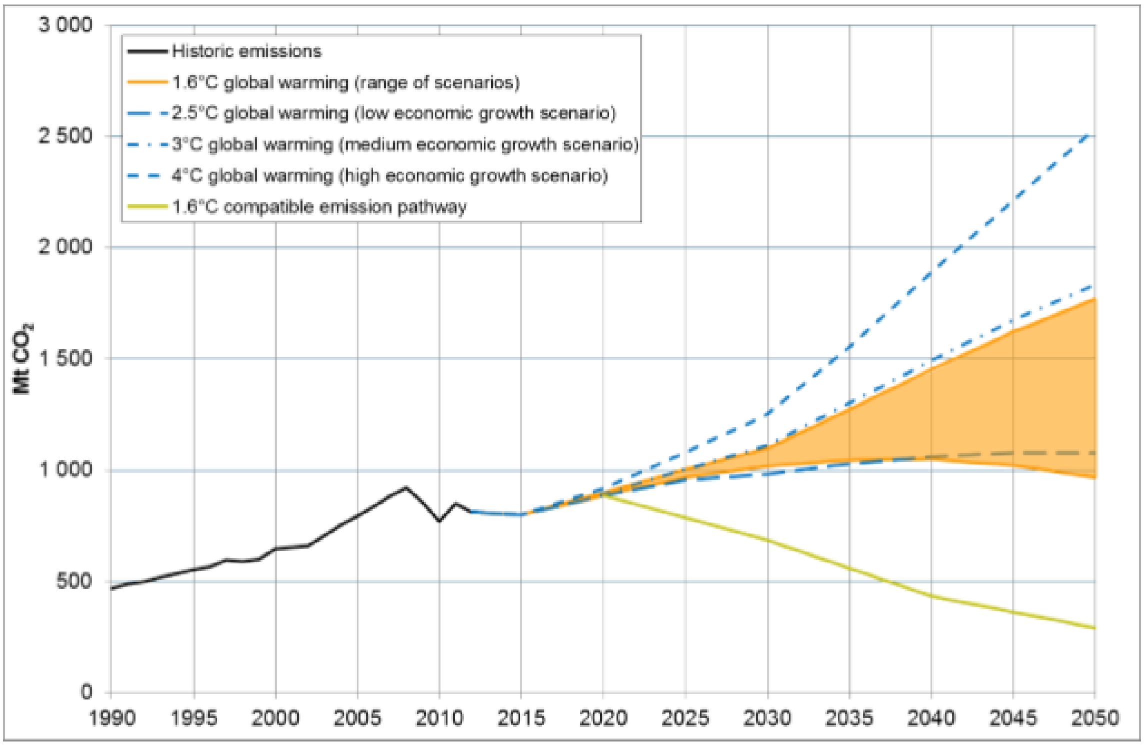
[222] http://www.bbc.com/future/story/20180814-norways-plan-for-a-fleet-of-electric-planes
[223] https://www.airbus.com/newsroom/press-releases/en/2017/11/airbus--rolls-royce--and-siemens-team-up-for-electric-future-par.html
[224] Ibid.
[225] The 44 States comprising the European Civil Aviation Conference, which includes the 28 EU Member States.
[226] Whilst the focus of available data relates to passenger traffic, similar issues and comparable outcomes might be anticipated for cargo traffic, both as belly hold freight or in dedicated freighters.
[227] (ECAC-EU, 3rd Edition, 9 July 2018) p.24, Table 3

airports. This is comparable to the traffic growth as foreseen under the PRIMES projections. According to this EUROCONTROL-EASA study which focussed only at limiting GHG emissions at 2020 levels, aircraft technology and ATM improvements alone will not be sufficient for ECAC State registered airlines to meet this post-2020 carbon neutral growth objective as set by ICAO.

5.2.2.6 SECTION ON MARITIME (including non PRIMES; POLES/PRIMES PRO MEMORI)

The transition towards a low-carbon shipping sector will bring a number of opportunities for the EU but also specific challenges. Emissions from the sector are projected to increase, but need to decrease[228] significantly for a pathway compatible with 1.5C and 2C warming. [INSERT PRIMES/POLES DATA WHEN READY]

Figure 1: Historical, projected and permissible CO_2 emissions from international maritime transport under different economic forecasts



Notes: The projections are based on the expected demand for international shipping under the different economic scenarios and do not consider emission budgets. The green line shows a pathway for the shipping sector that would be compatible with the Paris Agreement (see Cames et al. 2015, the pathway shown here is based on constant share of RCP 2.6 CO_2 emissions).

Source: IEA 2014, IMO 2009, IMO 2015a, CE Delft & Lee 2017, Cames et al. 2015

[228] *Source:* *http://www.europarl.europa.eu/RegData/etudes/BRIE/2017/602062/IPOL_BRI(2017)602062_EN.pdf*

In terms of long-term opportunities, the low-carbon shipping transition will need to rely on alternative and renewable fuels, shifting away from fossil-based marine fuels, leading to significant savings on local pollutants (air quality) and greenhouse gas emissions. For the EU shipping value chain, it is also an opportunity to maintain and increase its competitive edge in a very competitive and growing global market. Innovation in the form of new digital services, energy efficiency technologies, ship intelligence, alternative fuels or new energy storage capacity is expected to create a technology push that will work in synergy with the market pull initiated by new environmental considerations. More broadly, innovation will impact the whole logistic chain from port to port and further inland. Innovation is also expected to take place in business relationship among shipping market actors, leading to improved predictability of cargo flows, more transparency and a more efficient sector. Increased transparency in the form of green shipping certificates or labels on products will increase business and citizens awareness about the carbon foot print of shipping, and will drive the market transformation towards more sustainable fleet and behaviours.

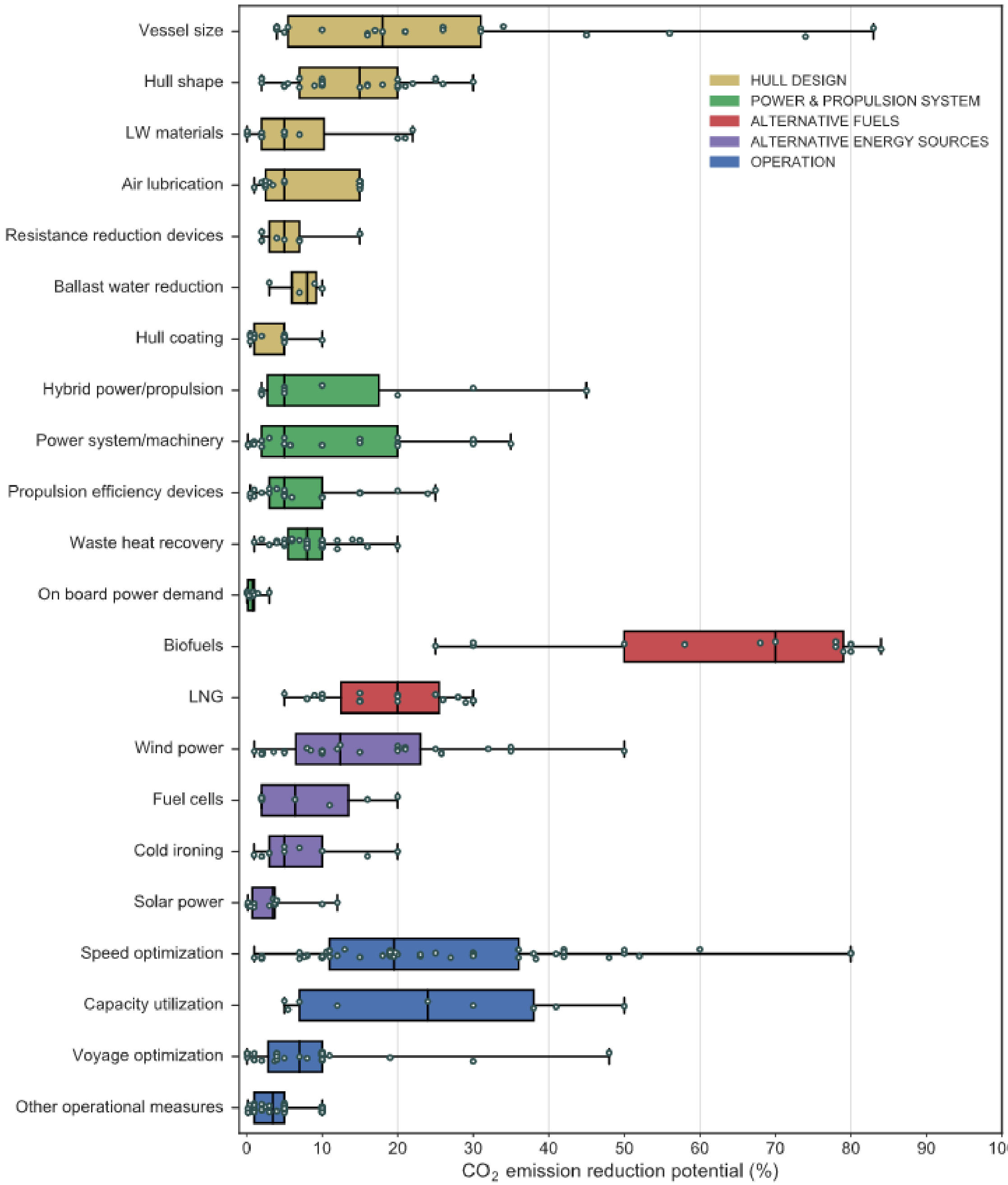


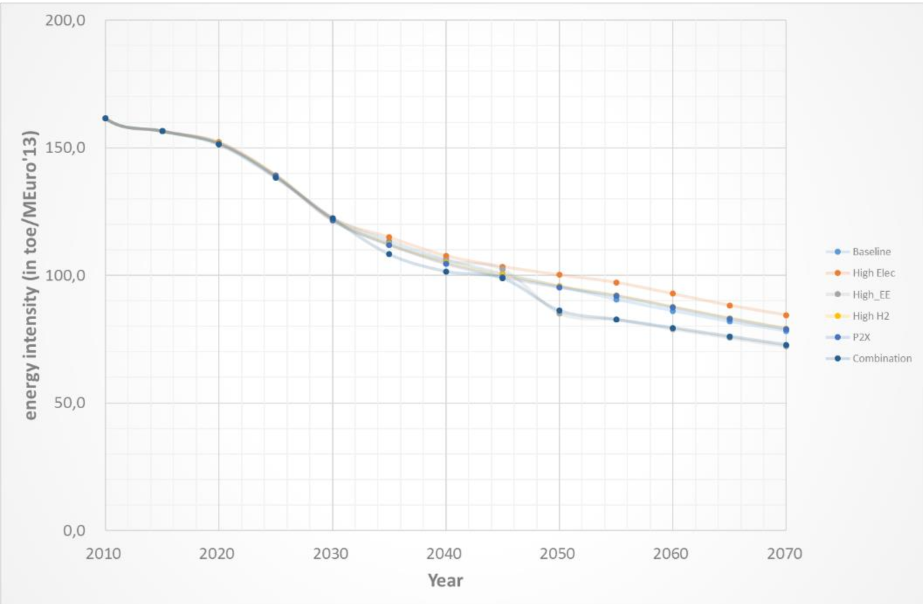
Fig. 2. CO_2 emission reduction potential from individual measures, classified in 5 main categories of measures.

In terms of challenges, the market barriers characterising the shipping sector such as the lack of information, the split incentives issue or the lack of access to capital will continue to pose major challenges if not swiftly addressed. Another challenge relates to the enforcement of regulatory measures, as shipping companies need to be put on an equal footing in order not to distort competition. On the short term, the possible ending of slow steaming practices and the introduction of higher speed regimes could lead to serious increase of GHG emissions if ships do not increase their technical energy efficiency at the same time. Finally, the development of adequate alternative fuel solutions poses serious research and innovations challenges as well as the need to ensure sufficient investment into new bunkering infrastructures.

5.2.3 Industry

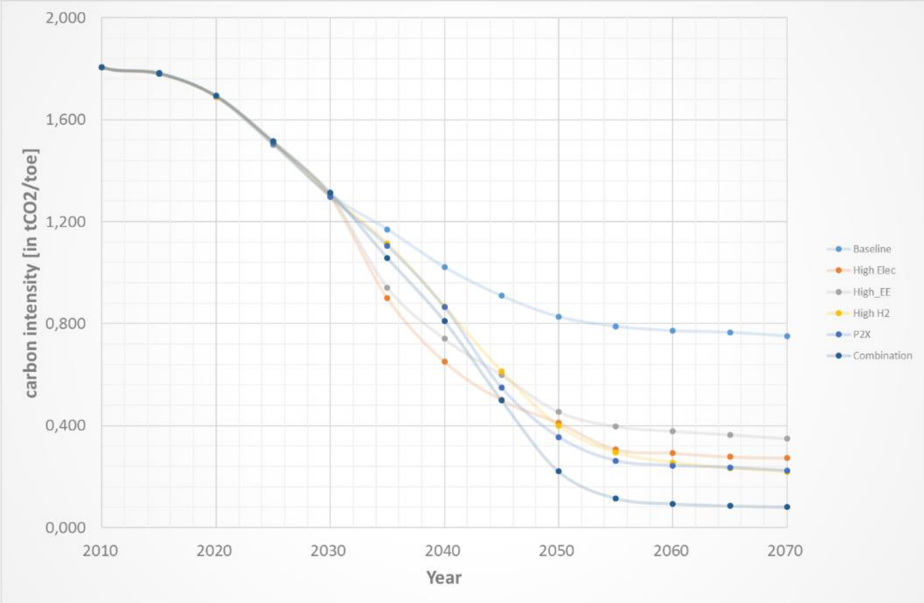
Despite a projected increase in industrial output, final energy consumption in industry is projected to decrease between 2030 and 2050. In the Baseline scenario, final energy consumption in industry, in 2050, amounts to 255 Mtoe, or 23% lower than in 2005. Similar trends can be observed for all the decarbonisation scenarios with notable differences depending on the technology pathway. Electrification of certain industrial processes is not efficient and requires high amounts of electricity. Of all the decarbonisation pathways analysed, the High Electrification scenario shows the lowest progress in energy efficiency: final energy consumption in 2050 is 19.4% lower compared to 2005. With a decrease in final energy consumption of 22.9%, the Hydrogen scenario shows improvements similar to the Baseline. Energy efficiency gains in energy intensive industries are the main driver of change. The rate of change is higher between 2020 and 2030 with a slower pace of change between 2030 and 2050 as energy efficiency options shrink. Figure 17 shows the energy intensity (in toe/MEuro'13) by sector in the High Electrification and Hydrogen scenarios.

Figure 17: energy intensity in industry.



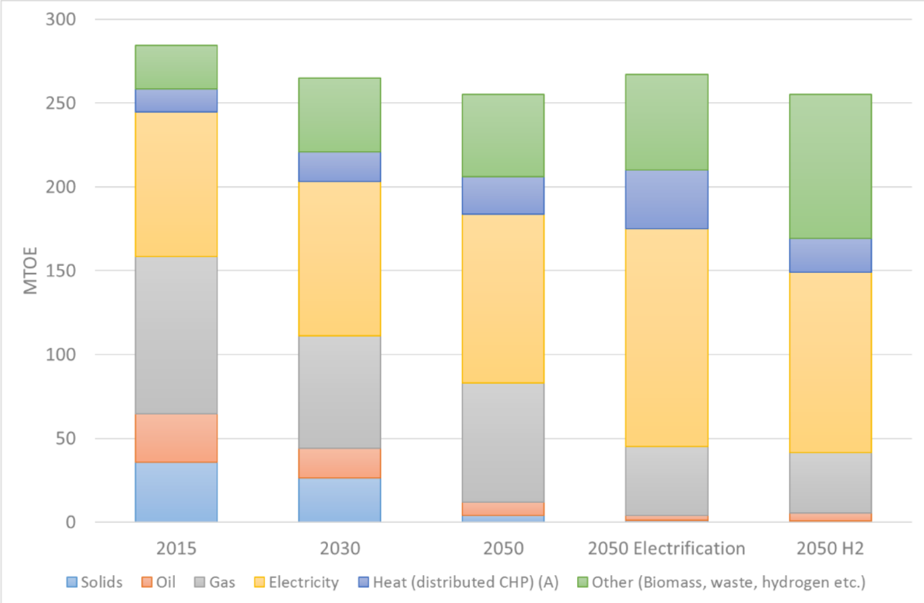
Decarbonisation of the industrial sector is driven by the decreasing energy intensity and by fuel switching to carbon-free energy sources. Compared to 2005, industrial CO2 emissions in 2050 are 40% lower in the Baseline scenario and approximately 70% lower in decarbonisation scenarios with small difference depending on the technology pathway. Figure 18 shows the carbon intensity (in tCO2/toe) by sector in the High Electrification and Hydrogen scenarios.

Figure 18: carbon intensity in industry.



Compared to the rest of the world, the European industrial sector is characterised by deeper cuts in energy use and emissions. According the IRENA 2050 Global Energy Transformation report, in a decarbonisation scenario, final energy consumption of the global industrial sector is set to rise modestly between 2015 and 2050 reflecting strong output growth in emerging economies. In Europe, final energy consumption in industry is set to decreases by 20% over the same period. According to IRENA, industry will reduce CO_2 emissions by more than 45% globally between 2015 and 2050. Over the same period, industry in Europe will reduce CO_2 emissions by more than 60% in a decarbonisation scenario. Figure 19 shows the finale energy consumption in industry by fuel in the Baseline and decarbonisation scenarios. [IEA?]

Figure 19: Final energy consumption in industry by fuel in the Baseline and decarbonisation scenarios.



The potential for energy efficiency remains high in the industrial sector until 2050. In the High Energy efficiency scenario, final energy consumption in 2050 amounts to 227 Mtoe or 31.5% lower than in 2005. This is a significant improvement compared to the Baseline is obtained with a higher level of capital investments. Table 1 shows – for 2050 – the improvements in energy efficiency (compared to 2005), the emissions reduction (also compared to 2005) and the additional annual investments expenditures compared to Baseline.

Table 1: energy consumption, emissions and investments in 2050.

	Baseline	High Elec	High_EE	High H2	P2X	Circular	Combination
Final energy consumption % decrease since 2005	-23,0%	-19,4%	-31,5%	-22,9%	-23,3%	-38,3%	-20,1%
CO2 emissions reductions compared to 2005 (%)	-40,0%	-67,0%	-68,0%	-70,0%	-71,0%	-74,0%	-77,0%
Additional investment expenditure (average annual 2031-50, bn €'13)	--	2,5	26,3	2,2	2,3	14,7	25,2

Irrespective of the technology pathway chosen, decarbonisation scenarios reaching overall emissions reduction of - 80% in 2050 compared to 1990, tend to have lower energy efficiency than Baseline. This is because in industry, some abatement options (especially to decarbonise high temperature process heat) are relatively inefficient and abatement comes at the cost of higher energy consumption. It is possible to achieve high levels of emissions reduction with energy efficiency measures, but this requires a considerable increase in investments as cheap energy efficiency options are exhausted. (Regarding energy consumption and investments, the Circular Economy scenario is similar to the High Energy Efficiency one. The Circular Economy scenario is described more in detail in section 5.5.)

Another important option to reduce emissions in industry is electrification of industrial processes. In all scenarios, electricity consumption in industry increases significantly. Final electricity consumption in 2050, increases 17% in the Baseline scenario and by 51% in the electrification scenario compared to 2015. Scenarios based on alternative energy carriers (the Hydrogen and Power to X scenario) electricity use is similar to the Baseline. Table 2 shows the final use and the overall share of electricity in industry in 2050.

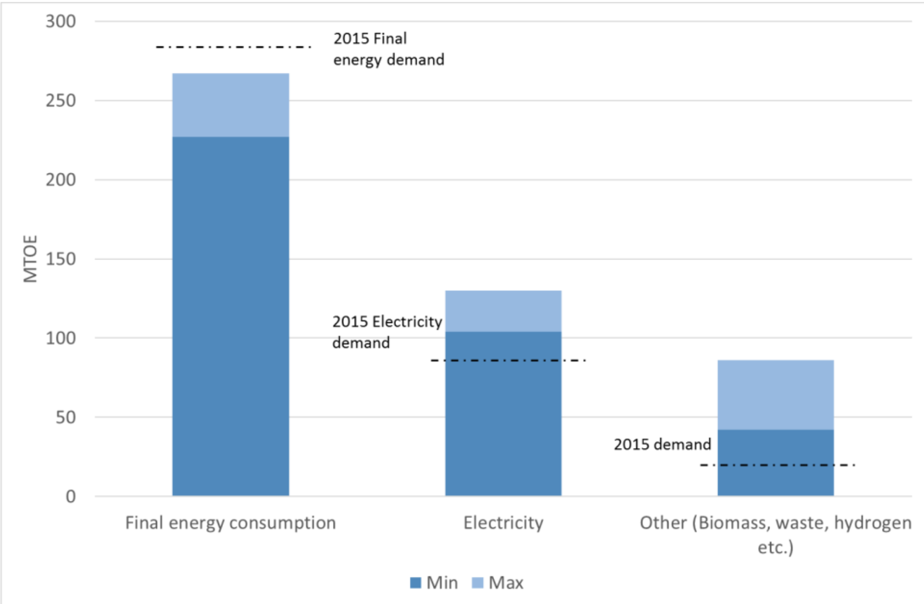
Table 2: electricity use and share in 2050.

	electricity in FEC (Mtoe)	Electricity share
Baseline	100,7	39,5%
High Elec	129,9	48,6%
High_EE	119,5	52,6%
High H2	107,5	42,1%
P2X	103,9	40,9%
Circular	108,8	53,2%
Combination	104,4	45,5%

A part from energy efficiency measures and electrification of industrial processes, other options exist to reduce emissions. Several industrial processes can substitute fossil fuels with hydrogen or biomass. Natural gas can be used in conjunction with Carbon Capture and Storage or Carbon Capture and Use to decarbonise existing processes. The Hydrogen scenario, 32.4 Mtoe of hydrogen are used in the industrial sector in 2050 (of which, 13.4 distributed by pipelines). In the Power to X scenario, hydrogen is combined with CO_2 captured from combustion processes to form methane and other hydrocarbons. In this scenario, 24.4 Mtoe of e-fuels are used in industry in 2050. Biomass and waste use in the Baseline scenario increases by 76% in 2050 compared to 2015 to reach 46 Mtoe. In the Hydrogen, High Electrification and Power to X scenarios, biomass and waste use reaches 50.6, 54.1 and 62.4 Mtoe respectively in 2050 (other scenarios use similar amounts as in the Baseline). In the decarbonisation scenarios reaching – 80% emissions reduction, the PRIMES model projects deployment of CCS technology capturing approximately 58 million tonnes of CO_2 from industrial processes (with small differences between scenarios), but note in the Baseline.

The decarbonisation scenarios described above show different possible technology pathways to decarbonise industry. Which technology will prevail, it is not known; it is however possible to describe the options space the scenarios above are mapping. **Error! Reference source not found.** shows the minimum and maximum value of final nergy demand, electricity demand and use of other fuels across scenarios in 2050.

Figure 20: Minimum and maximum energy use in industry in 2050 across scenarios.



The ranges across scenarios appear somehow limited, however the analysis show that cost increase rapidly as we increase the ambition of single options beyond their estimated potential (see investment costs reported in Table 1 above). While it is not possible to predict the effect of disruptive innovations and unforeseen technological development, the scenarios present realistic projections based on the current best estimate of costs and technologies.

In the context of more ambitious decarbonisation targets, it is possible to further reduce GHG emissions in industry. This, however, requires a higher level of investments. Table 3 shows (for 2050) the improvements in energy efficiency (compared to 2005), the emissions reduction and the additional annual investments expenditures compared to Baseline for 3 scenarios reaching more ambitious decarbonisation targets in 2050. A more detailed description of the PRIMES model results for industry can be found in Annex [x].

Table 3: energy consumption, emissions and additional investments compared to Baseline in 2050 in high ambition scenarios.

	Combination	**1,5 C**	**Behavioural C.**
Final energy consumption % decrease since 2005	-20,1%	-20,1%	-38,8%
CO2 emissions reductions compared to 2005 (%)	-77,0%	-81,0%	-84,0%
Additional investment expenditure (average annual 2031-50, bn €'13)	25,2	26,6	24,1

Analysis: PRIMES results, literature, studies/roadmaps stakeholders, other studies GROW?

5.3 Energy supply

Energy supply will be analysed in detail in electricity and gas supply subchapters below. In addition, biomass supply will be analysed in the forest and land use sector subchapter. However, some general observations can be done for the entire level of Primary Energy Consumption (PEC).

Already in the Baseline, the PEC is substantially reduced. Looking at decarbonisation scenarios, they achieve the **PEC reductions (compared to 2005) ranging between 21 and 48% in 2050** (compared to 34% achieved in the Baseline). The consumption then remains stable till the end of the projection period - in all except in 1.5C scenarios which then further, albeit only slightly, reduce PEC in the period due to their higher decarbonisation ambition. The lowest reductions are achieved in P2X and COMBO scenarios as they both use **synthetic fuels which can satisfy the decarbonisation objective without significantly curbing the demand and at the same time require large amounts of electricity to produce** them. EE and CRIC scenario achieve the highest (and similar between them) reductions. Surprisingly, 1.5 C scenarios do not require the highest reductions thanks to combined technology options for zero-carbon fuels supply.

Looking at the **energy mix** (in Gross Inland Consumption - GIC), **solids virtually disappear from the energy system** already in the Baseline while even smaller negligible quantities remain in the decarbonisation scenarios (less than 5 Mtoe in 2050 in all decarbonisation scenarios).

Oil shares decline most sharply from 31% in 2030 to between 23 and 11% in 2050 with sharpest decreases in 1.5C scenarios and lowest in EE and CIRC (as these two scenarios mostly target other than transport FEC sectors). And **yet oil remains the dominant fossil fuel in the GIC**.

For **natural gas, the share of 22% in 2030 declines to between 16 and 12%** in 2050 with little differentiation among scenarios (better visible and described in sectoral results). Gas remaining in the energy mix at such high levels is enabled by CCS. These figures are consistent with the shell Sky and IEA ETP B2DS scenarios in which the share of natural gas drops to 15% and 10% of primary energy demand respectively [add more studies, notably ENER Gas in 2050 study].

Nuclear energy share that declines in the Baseline, **increases in decarbonisation scenarios** but only slightly and with negligible differentiation among scenarios.

Renewables share increases in a spectacular manner growing to between 51 and 63% in 2050 and remaining stable till 2070. Applying the formula for **RES share calculation in final energy consumption** as in recast of RED[229], the share of RES would grow from 2030 target of 32% to **between 65 and 100% in 2050** and to **between 78 and 109% in decarbonisation scenarios in 2070**[230]

5.3.1 Power sector

In line with earlier analyses of the Commission (notably in CE4A package), electricity supply increases significantly in all decarbonisation scenarios by 2050 - both compared to 2030 projections and to the Baseline. The increases in 2050 compared to 2030 range from 33% (EE scenario) to 117% (P2X scenario). Presented differently, increases in 2050 compared to the Baseline range from 8% in EE scenario to 75% in P2X scenario. The EE scenario has many of the final energy demand uses electrified (transport, industrial processes, heating), which drives up the electricity demand yet at the same time very ambitious EE measures keep this demand increase in check. Also CIRC scenario offsets large part of growing electricity demand by decreasing the industrial demand linked to reduced production of new materials and the residential sector demand by reducing the number of surface of dwellings. Otherwise, ELEC, H2 and COMBO scenarios display higher increases (driven by either additional electrification or electricity use linked to H2 production) but these are dwarfed by the increases in P2X scenario (since e-fuels production requires large amounts of electricity and is not very efficient process) and 1.5C scenarios (either because of demand linked to creation of negative emissions or why so in 1.5C B?). In all scenarios the electricity supply has to increase further by 2070 (between 52 and 163% compared 2030 or between 8 to 87% compared to the Baseline) with highest increases in P2X, where this is linked to further deployment of e-fuels that become competitive with other energy carriers. Almost as big increases in 2070 can be found in 1.5C scenarios - this is linked to increased decarbonisation ambition pursued in 2070 and this mainly happening because of further deployment of electrification, H2 and e-fuels. In comparison, the Shell Sky scenario shows a strong electricity growth of 66% between 2030 and 2050 while electric consumption hardly grows during this period in the IEA ETP B2DS scenario, which opts for other decarbonisation options.

[229] Explain how to calculate.
[230] explain why over 100%

The demand for electricity, it will be analysed in detail in other sections of this chapter but some common observation can be made here for all the FEC sectors (i.e. main source of increase in electricity demand is which FEC sector etc).

In all scenarios, the additional electricity demand is fully satisfied by domestic production – mostly by wind and solar, some contribution comes from additional nuclear capacity. In some scenarios also biomass consumption grows but again without increasing imports for the feedstocks. The very significant increase in electricity demand can be fully met by EU resources as illustrated by PRIMES results and many other studies. There can be, however, concerns about availability of land and public acceptance – especially of the grids. This issue is however not possible to capture in modelling.

All decarbonisation scenarios have assumptions about deployment of Demand Side Response (DSR) and consequently all display a higher demand side load factor than the Baseline. On the top of DSR, e-fuels help to further attenuate the peaks and valleys of electricity demand (in addition to the DSR) and thus these scenarios have the highest Demand Side Load Factor.

The changes in power generation illustrate how in the context of growing ETS prices fossil fuels (unless equipped with CCS) are reducing their role, renewables become increasingly competitive (also facilitated by possibility of storage in EVs batteries, in H2 and e-fuels and demand side response). On the other hand, despite high ETS prices, nuclear and CCS are persistently blocked by high costs (reflecting also public acceptance issues). Looking at power mix across scenarios it can be thus observed that both solids and liquids disappear by 2050. While liquids have been marginal already in 2030 (0.5% share), the solids share in 2030 still stood at 13%. Natural gas is the only fossil fuel left in the mix but its shares fall from 9% in 2030 to 4-5% in 2050 in H2 and P2X and even less in all the others. The lowest share is found in EE and CRIC scenario that have the lowest electricity demand satisfied almost entirely with RES (but what about balancing?). It has to be emphasised that e-CH4 is only marginally used in power generation even in P2X scenario (less than 1Mtoe in EU28). Likewise, H2 is not used for power generation but provides important services as additional storage. While e-CH4 could be used for storage it is not observed in any of the scenarios even the P2X one (since H2 fulfils this role much more efficiently).

RES shares in power generation are very similar across scenarios getting close to 85% in 2050 already (10 pp above the Baseline) and remaining at this level in 2070. This is above the IEA ETP B2DS and the Shell Sky scenarios, which reach RES-E shares of 75% and 77% respectively [add more scenarios]. RES-E share[231] calculated according to RED recast shows very similar pattern with shares incrementally higher thanks to formula that excludes own consumption. Among renewables, wind is clearly the dominant technology having 50% of the power mix in 2050-70 in all decarbonisation scenarios. This is a spectacular growth from 28% in 2030 and a 10 p.p. increase compared to Baseline projections. Solar share (combined with other RES technologies) grows up to about 15% (from 8% in 2030). Interestingly, the Baseline projects similar solar share

[231] Explain formula.

but with much lower electricity consumption. Biomass & waste share remains quite stable across scenarios and in 2050-70 perspective (6-10%) – this highest shares are found in P2X, COMBO and 1.5C scenarios (due to XX in P2X and COMBO, role of biomass in creating negative emissions in 1.5C scenarios)

Finally, the nuclear share remains rather stable across all scenarios and in 2050-70 perspective (12-16%). It is a small decline compared to 2030 projections (21%) but no difference to 2050-70 Baseline projections. While the share of nuclear is also almost unchanged compared to the Baseline its capacity grows in majority of the scenarios (see below). The Shell Sky and IEA ETP B2DS scenarios see the nuclear generation roughly stable in absolute terms. Due to the different growth rates of the electricity sector as a whole, nuclear energy is only responsible for 11% of electricity production in the Shell Sky scenario but still for a quarter of electricity production in the IEA B2DS scenario [add other studies].

Both increase in electricity supply and increased shares of renewables are even more visible looking at capacities. This type of analysis is helpful to analyse the role of gas and nuclear whose shares in power mix were showing only small changes. The overall electricity capacities increase (compared to 2030) in 2050 between 48 and 116% and in 2070 between 61 and 146%. Against this background wind capacity increases (compared to 2030) between 103 and 205% in 2050 and grows even further in 2070 (113 to 259%). The solar capacity shows even more spectacular growth: between 137 and 331% in 2050 and between 153 and 400% in 2070.

While the share of gas declines in the power mix, the situation is much more nuanced looking at capacities. In 2050, in all except one decarbonisation scenarios, the capacity (compared to 2030) declines (between -7 and -29%) while it grows by 22% in ELEC scenario (explain why). In 2070, however, the gas capacity (compared to 2030) increases in some scenarios: EE, CIRC, ELEC (most substantially because of XX) and 1.5C scenarios and declines in others: H2 and P2X (where again H2 substitute gas in the balancing services).

While nuclear share is stable across scenarios, in 2050 the nuclear capacity (compared to 2030) shows some small decreases (in EE, CIRC, ELEC) and small increases in all other decarbonisation scenarios. In 2070, all scenarios show increase in nuclear capacity ranging from 1 to 24%. The highest increases can be found in scenarios deploying H2 and e-fuels as nuclear provides the baseload electricity - crucial for profitable operation of electrolysers.

The role of CCS is very limited in all scenarios as no assumptions were put forward to support deployment of the technology. It is incentivised by the ETS prices but clearly less competitive than renewables and with e-CH4, H2, EVs batteries and biomass available in sufficient quantities, the need for fossil fuels equipped with CCS to balance the electricity system is much lower. Consequently, the share of electricity generated from installations equipped with CCS remains in all but one scenarios below 1% (P2X has 1.2% in 2070 due to XX). Even in 1.5C A scenario, which uses CCS to create highest amount of negative emissions, the combined share of CCS-equipped generation reaches only 0.8% in 2070. [Analyse 3rd party studies for the role of CCS]. As to capacity it amounts to maximum X GW (in 2050) and Y GW in 2070 in 1.5 CA scenario and all other scenarios have much smaller capacity.

As a result of the changes described above the power sector decarbonises completely already by 2050 and remains decarbonised in 2070. Moreover, the power sector is the source of negative emissions (in non-negligible quantities) in P2X, COMBO scenarios and then mostly in 1.5C scenarios which both relay on this technology to achieve carbon neutrality by 2070. The power sector also produces negative emissions in the IEA ETP B2DS scenario while it still produces but negligible emissions in the shell Sky scenario [add more scenarios].

As electricity supply grows, storage plays increasingly prominent role in all decarbonisation scenarios albeit there is clear demarcation between EE, CIRC and ELEC scenarios which relay more on hydro pumping and batteries and other scenarios that develop H2 and e-fuels in larger quantities and also benefit from storage offered by H2 – necessary to accommodate the largest amounts of variable renewables which in these scenarios are needed to respond to the highest electricity demand. Looking at absolute values (i.e. TWh operated), there are multiple increases in the volume but in terms of ratio of storage to net electricity generation, it remains unchanged from the Baseline for most of the scenarios – except EE, CIRC and ELEC (which do not develop storage based on H2 but very efficiently use storage of batteries and additional hydro pumping). Likewise, looking at installed capacity of storage, there is a multiple increase in all scenarios but the EE, CIRC and ELEC have the lowest ratio (13-16% in 2050-70) while other scenarios display the ratio between 20 and 36% (in 2050-70). This is because H2 in remaining scenarios offers competitive storage services but not very efficient and thus requiring bigger capacity. It is use of storage that also inflates the electricity demand (as would be recorded in energy balances under "energy branch consumption"). The use of electricity for storage/synthetic fuels production (excluding hydro pumping) would amount to between XX and YY% of electricity demand in 2050 and ZZ and YY% in 2070 being the highest in the P2X scenario as the production of e-fuels is the highest in the scenario and this process is using a lot of electricity with conversion rate of, on average 3.8. Interestingly, transmission and distribution losses do not follow the same path as storage and, except for ELEC scenario they do not increase compared the Baseline despite significant growth in electricity supply. This reflect assumption in PRIMES that additional electricity will be harvested in a very efficient manner from North Sea and a few spots in the South Europe rather than by very scattered electricity network.

In order to finance this transition significant investments are needed - much higher than what already observed in the Baseline. For the electricity grids alone, in 2050 the investments increase between 32 and 65% and in 2070 between 13 and 41% - compared to the Baseline. As for the investments in power plants, in 2050 they increase between 55 and 189% - compared to the Baseline. In 2070, the investment decrease slightly in EE and CIRC scenario as they manage to keep electricity demand growth in check but grow in all other scenarios and up to 62%. The performance of scenarios in this respect is closely aligned with the magnitude of electricity demand increase. Despite, these heavy investments, electricity prices (which in PRIMES modelling enable to fully recuperate capital and all other costs) increase only slightly in 2050 in EE and CIRC scenario whereas they decrease visibly in 2050 in all other scenarios and in 2070 in all decarbonisation scenarios (up to 25% in P2X scenario). This is due large penetration of renewables, which by 2050 are fully competitive, do not require any subsidies and have near zero marginal costs. Operation of ample storage as is the case of P2X scenario enables to further reduce the operational costs.

Not covered in PRIMES but can write a para or two the following issues

- self-consumption

- decentralisation

5.3.2 Gas sector and new energy carriers

While its share in Gross Inland Consumption declines, in all decarbonisation scenarios, gas remains relevant in the energy mix. However, depending on the nature and the ambition of the scenarios natural gas is increasingly complemented by synthetic gas that is produced from H2 and CO2. In several scenarios (notably H2 scenario), some traditional uses of gas (e.g. residential heating) are substituted by H2.

With primary energy consumption declining (to a different extent depending on assumptions but consistently across all scenarios), this means that absolute consumption of gas (in Mtoe) is declining. While gas consumption stood at some 300 Mtoe in 2030 (and remained at this level in the Baseline against the primary energy consumption that was stagnating), in the decarbonisation scenarios it declines in 2050 to between 92 Mtoe and 235 Mtoe and in 2070 between 78 and 228 Mtoe. The lowest consumption is found in 1.5C B scenario and the highest in P2X one.

There are two sources of differences between the PRIMES scenarios: reduction of demand and the availability of alternative energy carriers on the supply side. On the supply side, all scenarios relay on some domestic natural gas production albeit it declines throughout the time reflecting the depletion of domestic resources. While the natural gas production in the EU, in 2030, stands at 78 Mtoe by 2050 it declines to 58 Mtoe in the Baseline already and even slightly more in the decarbonisation scenarios. In addition to natural gas production, the bio-CH4 is increasingly used in decarbonisation scenarios as it is fully interchangeable with natural gas and does not have direct emissions (just as biomass and waste, where it is classified in energy balances). The potential for bio-CH4 is, however, fairly limited and no additional assumptions were made in the scenarios about either increasing the domestic potential (interesting pilot projects develop in the Netherlands with this respect, notably XX project) or increasing imports of bio-CH4 (via existing pipe-line infrastructure or in LNG form). The whole consumption of bio-CH4 thus ranges between XX in 2050 and YY in 2070 and is mainly used in ZZ sector and in maritime transport.

The other "traditional" source of supply is the natural gas imports. These natural gas imports of the EU stand in 2030 at 229 Mtoe and declines to between 23 and 136 Mtoe in 2050 and between 24 and 114 Mtoe. The lowest imports can be found in scenarios that have the lowest energy demand (COMBO, 1.5C) and the highest in H2 and P2X scenarios which do not pursue the switch away from gas but rather substitute (part of) it with synthetic gas. Obviously the reduction of gas imports have huge impacts on the security of supply and reduction of fossil fuels imports bill, which are described in section XX (which one???).

The "new" source of supply is synthetic gas production in the EU. There is already one pilot project in the EU that produces synthetic gas (XX in Germany), many more in the world and the gas industry has put forward a plethora of studies which point to this development (at different levels of magnitude) with main rationale being decarbonisation and security of supply objectives, possibilities to use existing gas infrastructure, efficiency of the transmission and new business and jobs opportunities linked to new product. This is why an explicit assumption was put forward in P2X assumption to have the necessary production assets in the light of the demand for gaseous renewable fuels. Consequently, P2X scenario has 80 Mtoe of synthetic gas production in 2050 and 95 Mtoe in 2070. The COMBO scenario that builds upon strength of all other 2 C scenarios has production of some 40 Mtoe throughout 2050-70 and 1.5 C scenarios build on this technology development, even marginally increasing the scale to meet more ambitious decarbonisation targets. By 2050, all synthetic methane in PRIMES scenarios is produced from H2 obtained electrolysis (and not steam reforming) and thus the final product can be labelled as e-CH4. CO2 molecules come in majority from CCS processes (be it in power generation or in industrial processes), then bio-genic sources (bio-mass combustion) and only smaller part from direct air capturing and thus indeed the e-CH4 produced has no direct emissions.

Substantial part of e-CH4 is produced by renewable electricity. Looking simply at the average EU electricity mix, renewables have there in 2050-70 some 80% share, which would mean that according to current statistical procedures, 80% of e-CH4 would be considered renewable.

It was an explicit assumption in P2X and H2 scenario to have the obligation of the growing share of renewable gas in the gas distribution, this was necessary to create a stable demand for such fuels and thus overcoming typical market failures that are well represented in the PRIMES model. Such share is respectively XX in 2050 and YY in 2070.

Importantly, from CH4 also more complex synthetic hydrocarbons can be produced and if fulfilling conditions described above for natural gas they can be labelled as e-fuels or even renewable e-fuels. Such fuels can play very useful role in transport. Their deployment reaches up to XX in 2050 and YY in 2070 in PtX scenarios and at smaller scale is present in COMBO and 1.5 C scenarios.

Finally, on the supply side, H2 to some extent can replace natural gas while fulfilling the same objectives as e-CH4. Different magnitude of the H2 deployment was explored in all decarbonisation scenarios. Already in 2011 Roadmaps, some limited deployment of H2 was envisaged in most of the decarbonisation pathways ever since there was no major breakthrough in the H2 technologies but the costs lowered, new pilot projects were launched and the industry increasingly sees bigger role of H2 in its decarbonisation visions and pathways. While in the Baseline, H2 develops only as a niche application (for freight transport) and its deployment is limited to a few Mtoe, the decarbonisation scenarios have the deployment that ranges between 16 and 116 Mtoe in 2050 and 23 and 157 Mtoe in 2070. The H2 scenario by definition has the highest production but also the COMBO scenario incorporates many H2 uses and 1.5 C scenarios escalate it further to reach the net zero emissions in 2070 (albeit not to the extent as H2 scenario). The smallest role is played by H2 is scenario that focus on curbing the demand (EE and CIRC) and in ELEC and P2X scenario its role is also limited since in competition with other energy carriers. Only small part of H2 is distributed via pipelines as the current technical requirements allow for blending up to 15% of H2 in the natural gas pipelines (and most likely this limit will be increased to 20%) while the largest part is used directly (in transport and some industrial uses but not in heating as fuel cells in this application are not projected to become competitive). Even in the H2 scenario with the largest deployment, there is no need for establishment of dedicated H2 infrastructure nor the upgrade of existing natural gas pipes so that they can carry higher H2 blends or pure H2.

In PRIMES a very simple assumption was made about production of H2/ e-CH4 (in the scenarios with larger deployment) domestically. However, a recent climate mitigation study on behalf of the German industry association argue for a large-scale import of e-fuels from regions with a high potential of cost effective wind and solar energy in Northern Africa and the Middle East.[232] Another assumption was made that every MS produces these fuels in sufficient quantities for its own demand. The current studies indicate that some areas could be better suited to production of H2/e-CH4 be it because of abundant production of renewables (e.g. offshore in the North Sea) or proximity to nuclear power stations or close to industrial buyers. It could well happen that H2/e-CH4 are produced with renewable electricity only (with dedicated wind or solar parks or via green certificates scheme) –depending, among others, on ambition of renewables policies. This was, however, not yet explored in PRIMES modelling.

The demand for gas, it will be analysed in detail in other sections of this chapter but some common observation can be made here for all the sectors.

As already mentioned in power supply chapter, gas remains part of the power mix. While its shares in power mix decline (compared to 2030 and the Baseline), in absolute values, several scenario even show (in 2070) increases in absolute consumption of gas in the power mix. Large part of natural gas plants is equipped with CCS. Interestingly, neither H2 nor e-CH4 play a large role in power generation – they are clearly not competitive with renewables and their only value comes in fulfilling balancing needs. Still, even in this application, natural gas equipped with CCS is more attractive cost-wise.

Also as mentioned in power supply chapter, production of H2/e-CH4 requires large amount of electricity increasing significantly electricity demand. On the other hand it offers storage for the balancing of the electricity system and thus improves the load factor.

Natural gas has also some non-energy uses (organic chemistry). Some differentiation in this respect was pursued in PRIMES scenarios. CRIC scenario replaces some part of natural gas with XX and 1.5 C scenarios altogether reduce the demand for this type of products.

[232] Climate Paths for Germany, Study for the Association of German Industry, https://www.bcg.com/publications/2018/climate-paths-for-germany-english.aspx

Final demand for gas overall declines in all final energy consumption sectors thanks to energy efficiency measures and behavioural change (the latter only in 1.5 C B scenario) albeit in P2X and H2 scenario the reductions are the smallest thanks to H2/e-CH4 deployment.

Most of the e-CH4 (in the scenario that develop it) is used in residential sector (where the gas demand has been the highest in the Baseline), closely followed by industry, for energy purposes. Transport makes only small use as only small portion of vehicles can use gaseous fuels. Conversely, H2 (in the scenarios that develop it at considerable scale) is mostly used for transport – mostly for HDV which do not have the option of electrification. Industry is the second biggest source of the demand as several sectors (but not all of them) find H2 a viable alternative.

Deployment of H2/e-CH4 requires considerable investments in their production and distribution assets. The current projections indicate (on average for 2031-50 and 2051-70 periods) some 5 bn/year investment requirement in H2 scenario and around 30 bn/year in P2X scenario. While COMBO scenario (that has both H2 and e-CH4) keeps those investments at 12 bn/year, the 1.5 C require over 16 bn/year.

5.4 The industrial transition

5.4.1 The Industrial Transition

Industry is a major part of the EU economy and responsible for a large share of GHG emissions, as well as energy and resource consumption. Compared to other energy sectors, industry has not undertaken sufficient transformational steps to deep decarbonisation. With the need to progress even more deeply with emission reductions, industry – together with transport – come strongly into the picture. This section collects visions, present analyses and explains the challenges on how industry can reduce its emissions. These are compared with the results of modelling performed for the Commission, using two different models, PRIMES and FORECAST[233].

The observed lesser effort in the industrial sector compared to other sectors is often attributed to the intense global competition and the need to invest in specific sub-sector and process solutions. Perhaps for these reasons, it is less clear how deep reductions in industrial sector emissions will be achieved. But the solutions do seem to be there. European companies have been increasingly active in researching ways to decarbonise their activities and finding break-through low-CO2 innovations. Given the long time to develop new technologies and the investment cycles of industry (20-30 years), it is likely that the deep emission reduction technologies that will be deployed by 2050 are already known today[234]. Several recent projects and examples are demonstrating how deep decarbonisation of processing industries can happen.

More specifically, for the energy-intensive industries, fuel-switching alongside with the successful demonstration and deployment of breakthrough technologies – in particular in

[233] A detailed description of the models can be found in Annex IV.
[234] Breaking Through. Industrial Low-CO2 Technologies in the Horizon, IES, 2018.

relation to process-based emissions – and the implementation of demand side measures (energy efficiency and circular economy) bear the potential to deep emission cuts in this sector. In addition, Carbon Capture, Utilization and Storage ("CCUS") technologies may be required for deep CO2 emission cuts, in particular also to reduce process-emissions and to use captured carbon for reuse (such as mineralisation towards construction products).

Contrary to the energy related emissions, dealing with process emissions requires a more sector specific approach. The solutions for mitigating process emissions need to be specific for many processes, even requiring changes in the established business models. On the other hand, such changes can create new opportunities, including the possibility for increasing the collaboration between industries based on win-win solutions. These measures can be combined with the development of alternative materials, for instance replacing cement and steel with wood in the construction sector.

Lately the concept of circular economy has been gaining momentum as a further option to reduce emissions in industry. Circular economy takes an industrial value chain approach for the decarbonisation of industry. It stretches from dealing with the energy intensive processing of materials, via increasing material efficiency and redesigning consumer goods, to the end-of life including reuse/recycling strategies. Combined with energy efficiency, it can deliver significant contributions from the demand side, helping to maximize resource efficiency. Most importantly, such demand side measures can facilitate and reduce the cost of the transition, as the supply side will not have to take all the burden and it will be possible to avoid the most expensive decarbonisation options, especially in the harder to abate sectors.

In order to better account for all these facets of transition, this section will both discuss sector specific pathways as well as other, more horizontal, emission reducing solutions.

5.4.2 Transition Pathways for Industry

XXX The overview of the results will be extended when the updated Fraunhofer report arrives. References to more economy wide or industry wide studies will also be added (need to choose most relevant between 7, 8, 9, 10, 11, 17, 20, 26, 55, 56, 61, 70, 74 + the Climact/ECF analysis in the additional industry material). XXX

There is an increasing amount of evidence indicating that continuation of current efforts and policies in industry can achieve additional GHG emission reductions by 2050, ranging between 55 to 65% compared to 1990[235, 236]. Such reductions, stemming mainly from foreseeable technological developments, megatrends such as digitalisation and automation, as well as existing measures and policies, cannot deliver though the desired levels of ambition.

Achieving the reductions required for a 2°C level of ambition, estimated between 75 to 85% GHG reductions compared to 1990, is found by many studies as being possible, even by using to a large extent existing technologies[237, 238]. Moreover, such reductions are found to be

[235] Climate Paths for Germany, 2018, BDI.
[236] Reference XXX
[237] Climate Paths for Germany, 2018, BDI.
[238] Reference XXX

economically viable, creating also opportunities for the European industries[239]. Energy efficiency, CCS, increased use of sustainable biomass and electrification, with electricity increasingly produced by renewables, are important means to achieve this. Other pathways often discussed relate to hydrogen, clean gas and lately circular economy measures. Such pathways are also feasible, and often found even more beneficial for the EU Industry, but do require more investments in infrastructure (not necessarily in industry), possible changes in existing industrial value chains and technological breakthroughs.

The analyses indicates that further increasing the level of ambition, even up to GHG emission reductions close to 95% consistent with a 1.5°C level of ambition, makes necessary the availability of all pathways and technologies mentioned above[240, 241]. In order to achieve higher reductions, a common approach across subsectors is not sufficient; sector or even process specific solutions need to be applied to the more carbon intensive sectors and processes.

The above results are consistent with the ones of PRIMES, as presented in 5.3.2, independent of the level of ambition. In fact, independent of the pathways chosen to be analysed in the various studies, the conclusions do broadly converge to the availability of different solutions for achieving the 2°C level of ambition.

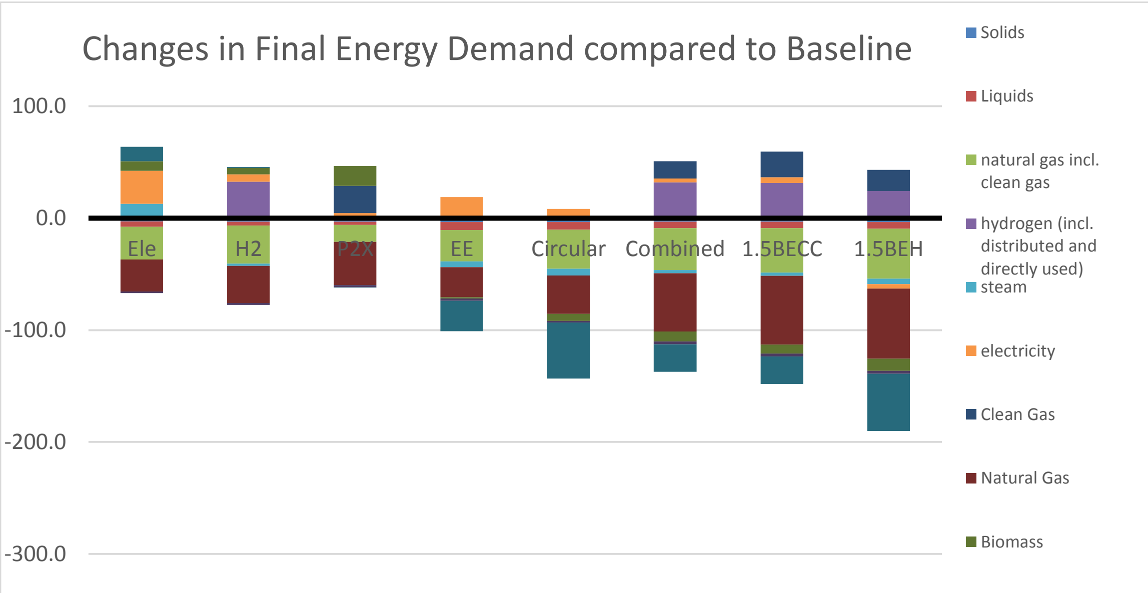


Figure XXX (not successful, to be improved)

At the same time, most studies indicate that a higher ambition in industry seems to require a relevant stepping up of the effort, but not radical – and possibly not viable – solutions[242]. This would require that all options are available and all enabling conditions are in place. An important enabling condition is that the energy sector has been mostly decarbonised, both

[239] A number of industries have already voluntarily committed to reducing their emissions, while identifying sustainable and economically viable low carbon business cases. For examples see e.g. the European Round Table of Industrialists (ERT).

[240] Reference XXX

[241] Reference XXX

[242] Reference XXX

referring to the power sector, but also to the gas sector. Concerning the later, PRIMES results highlight the importance of clean gas, biogas and hydrogen replacing natural gas in the distribution networks. Therefore, in order to achieve higher levels of ambition, technological breakthroughs are necessary, as well as significant investments in infrastructure[243].

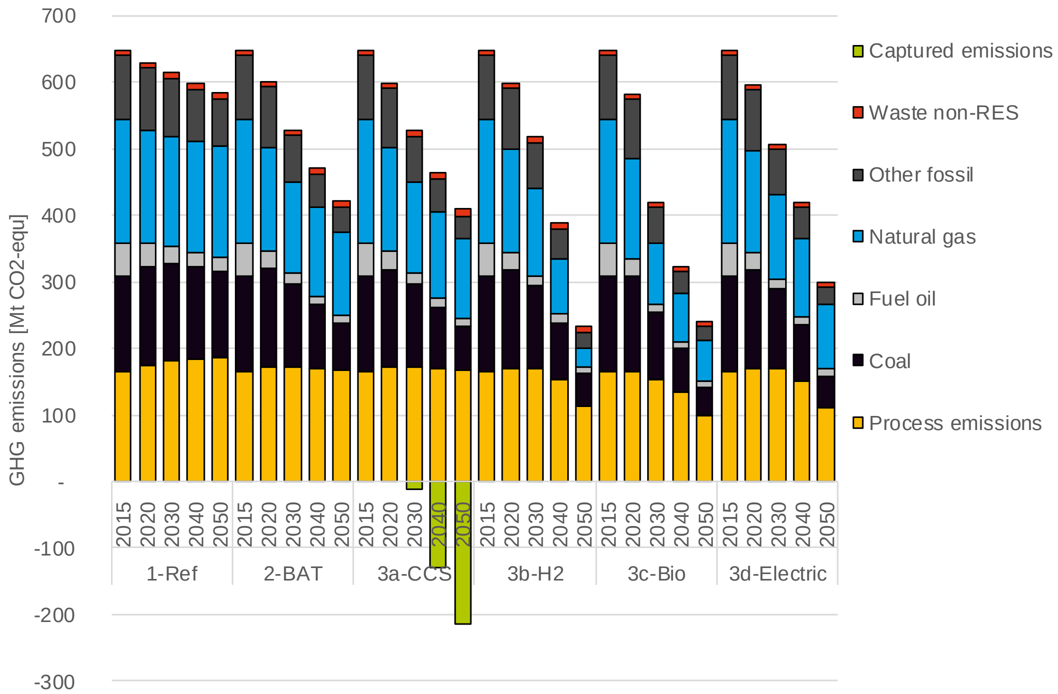


Figure XX21: Total industrial GHG emissions by scenario and energy carrier (EU28)

Figure XXX above gives an overview of the results of the FORECAST model. The GHG emissions, mainly coming from process related emissions and fossil fuels, are observed to decline steadily during the projection horizon in all scenarios, with all emission sources contributing to these reduction. However, the relative importance of process related emissions is increasing towards 2050, while other emission sources like coal, other fossils or natural gas are decreasing. However, in all four decarbonisation scenarios, also fossil fuels are still used in 2050. Reasons are long capital lifetime, inertia in the technology stock replacement and remaining niches (e.g. a natural gas boilers installed in 2030 are most likely still in operation in 2050) [244].

The above point to a need for a policy framework that can facilitate these investments, support innovation and incentivize all the necessary changes, without risking the position the global competitiveness of the European industries. Considering the longevity of industry's capital intensive investments and thus the inertia in replacing industrial plants, the timing of such policy actions becomes more important when ambition increases. Industrial investments made today will most likely be in place in 2050, thus it is important to ensure that proper incentives are given for the most low carbon investments to be made.

[243] Reference XXX
[244] From the preliminary Fraunhofer study, waiting for the updated version and raw data to replot the figure

5.4.3 Iron & Steel

As an energy-intensive industry, the European steel industry accounted in 2016 for around 7% of the verified emissions of all stationary installations of the European Union and around 22% of its industrial emissions excluding combustion.

Steel making consists of two main processing routes, each having about equal share in the steel making process in Europe: primary steel making, based on the iron ore reducing process in a blast furnace (BF), and secondary steel re-melting, using scrap metal in an electric arc furnace (EAF). The majority of the emissions come from the iron reduction process, where there is a chemical reaction between carbon and iron ore, producing molten iron, which is then converted to steel. Therefore the two main methods to decarbonise steel is either to increase the use of secondary steel making route, which can be even almost carbon free in the case of low carbon electricity generation, or to reduce the carbon intensity of the BF route shifting to EAF.

The efforts so far to reduce the emissions from the BF route have mainly focused on resource efficiency (energy and material), as well as improved process control. Therefore the additional potential for improvement through technological improvements (mainly via energy efficiency) of the specific process are diminishing[245]. The best alternative for deep decarbonisation is the replacement of BF route by EAF using direct reduced iron (DRI)[246], reducing the carbon intensity of the process by 36%[247].

Two questions arise at this point: the origin of the DRI and the use of CCUS. If the DRI is produced using natural gas the total reductions will be around 30%[248], while if it is produced via electrolysis iron ore reduction it allows for electrification of the most energy-intense step in iron making[249], leading to reductions up to 80-85%. The combination of the above (except in the case of electrolysis) with CCS has the potential to significantly bring down steel's emissions and reductions to around 80%, for example with the deployment of technologies like HIsarna (smelting reduction) or ULCORED (direct reduction) – both connected to CCS (or CCUS).

In general, studies[250] [251]indicate that without electrolysis or CCUS, the shift away from BF can lead to sector emission reductions around 25-30% compared to 2010. In the cases of electrolysis

[245] Study on Energy Efficiency and Energy Savings Potential in Industry and on Possible Mechanisms, ICF, 2015.

[246] DRI can be considered as a source of clean iron units that can be used both in the EAF and the BF route.

[247] Steel's Contribution to a low-carbon Europe 2050, Boston Consulting Group, 2013.

[248] European Steel. The Wind of Change, European Commission, 2018.

[249] Under the ULCOS programme, supporting low-energy primary steel making, this is known as ULCOWIN and ULCOLYSIS.

[250] Steel's Contribution to a low-carbon Europe 2050, Boston Consulting Group, 2013.

[251] Power to Steel: Reducing CO2 through the integration of renewable energy and hydrogen into the German Steel Industry, Otto et al, 2017.

or CCUS the reductions can be much higher, going from 55% in the case of only CCS up to 85% when CCS is combined with breakthrough technologies[252].

The analysis performed by PRIMES has a more positive view on the possible reductions in iron and steel in the baseline scenario. By switching from solids to biomass, implementing technology improvements and strong energy efficiency measures, PRIMES projects 72% decrease in CO2 emissions compared to 2010. In the case of the 2°C options and the application of additional low carbon measures the emissions are projected to decrease between 83% (in the EE scenario) up to 94% (in the H2 scenario). The higher ambition scenarios manage to deliver even higher reductions, up to 98%, by using even more hydrogen than the H2 scenario and clean gas, which replaces natural gas and is distributed through the gas network. *(Note: Such a paragraph and a related graph will be included for each subsector, but it's not currently in. An additional paragraph will be included when the Fraunhofer study arrives, and an effort will be made to have a graph comparing own and external analysis in order to have an overview of an indicative range of results).*

The shift from primary steelmaking to secondary smelting of steel scrap depends on the availability of scrap metal within the EU market and does not depend on technological developments per se. Europe has a large stock of steel and further increase in demand is not expected. Still there are many factors that significantly reduce the amounts of steel that can be recycled, most importantly low collection rates, losses in the processes, downgrading of steel and copper contamination[253]. These issues can be resolved to a large degree by improving circularity, thus significantly increasing the availability of scrap so that the secondary route can increase its share from around 40-45% today up to 85% in 2050[254]. The combination of these measures can reduce the emissions of the sector by around 75%, as primary production would continue to serve the rest of demand. Demand side measures in the context of the circular economy could then further reduce steel produce by the primary route, like increased use of aluminium in manufacturing and reduction of the number of circulating cars due to transport becoming a service[255].

The main technological pathways, with projects under development, emissions reductions and market entry are summarised in the table below:

Technology option	Examples	TRL	Max. emissions reductions	Market entry
DRI RES-H2	HYBRIT, GrINHy, H2Future, SuSteel, SALCOS	7	up to 95%	2030/2035
DRI RES-Electrolysis	SIDERWIN,	6	up to 90%	2025/2030

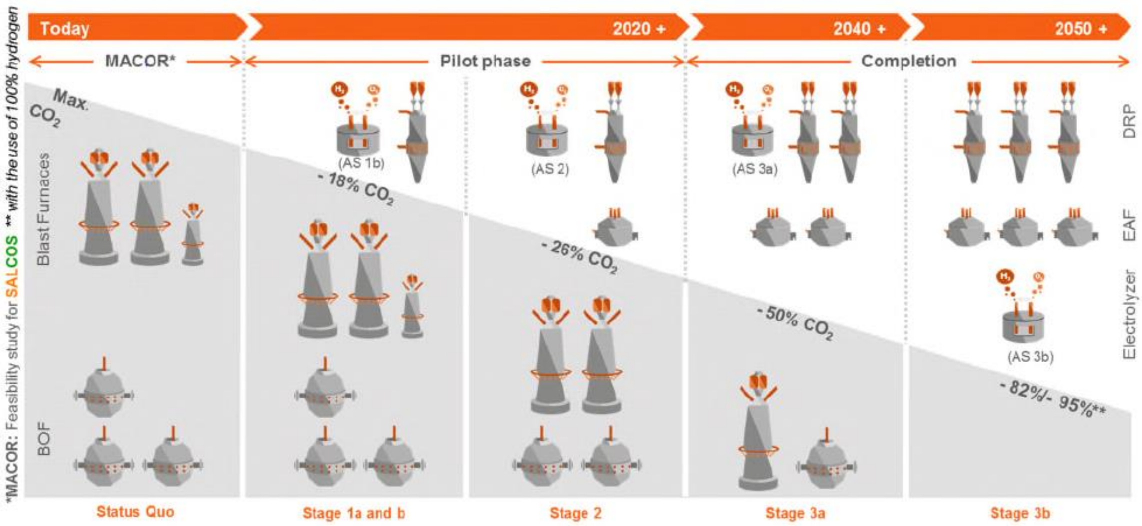
[252] A Steel Roadmap for a low carbon Europe 2050, EUROFER, 2013.
[253] According to the study "Steel's Contribution to a low-carbon Europe 2050" by BCG (2013) the maximum share of scrap steel based on current practices is 44%.
[254] The Circular Economy, Material Economics, 2018.
[255] In the context of a circular economy, the reductions in demand could possibly reach the point where the available scrap steel would be able to cover most of the demand.

	ULCOWIN			
Bath smelting[256]	HIsarna	5-6	up to 20%	2025
Top gas recycling[257]	ULCOS-BF, IGAR	7	up to 30%	2020/2025
Carbon capture and usage	Carbon2Chem, Steelanol	5-7	case specific	2025/2030
Near net shape casting	Castrip, Salzgitter, ARVEDI ESP	8-9	up to 60%	2015

Source: Ecofys report[258]

The above indicate that measures need to be taken in both fronts, both from the shift away from the BF route, as well as to use the of more scrap metal. Combining the most ambitious of both options could reduce the emissions of the sector up to XXXX%.

The preferred solutions though imply certain challenges[259]. Most of the technologies discussed in this section for deep decarbonisation have a low technology readiness level (TRL), thus more R&D will be required before commercialisation of these technologies. For the shift from the BF route, existing facilities will need to be replaced by new plants, while since these plants will be mostly electrified a very high share of renewable electricity is necessary to deliver the high emission reductions. The transformation to nearly zero steel making is possible, see one example in figure XX, but it will take time and determination, starting from now, and spreading the technologies across the sector so the total steel production is nearly zero carbon in 2050. As for the increased circularity, concentrated policies across Europe will need to be introduced.



[256] Higher potentials with CCU/S: up to 80%.
[257] Higher potentials with CCU/S. up to 60%.
[258] Ecofys, 2018, Impact on the Environment and the Economy of Technological Innovations for the Innovation Fund (IF) in the Fields of Energy-intensive Industries, Renewables, CCS/CCU and Energy Storage (under review – to be published in October at the latest)
[259] A Steel Roadmap for a low carbon Europe 2050, EUROFER, 2013.

Figure XX Staged transformation of a steel plant to hydrogen reduction and electric arc furnace through use of natural gas in transition stages in SALCOS[260]

At the same time this presents significant opportunities for the industry, as it can further modernize, reduce its costs along with reducing its carbon intensity. The replacement of older plants could allow for opportunities of industrial symbiosis e.g. with chemical industries for the production of plastics or fertilisers, in which case application of CCUS could provide economic benefits.

5.4.4 Chemicals

The European chemicals industry accounted in 2016 for around 4% of the verified emissions of all stationary installations of the European Union and 14% of the industrial emissions excluding combustion[261].

Chemicals is a very complex, wide and diverse sector, with even more diverse subsectors. The petrochemical and the basic inorganic subsectors produce the organic (olefins, alcohols, aromatics) and inorganic (ammonia, chlorine) building blocks for the chemical industry. The polymer (plastics) and specialty chemical (paints, dyes) subsectors produce intermediate or end user products, while the consumer chemicals (soaps, cosmetics) are sold to end customers[262]. Petrochemicals, basic inorganic and polymer subsectors account for roughly 70% of the sectors GHG emissions, and therefore these are the subsectors most studies focus upon.

Own analysis and other studies[263] [264] [265] [266] indicate that energy efficiency improvements and fuel switching can reduce significantly emissions in 2050 compared to 2010 by 55-60%, largest

[260] https://salcos.salzgitter-ag.com/. SALCOS plans to proceed in stages: (Status quo) add a natural gas based direct reduction plant for iron ores to the actual plant layout at the integrated site in Salzgitter. The direct reduced iron from this plant is to be fed to the existing blast furnaces (CO_2 reduction: 10%, as natural gas used for reduction has a certain amount of hydrogen content). (Stage 1a and b) Additionally, large amounts of hydrogen may be fed to the process, replacing the needed natural gas partly. The hydrogen will be produced via electrolysers operated with power from renewable resources. (CO_2 reduction: 18%). (Stage 2) Addition of an electric arc furnace plant, to be fed with the direct reduced iron from the then already existing direct reduction plant (CO_2 reduction: 26%). (Stages 3a and 3b) Further steps are principally based on the same approach as the steps before, leading to the complete transformation of steelmaking from the blast furnace/basic oxygen technology to direct reduction/electric arc furnace route in the decades to come. The maximum CO2 reduction possible by the SALCOS concept in this ultimate configuration is 95%.

[261] Some chemical company data are reported under the fuel combustion category; hence, actual emissions of the chemical industry may be higher.

[262] European Chemistry for Growth, CEFIC, 2016.

[263] European Chemistry for Growth, CEFIC, 2016.

[264] Energy Efficiency and GHG emissions: Prospective scenarios for the Chemical and Petrochemical Industry, JRC, 2017.

[265] Low carbon energy and feedstock for the European Chemical Industry, DECHEMA, 2017.

[266] Study on Energy Efficiency and Energy Savings Potential in Industry and on Possible Mechanisms, ICF, 2015.

share of reductions coming from fuel switching[267]. Moreover chemical plants can install abatement technology with an average emission reduction of N2O by 90% in the same period.

Deeper emission reductions are also technically possible, 85% or even above, but would require change of feedstock, application of CCUS technologies and increased recycling. In particular, the lower use of fossil-based feedstock, replaced by the use of hydrogen, bio-based material and recycled materials, which show strong potential for emission reductions. Although many new business opportunities are created, at the same time significant investments would be needed so that industrial plants could adapt to this business model.

The potential of bio-economy is not clear, with conflicting evidence. Bio-based ammonia and methanol production may not have a high potential, unless low cost synthetic gas is available, contrary to the bio-based production of cracker products (from naptha to e.g. bio-ethanol), assuming though increased availability of sustainable biomass in Europe[268] [269] [270]. On the other hand, the use of low carbon hydrogen and CO2 as feedstock for the production of low-carbon methanol shows strong potential for emission reductions, but has a number of pre-requisites including wide availability of affordable renewable energy[271][272].

It is particularly worth highlighting the importance of improved recycling of plastics. Today only 60% of plastics is recovered in average in Europe, with 60% used for energy recovery purposes. Plastic waste can be significantly reduced by increasing the mechanical and feedstock recycling[273] up to 60-70% of yearly plastic waste volumes[274] [275]. This would require standardisation, improved collection and sorting and would result in both more limited use of raw material (of fossil origin)[276], as well as less energy, since recycled plastic is a less energy demanding process. As a result a cascading use of plastics would be introduced, with downgrading (with mechanical recycling) or upgrading (with feedstock recycling) or after the plastics have degraded to energy recovery.

Moreover the chemical industry can be an ideal consumer of the CO2 produced in its own processes, and this can lead to both the avoidance of emissions if embedded in long lived material or at least reduced use of fossil fuel [277]. As an example the production of methanol from hydrogen and CO2 is identified as a beneficial option, assuming that it is economic in the

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[267] According to the ICF (2015) study the economic potential is much lower than the technical one.
[268] European Chemistry for Growth, CEFIC, 2016.
[269] In EU the two main bio=based materials available for the production of bio-chemicals are straw and forest products.
[270] Chemistry for Climate, ECOFYS, 2018.
[271] Low carbon energy and feedstock for the European Chemical Industry, DECHEMA, 2017.
[272] Ramboll, 2018, CCU: technological and regulatory aspects (under revision)
[273] Mechanical recycling refers to the mechanical processing of waste plastics to produced recycled polymers. Feedstock recycling refers to the chemical or thermal processes breaking down polymers into products that can directly replace raw material.
[274] Chemistry for Climate, ECOFYS, 2018.
[275] The Circular Economy, Material Economics, 2018.
[276] EU production of polymers could reduce by 7%, European Chemistry for Growth, CEFIC, 2016.
[277] Low carbon energy and feedstock for the European Chemical Industry, DECHEMA, 2017.

future. Certain studies calculate the potential for using CO2 to 90% for petrochemicals, basic inorganics and polymers and 75% for specialty and consumer chemicals[278] [279].

The main technological pathways in the chemicals sector, with projects under development, emissions reductions and market entry are summarised in the table below:

Technology option	Examples	TRL	Max. emissions reductions	Market entry
CCU – Methanol		6-7	Significant, if renewable power is used	2030
CCU- Functionality driven	Recycled plastics-syngas	7	Significant	2030.
New hydrogen production route		5	up to 90% with CCS up to 100% if renewable power is used	2030
CCS for ammonia		6-7	Up to 90%	2025
Bio-based #1			Significant, exact number depending on the upstream emission factor of biomass	2030
Bio-based #2 (drop in)		7	Significant, exact number depending on the upstream emission factor of biomass	2020

Source: Ecofys report[280]

Many of the above potentials can be realised if chemical plants are installed together in industrial parks with plants from the chemical or other sectors, sharing their energy and material resources[281].

Overall the analyses performed indicate that there are three preferable pathways for the chemical industry:

- Circular economy, combined with increased used of bio-based material as feedstock. The limitations of this approach seem to be on the access to sufficient biomass feedstock.
- Electrification, combined with the use of hydrogen as feedstock. This pathway tends to have very high investments in renewable generation, electrolysers and other infrastructure, thus possibly being the higher cost pathway but at the same time the one with the higher reduction of emissions.
- CCUS may be a less costly route but delivering the required reductions in the case of CCU only when energy used is renewable. A combination of these options, together with the reductions of N2O emissions, seem to be the most promising approach. Industrial symbiosis can further support this option, as it can provide for the high

[278] European Chemistry for Growth, CEFIC, 2016.
[279] Energy Efficiency and GHG emissions: Prospective scenarios for the Chemical and Petrochemical Industry, JRC, 2017.
[280] Ecofys, 2018, Impact on the Environment and the Economy of Technological Innovations for the Innovation Fund (IF) in the Fields of Energy-intensive Industries, Renewables, CCS/CCU and Energy Storage (under review – to be published in October at the latest)
[281] Low carbon energy and feedstock for the European Chemical Industry, DECHEMA, 2017.

demand for hydrogen and CO_2 as feedstock, together with other benefits related to the provision of heat, waste management etc.

5.4.5 *Non-metallic minerals*

Together, the cement and lime sectors accounted for about 8% of total greenhouse gas (GHG) emissions in the scope of the EU Emissions Trading Scheme (ETS) in 2016 and for about 28% of the industrial sector emissions within the ETS. In 2016, CO_2 emissions in the cement industry were about 112 Mt, while they were at about 30 Mt in the lime industry.

The sector of non-metallic minerals is an energy intensive sector which includes three main subsectors: cement, glass and ceramics. Together with the iron & steel and the chemicals sectors they account for 70% of total industrial emissions. Cement (and lime) is the main emitting subsector, being attributed with 80% of the sector's emissions. The remaining emissions of the sector are approximately split between glass and ceramics.

Cement has two main sources of CO_2 emissions: the burning of fossil fuels in the clinker/lime furnace and the process related emissions from the decarbonation of the limestone. Together these two sources make up about 85 % of total CO_2 emissions of the entire Portland Cement production value chain.

By using today's best available technologies, mitigation potentials are limited, including energy efficiency[282], fuel switching to less carbon intensive fuels (namely biomass) and reducing the clinker content in the cement. For instance, the remaining thermal efficiency potential until 2050 is estimated to be less than 10%[283]. Thus, breakthrough technologies are essential to achieve the necessary reductions, which together with circular measures (resource, material and product efficiency) and CCUS, can reduce emissions up to 75% compared to 2010[284].

A similar reduction potential is assessed on a global level by the IEA Technology Roadmap on "the Low Carbon Transition in the Cement Industry", where it is found that the integration of CCUS in the cement production can reduce global cement emissions between 2014 and 2050 by 48%, while new technologies for the reduction in the clinker to cement ratio in cement by 37%. On the other hand, although the UK Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050 for cement identifies a similar very high potential for CCUS, leading to 62% of reductions, it finds less benefits in reduction of the clinker content, at around 5-10%. Both studies identify also the fuel switch to biomass as an important emission reduction solution.

The big uncertainty in cement, highlighted in the sometimes contradicting expectations on how much the carbon intensity of cement can be reduced, related to the generally low TRL of the many innovative technologies that are in the stage of R&D today. These options range from new raw materials to new cement alternatives, but even extend to the more efficient use of

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[282] Study on Energy Efficiency and Energy Savings Potential in Industry and on Possible Mechanisms, ICF, 2015.

[283] CSI und ECRA, 2017

[284] The role of Cement in the 2050 Low Carbon Economy. CEMBUREAU, 2013.

concrete in the construction sector, when considering the entire value chain. There are various concepts under development, with a large number of concepts and projects covering different ambition in reducing cement carbon intensity, from 30% to even 90%, and with the tendency to have specific applications.

Low carbon cements are substances made from alternatives to Portland clinker, which can be produced using less energy and release fewer emissions in productions. Some novel cements can even lead to reinforced concrete[285]. One of the most advanced binders is claimed to be Solidia, which based on company claims could possibly reduce CO2 emissions up to 70%[286] compared to the standard ones. This is mainly achieved by altering the raw materials used, thus reducing process and combustion emissions. So far though these cements have been slowly penetrating the market. Experts justify this for a variety of reasons, most notably the existing regulatory framework, which is based on the Portland cement, their low technological maturity and the limited applications they may have.

Significant potential lies also in the increased material efficiency and substitution[287], in the context of a circular economy, not considered in most analyses. Although cement cannot be recycled as other material, there is an opportunity to recover up to 30-40% of unused clinker from concrete at end to life, replacing new cement. If used to produce higher strength and lower carbon intensity aggregates, the recovered cement can replace up to 80% of new cement in construction, saving almost half the CO2. Moreover if building components could be re-used and buildings designed for disassembly, the need for new cement production would decrease. Another alternative is wood-based construction, since timber can have a similar strength to reinforced concrete. Despite though the obvious benefits in carbon savings, it is often viewed that wood-based construction entails more risks due to its reduced stability, ability to handle compression and shorter lifecycle. In general though an opportunity lies here, which has not been assessed sufficiently compared to other options.

The main technological pathways in the cement/lime sub-sector, with projects under development, emissions reductions and market entry are summarised in the table below:

Technology option	Examples	TRL	Max. GHG emissions reductions	Market entry
Less carbon cement (new binder)	Aether	6-7	30%	2020
Low carbon cement (new binder)	Celitement	6	50%	2022
Low Carbon cement (also CCU: CO2 absorbing concrete)	Solidia	8	70%	2020
CCS Post combustion		8-9	95%	2022
CCS (direct separation)	LEILAC project	5-6	~70%*	2025

285 Making Concrete Change. Chatham House, 2018.
286 http://solidiatech.com/wp-content/uploads/2018/05/ERA-Discovery-FINAL.pdf
287 The Circular Economy, Material Economics, 2018.

* only process related emissions

Source : Ecofys report[288]

The European glass and ceramics industry accounted in 2016 for around 2% of the verified emissions of all stationary installations of the European Union and around 6% of its industrial emissions excluding combustion.

Moving to the decarbonisation potential of the glass and ceramics sub-sectors, this is mainly centred around the drying and firing process. Certain energy efficiency improvements can be performed, but their potential is found limited due to the advances the past period. As both sub-sectors today use mainly natural gas for producing heat, the biggest reductions can be achieved by switching the fuel to electricity or biogas. In the case of glass use additional reductions can be achieved through the use of CCS, as well as with increased recycling, re-use and other circular interventions. In UK Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050 the maximum potential reductions compared to 2012 were around 60% for ceramics and 90-96% for glass (higher reductions corresponding to the inclusion of CCUS).

The main technological pathways in the glass/ceramics sub-sector, with projects under development, emissions reductions and market entry are summarised in the table below:

Technology option	Examples	TRL	Max. emissions reductions[289]	Market entry
RES electrification	-	5-6 ceramics- 8 glass	up to 80%	2015/2020
Oxy-fuel combustion incl. heat recovery (glass)	OPTIMELT	7[e]	up to 60%	2025
Waste heat recovery	Organic Rankine Cycle	5 ceramics 8-9 glass	up to 15%	-
Batch preheating		8	up to 15%	-
Recycling **(glass)**	-	9	up to 60%	-

Source: Ecofys report[290]

5.4.6 *Pulp & Paper*

The European pulp and paper industry accounted in 2016 for around 1.5% of the verified emissions of all stationary installations of the European Union and around 5% of its industrial emissions excluding combustion.

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[288] Ecofys, 2018, Impact on the Environment and the Economy of Technological Innovations for the Innovation Fund (IF) in the Fields of Energy-intensive Industries, Renewables, CCS/CCU and Energy Storage (under review – to be published in October at the latest)

289 Reductions partly lower for ceramic industry (e.g. gasification of biomass up to 29%, oxy-fuel firing/oxygen enrichment up to 12.5%).

[290] Ecofys, 2018, Impact on the Environment and the Economy of Technological Innovations for the Innovation Fund (IF) in the Fields of Energy-intensive Industries, Renewables, CCS/CCU and Energy Storage (under review – to be published in October at the latest)

As it's name implies, this sector aims in the industrialised production of paper and pulp, the wood-based resource used to produce paper. Pulp is produced mechanically, chemically or from recycled paper, with its intended quality determining the processing steps and the raw materials to be used. Drying the paper web is then the important energy-consuming process in paper mills.

The two main mitigation pillars for pulp & paper are improving energy efficiency and switching to low-carbon fuels and electricity. Nevertheless, the European Paper industry has greatly improved its energy efficiency over the last decades using waste heat and improved drying techniques. The remaining energy efficiency potentials due to applying the best available technology (BAT) are limited. In addition, fuel switching from fossil fuels to renewable sources like biomass (and electricity) has already taken place largely. In addition, the competition for biomass with other sectors represents another challenge. Therefore for deeper decarbonisation breakthrough technologies need to be further developed and become commercial.

When it comes to decarbonising the paper industry, the industry has the advantage of having direct access to bio-based materials. In addition, the paper industry only generates energy-related, but no process-related emissions (like for example the cement industry) which are much more difficult to reduce. Finally the demand for steam in the paper industry is quite flexible in terms of the energy carrier used for its production (in contrast to furnaces in the high-temperature range, e.g. in the steel industry). The above allow for many possibilities regarding fuel-switching to low carbon fuels, which will be performed purely on an economic basis. The full electrification of the sector seems particularly appealing, as the sector could be used to increase flexibility of the energy system e.g. by providing demand side flexibility or storage capacity storing energy as hydrogen or pulp.

Another opportunity for paper and pulp is the Black liquor gasification (BLG). This is a technique used in pulp mills to generate surplus electricity or bio fuel. In the black liquor gasification process concentrated black liquor is converted into inorganic compounds (mainly sodium and sulphur) suitable for the recovery of cooking chemicals and combustible fuel gas comprising primarily hydrogen and carbon monoxide. BLG is often discussed in the context of the future paper factory becoming a biorefinery[291].

Recycled fibre quality can be improved by improving the collection, sorting (e.g. by filler content, brightness, fibre length) and ecodesign for recycling. This will allow more efficient treatment and refining of fibres . New recycling technologies like the before mentioned steam forming without wetting and drying could even further decrease energy demand in the paper industry. Digitalisation might also provide the next generation of efficient recycling technologies.

Main characteristics of selected mitigation options pulp and paper industry

[291] Best Available Techniques (BAT) Reference Document for the Production of Pulp, Paper and Board, JRC, 2015.

Technology option	Examples	TRL	Max. emissions reductions	Market entry
New drying techniques	Impulse drying Superheated steam drying	8-9 3-5	up to 20%	2020
Foaming of fibrous materials		5	n.a.	2025
Black liquor gasification		8-9	up to 11%	2020
Enzymatic pre-treatment		6-8	up to 5%	2025
Heat recovery	e.g. paper	9	up to 5%	-

Source: Ecofys report[292]

In general the sector is not one of the harder to decarbonise sectors. The European forest fibre and paper industry has expressed the position that the above mentioned measures can lead to an 80% decarbonisation of the sector compared to 1990, while at the same time increases its added value in Europe by 50%[293].

5.4.7 Non-ferrous metals

The non-ferrous metals sector covers base metals (aluminium, copper, lead, zinc, nickel and tin), precious metals (gold, silver, etc) and the so-called technology metals (molybdenum, cobalt, silicon, selenium, manganese, etc). Aluminium and Copper production cover almost entirely the emissions of the sector.

As an energy but also electricity-intensive industry the European aluminium industry accounted in 2016 for around 1% of the verified emissions of all stationary installations of the European Union and around 2% of its industrial emissions excluding combustion. In aluminium production two main process routes can be distinguished: primary aluminium production from bauxite and the much less energy-intensive aluminium production using scrap and electricity as main inputs.

The biggest opportunity reductions for both aluminium and copper is the shift to more secondary production through further recycling and re-use. This could then bring significant benefits, as the recycling of aluminium reduces energy consumption by 95% and emissions up to 98%. Moreover it opens up the possibilities for fuel switching to the least carbon-intensive fuel for use in combustion, be it electricity, clean gas or biomass.

Re-use of existing aluminium is seen as perhaps the biggest opportunity for making “order-of-magnitude” carbon/energy savings per tonne of metal. Recycling also offers substantial resource efficiency and other environmental benefits. Today aluminium recycled from end-of-life products covers just 27% - this share could increase up to 55%[294].The key barriers are the ability to isolate and gather this recyclable material easier and the infrastructure to handle it, as this would prevent its downcycling and enable the production of high-quality secondary

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[292] Ecofys, 2018, Impact on the Environment and the Economy of Technological Innovations for the Innovation Fund (IF) in the Fields of Energy-intensive Industries, Renewables, CCS/CCU and Energy Storage (under review – to be published in October at the latest)
[293] Investing in Europe for Indsutry Transformation, CEPI, 2017.
[294] The Circular Economy, Material Economics, 2018.

aluminium. At the same time it is important to reduce the losses of aluminium throughout its use cycle, as 25-30% of aluminium is estimated to be lost. Additionally energy efficiency could also bring some further reductions both in cost and in energy consumption for aluminium. There are some promising technologies, which could deliver overall energy savings up to 45% but they have very low TRL. A more advanced solution, currently in pilot phase, is the carbo-thermic reduction (non-electrolytic process), which could deliver around 20% energy savings. On the contrary copper companies seem to agree that production process has almost reached its technological plateau and the opportunities for further energy reductions are very limited.

CCS does not seem to be an option of first priority for the non-ferrous metals due to the smaller size of the installations and emissions in comparison to the sectors discussed so far.

The main technological pathways in the non-ferrous metals sector, with projects under development, emissions reductions and market entry are summarised in the table below:

Technology option	Examples	TRL	Max. emissions reductions	Market entry
Low emission electrolysis	HAL4E	5-6	n.a.	2023
Inert anodes/wetted drained cathodes		5	up to 35%	2020/2025
Magnetic billet heating		8-9 aluminium 5 copper	n.a.	2010 2020
Waste heat recovery (copper)		8-9	n.a.	-

Source: Ecofys report[295]

5.4.8 Refineries

As an energy-intensive large industry the European refinery industry accounted in 2016 for around 7% of the verified emissions of all stationary installations of the European Union and around 23% of its industrial emissions excluding combustion.

The petroleum refineries sector is composed of two key groups: the refined petroleum products and the coke oven products. Refined petroleum products accounted for 92% of the sector’s emissions. They are derived from crude oils, which are distilled in the refinery into a number of fractions (petroleum gases, naptha, asphalts and residue). Depending on the refinery’s complexity these fractions can be upgraded into commercial products, like kerosene and gasoline.

Between 1992 and 2010, EU refineries have increased their energy efficiency by 10%, picking most low hanging fruits. Still BAT techniques in 3 major categories of the refining process have

[295] Ecofys, 2018, Impact on the Environment and the Economy of Technological Innovations for the Innovation Fund (IF) in the Fields of Energy-intensive Industries, Renewables, CCS/CCU and Energy Storage (under review – to be published in October at the latest)

the potential to reduce refinery emissions by 25%[296] [297]. Moreover improve waste heat recovery can deliver 10% further reductions.

A major opportunity for the refineries seem to lies in the CCS technology, due to usual large size of the refineries, producing large amounts of CO2 at high concentration. The ideal target for CCS is the methane reformation unit, producing hydrogen and a CO2 stream at very high concentration, almost at 100%. The surplus hydrogen[298] can then be used as a fuel elsewhere. Application to other processes can still significantly reduce emissions between 90-96%, though these technologies have not reached the commercial stage still. The economics though of steam reforming have the potential to be competitive with electrolysis towards 2050, with high uncertainty on which technology will prevail[299].

Demand side trends and measures, can also lead to reduced consumption of fossil-fuel based liquids in transport, can also lead to reduced emissions. For example the increased share in transport of electric vehicles, or measures to reduce the circulation of LDVs or incentivize a modal shift to rail would work in this direction.

Technology option	Examples	TRL	Max. emissions reductions	Market entry
Carbon Capture and Storage	Total	8-9	60% (net; 90% gross reduction)	2025
RES-H2		7	up to 50%	2020
Bio-based refinery	REPSOL approach	6	up to 30%	2025
Power to Gas/Liquid (synthetic fuels)		6	80%	2025
Advanced biofuels		8-9	n.a.	2020

Source: Ecofys report[300]

In the context of the Paris agreement, reduced demand for fossil fuel based fuels should be expected. At the same time tough opportunities arise in the refining of clean molecules, which would allow refineries to be integrated into local economic value chains for the production of heat, hydrogen and synthetic fuels, biofuels and CO2[301]. This will allow refineries to continue supplying the market with fuels and remain competitive in an international context. Note though that in these cases, like the production of synthetic fuels, emission reductions can be achieved only if electricity is carbon free.

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[296] Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050, UK, 2015.
[297] Low Carbon Pathways. CO2 efficiency in the EU Refining System 2030/2050, Concawe, 2018.
[298] Normally the H2 is used in the refineries themselves. For using it as a fuel elsewhere capacities of SMR need to be expanded.
[299] Asset study (use common reference with ENER)
[300] Ecofys, 2018, Impact on the Environment and the Economy of Technological Innovations for the Innovation Fund (IF) in the Fields of Energy-intensive Industries, Renewables, CCS/CCU and Energy Storage (under review – to be published in October at the latest)
[301] Refining the Clean Molecule, CIEP, 2018.

Combining all the above options together could lead to emission reductions up to 70% compared to 2012[302].

5.4.9 *Circular Economy: The opportunities for industry*

Circular economy presents a great potential and opportunities for the industry. Ambitious demand side measures in the form of materials recirculation, increased product efficiency and circular business models can reduce emissions significantly in heavy industry by up to 60% in 2050 compared to 1990[303]. It offers opportunities for a more efficient use of materials, complementing the efforts in increasing energy efficiency. To reap of these benefits significant changes need to take place in our economy.

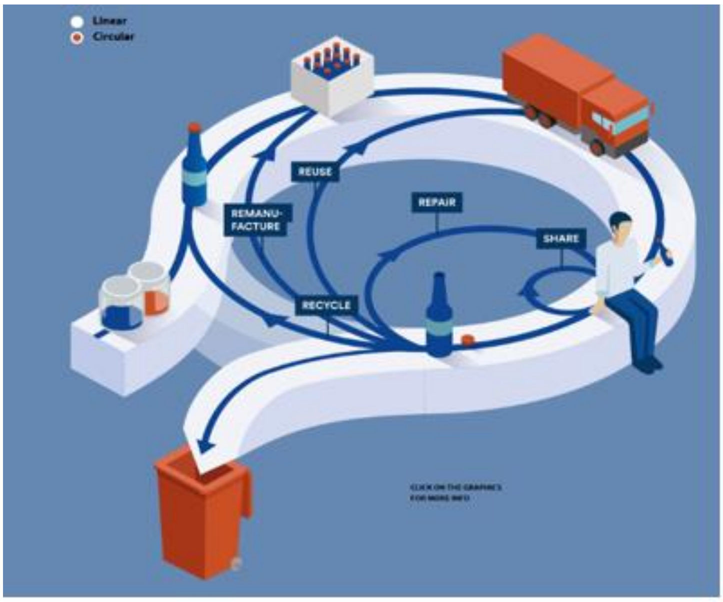

Figure 2: A circular economy. Source: European Parliamentary Research Service.

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[302] Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050, UK, 2015.
[303] The Circular Economy, Material Economics, 2018.

The Circular Economy

The current economic model is close to linear, often described by production, use and disposal. In a circular economy raw materials are used for production more efficiently, taking into consideration from the product design phase the use, repair, disassembly, remanufacturing and reuse of the products. After a certain level of degradation, the components of the product are gradually recycled, each component allowing for a possibly different number of reuse cycles. This way a circular economy minimises waste, especially when the materials used are fully recyclable. It also reduces extraction of new raw materials.

In order to transit to a circular economy it is also necessary to revisit the existing value chain model of our economy. The current model could lead to a moderate circular economy, with increased recycling and some limited reuse. To reap the benefits of circular economy though, certain changes need to take place in the value chains. Products will be decreasingly bought and consumed; instead they will have increased durability and be leased, rented or shared by the consumers. Industrial and manufacturing processes will be redesigned so that material loss in the production and between the different lifecycles phases of each product or material are minimized. Cascading use of material will lead to a diversified reuse across the value chain, for example cotton clothing first reused as second hand apparel, then as fibre-fill in upholstery in the furniture industry and later in stone wool insulation for construction (“Towards the Circular Economy”, 2013, Ellen McArthur Foundation).

A major objective of the circular economy is to retain value within the economic system (value-retention processes). In a circular economy companies may sell less new products than in the current linear one. At the same time though value creation opportunities will arise, both in terms of cost reductions and the increase of services offered together with the product. In terms of costs, due to the reverse cycle, energy, material and labour costs per product are expected to be reduced. New services, enabled by the digitalisation of the economy, will facilitate reusing or sharing the use of products, while offering advanced lifetime prolongation options for the products and logistical support via reverse logistics. This will maximise the utility of the customers, while significantly reducing environmental impacts.

What would be the impact of these changes? These changes will have a number of impacts on the economy, the environment, the GHG emissions and the energy system. Improved waste management allows materials to go back into the economic cycle, thus, reducing the input of raw materials. The quantities of virgin material used as feedstock will reduce, part of it replaced by increased recycled and uncontaminated material, which requires much less energy and carbon intensive processes for its processing, and part from the cascading use of material and reduced material loss during the processing phase. Industries will enter partnerships, sharing their infrastructure and their material inputs / outputs / waste in the context of increasing trends of industrial symbiosis. Mobility will become a service, with cars shared and operated in fleets, increasing the occupancy rates of cares and reducing their numbers and thus the material required for their production.

The Material Economics report (2018) identifies four materials and two value chains, accounting for more than half of industrial CO2 emissions today, that could significantly reduce their emissions by 2050. Increased recycling and reduced losses during production in steel, plastics, aluminium and cement can deliver about 40% reductions in emissions. Additional reductions can be achieved by the reduced material used for buildings and cars, when these are used and produced more efficiently.

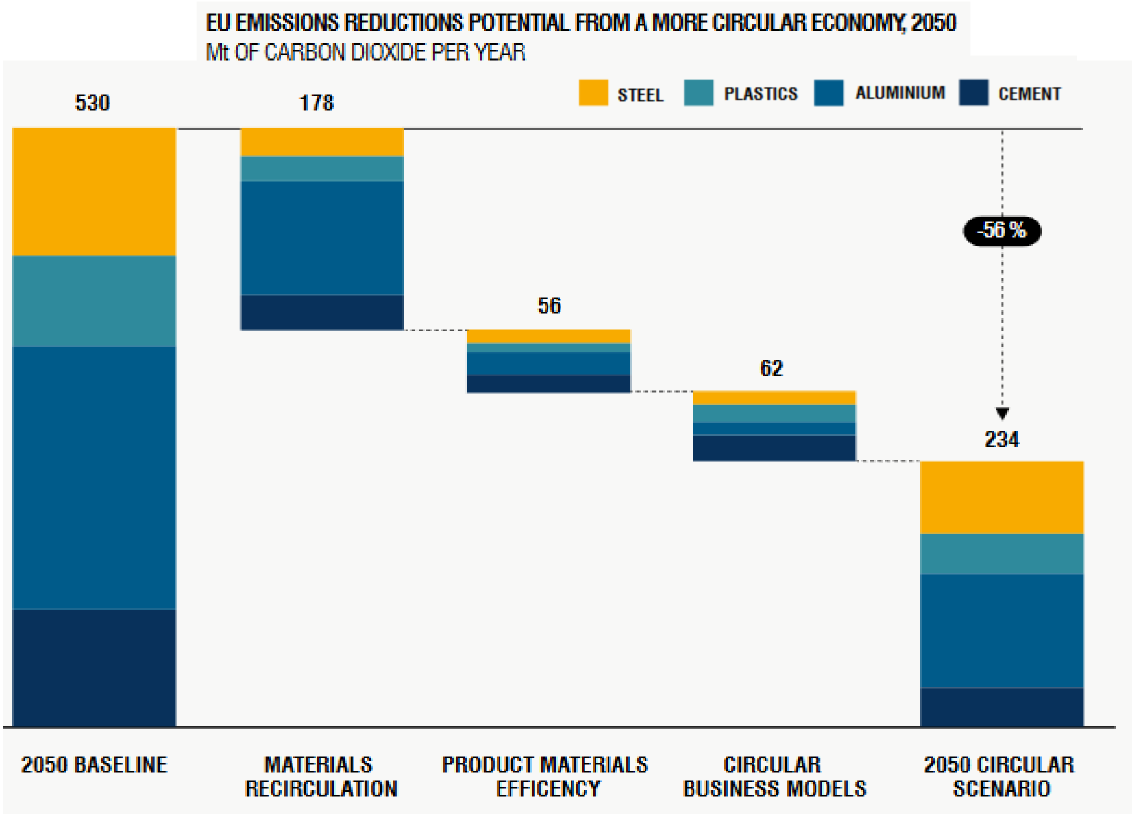

Figure XX: EU Emissions reductions potential from a more circular economy. Source: Material Economics, 2018

Quantification of the impacts of circular economy in industry with PRIMES confirms the high economic and emission reduction potential of this pathway. The Circular scenario assumes an average reduction of physical output for most industries by close to 10% by 2050, although the sectoral value added is retained at the same level assuming higher valued products. Moreover it assumes other circular measures, like increased recycling and reuse, improved waste management and reduced losses of material. Combined with moderate energy efficiency and fuel-switching, compared to the other scenarios, it leads to a scenario which achieves the 2°C ambition at the least energy related investment cost[304], its costs compared to Baseline being 9% above for 2050 and only 4% above for 2070.

[304] The energy related investment costs do not include certain additional costs that would be related to circular measures, like the improved of material collection methods, handling and transporting material for preparing their reuse etc

Circular economy can be seen as a big opportunity to create new markets, new technologies and new synergies. In a moderate form it will improve waste management and reduce raw material required. A more ambitious approach, bringing additional changes in the current supply chains, utilisation patterns and product design for more re-use and recycling, can deliver significant more benefits. A very ambitious approach could lead to even full circularity, but this would require also significant behavioural changes. Any level of ambition though does require a relevant level of changes to the regulatory framework and significant innovation to create the conditions the proper conditions that could foster the development of a circular economy[305] [306].

Circular Economy Examples

Short-loop recycling of plastics in vehicle manufacturing: Renault initiated a collaboration with multiple stakeholders with the aim of establishing a closed loop for plastics maintained wholly within the local automotive industry. As a result 36% of the total mass of a new vehicle is made from recycled materials; in a new Espace 20% of plastic is from recycled material. (Source: Ellen Macarthur foundation)

Re-using old bricks to build a greener future: "Gamle Mursten" ("Old Bricks") is a large-scale cleantech production company with patented cleaning technology for resuing building waste without the use of any chemicals, saving more than 95% of the energy otherwise used to manufacture new bricks. (Source: State of Green)

Product as a service: HP is gradually moving into the product as a service business model by focusing on leasing, renting and other service contracts for ink, print and PC services. Compared with conventional business models, printers using this service generate up to 67 percent less materials consumption per printed page. (Source: HP)

5.4.10 CCU

Carbon, capture and utilisation (CCU) is a technology closely linked with the circular economy, is. Capturing CO2 emissions from waste management processes (incineration), combustion or process emissions, which would otherwise be released, represents the last chance to keep the carbon in the technical use sphere. It thus supplements the options of reuse and material recycling, and is of particular relevance for mixed organic wastes, including hazardous wastes, as the chemical structure of the contained compounds is destroyed, their harmful properties thus being eliminated, as the carbon-based substances are converted to CO2. CCU could allow CO2 utilisation into one or several cycles, depending the application, avoiding the use of an equal carbon amount of fossil based resources. Its applications are quite wide, ranging from fuels to chemicals and minerals, see figure XX.

[305] Filling gaps in the policy package to decarbonise production and use of materials, DIW Berlin, 2018.
[306] The Role of Business in the Circular Economy, CEPS, 2018.

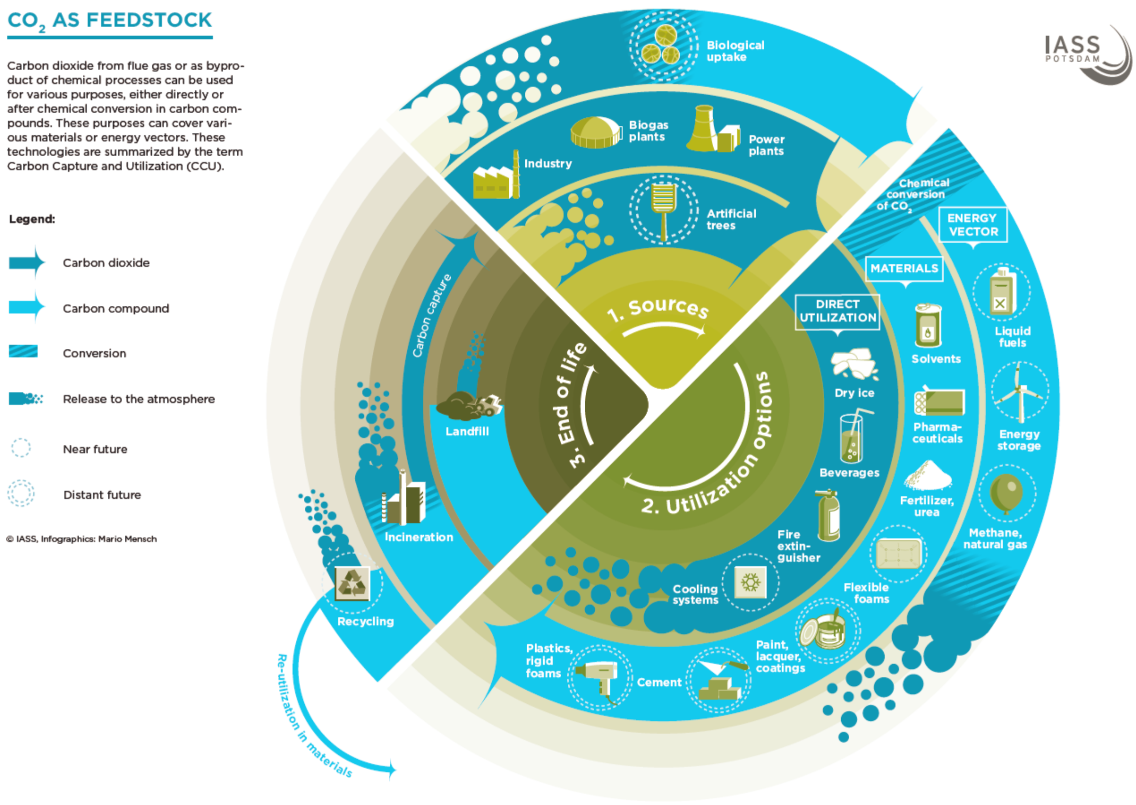

Figure XX: Overview of CO_2 sources, utilisation options and end of life considerations, Source: IASS Potsdam http://www.iass-potsdam.de/en/research/emerging-technologies/ccu

GHG emission reductions from CCU processes depend largely on the energy used and there is a general agreement that energy inputs in the processes need to be low carbon so the application of CCU technologies results in reduction of emissions. The current mitigation potential is thus limited, however in the future, when the power becomes low carbon, and the overall emissions reduce, the share of CO2 captured for CCU products can substantially increase, see Figure XX.

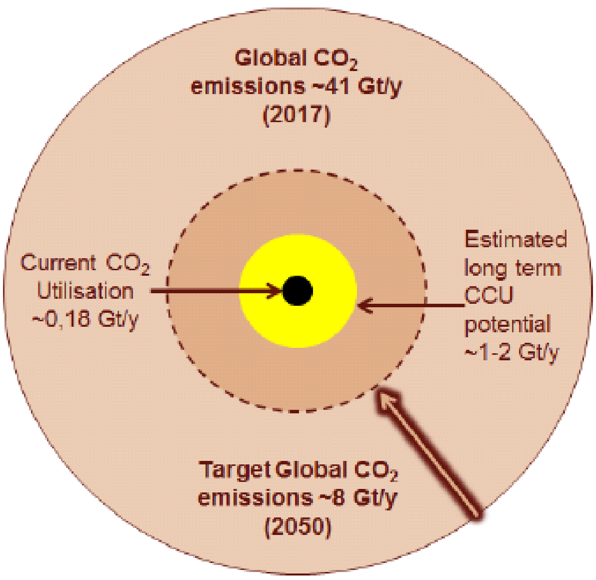

Figure XX: Global CO2 emissions and the role of CCU, Source: SAM HLG Opinion on CCU[307]

CCU technologies present a number of opportunities not directly linked to climate change mitigation such as boosting European industry competitiveness, providing an alternative carbon feedstock for the chemical industry, increasing energy security, providing energy storage options and synthetic fuels that can be used in existing infrastructure.

Some of the CCU technologies are still in various stages of technological development, their costs are high in comparison to conventional products and necessitate novel business models coupling industrial flows of different plants.

A possible commercial application of CCU is for the production of synthetic fuels, replacing biofuels in transport and thus reducing the need for importing biomass in the EU and allowing reallocation of domestic production. Their large CO2 binding volume and its higher price than methane could make this option attractive in the future, when their price is competitive with the price of fossil fuels[308]. On the negative side, such liquid fuel applications of CCU means that the CO2 is relatively quickly released to the air again after use. This is why their production is often considered together with CO2 captured from Direct Air capture plants[309]. PRIMES runs indicated that such an option could deliver the desired ambition, but at a higher cost than other options. The CO2 feedstock used for synthetic fuels can be seen in Figure XX (mainly coming from DACs).

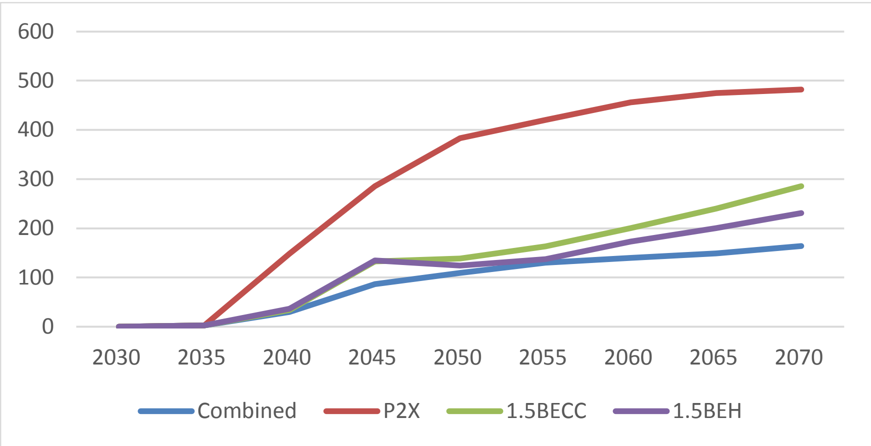

Figure XX: CO2 Feedstock used for the production of Synthetic Fuels (in Mt CO2)

CCU can be developed along CCS in CCUS clusters. There are a few of these CCUS clusters under development around major industrial sites in Europe such as the Ports of Rotterdam, Antwerp

[307] Scientific Opinion of the SAM HLG, 2018, Novel Carbon Capture and Utilisation Technologies, https://ec.europa.eu/research/sam/index.cfm?pg=ccu

[308] Currently the price of sunfire's synthetic fuels derived from CO2 for example, is twice as high as the benchmark price. Ramboll, 2018.

[309] One such innovative approach is considered by Carbon Engineering (http://carbonengineering.com/), claiming that this technology can become economic in the near future.

and Marseilles, Teesvalley[310]. The density of industrial sites would allow development of a common CO2 infrastructure and would make capturing and using CO2 even from installations with smallers emissions. The CO2 that cannot be used economically can be piped to geological storage sites.

In the context the circular economy the focus of the final use of CCU would be in materials. CCU based materials, in contrast to CCU fuels, have the further advantage that they can be used several times and feed into material recycling. Materials in detail can be plastics, building material substitutes or other materials that will be derived from CCU processes. Their lifespan depends on the end use of the CCU product. Examples would be the application in the automotive sector (e.g. polyurethane car seat cushions) or in the construction sector (e.g. concrete building blocks). Materials in general are suited for integration to the circular economy, as the overall lifespan can be elongated via material recycling.[311]

5.4.11 Industrial Symbiosis

In industrial symbiosis, traditionally separated industries are brought together in partnerships, optimizing the use of resources and minimizing waste and associated costs. The physical exchanges between industries may include materials, energy, water and by-products. As a result, industries enjoy economic gains, while reducing environmental impacts and costs.

The typical model that has been applied in several regions of the world is where an "anchor-tenant" organisation with energy and by-product linkages is connected to companies physically located nearby[312]. This is usually a result of the so-called unplanned symbiosis, like the Kalundborg industrial site located in Denmark[313]. Kalundborg Symbiosis started more than 40 years ago and is one of the most well-known and well-described industrial symbioses in the world. Kalundborg Symbiosis includes world-leading as well as smaller companies, with clear benefits for all of its participants.

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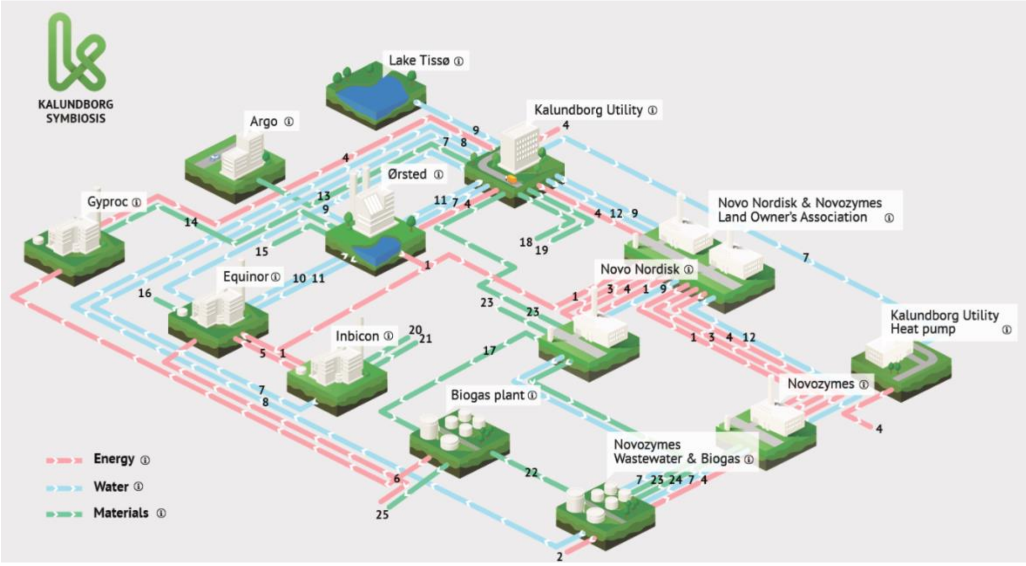
[310] SET-Plan Action 9 on CCUS, 2017, Implementation plan

[311] *Identification and analysis of promising carbon capture and utilisation technologies, including their regulatory aspects,* 2018, Ramboll

[312] *Planning and Uncovering Industrial Symbiosis*, 2011, Baas.

[313] http://www.symbiosis.dk/en/



Source: The Kalundborg Symbiose

An alternative model is the so called managed network, where a third part can work as a facilitator for existing companies or even centrally plan the site and attract new businesses [314]. Prime examples of this model are ports, like the Ports of Rotterdam[315], Amsterdam[316] and Antwerp[317]. Such cases may be further supported with the increasing digitisation of industry, allowing to more easily monitor the available input and output resources, as well as waste, and identify opportunities for collaboration.

Although the existing quantitative evidence supporting the case of industrial symbiosis are limited, mainly due to the complexity of such an exercise, the cases of potential win-wins are clear. Nevertheless, for these benefits to be realised a number of barriers need to be removed and coordination of interested parties needs to be facilitated[318].

5.4.12 Transition Enablers, Opportunities and Challenges

Existing literature makes clear that the reduction of emissions in industry are closely linked with the need for technology breakthroughs, as current BATs can deliver only limited reductions. Thus more research and innovation is needed, i.e. inert anodes for the aluminium industry or direct reduced iron for the iron & steel industry, and the economic framework conditions.

[314] *Cooperation fostering industrial symbiosis market pontential, good practice and policy actions,* 2018, Trinomics.

[315] *Decarbonisation Pathways for the Industrial Cluster of the Port of Rotterdam,* 2016, Wuppertal Institut for the Port of Rotterdam

[316] https://www.portofamsterdam.com/sites/poa/files/media/havenbedrijf/duurzaamheidsplan_en_digitaal_2017.pdf

[317] https://lib.ugent.be/fulltxt/RUG01/001/887/236/RUG01-001887236_2012_0001_AC.pdf

[318] Study on the energy savings potential of increasing resource efficiency, 2016, ECORYS.

Similarly, decarbonisation policies cannot be implemented and innovative solutions cannot be deployed without an extensive network of adequate infrastructure. As a minimum, there should be sufficient infrastructure about to fully support the major trends framing the energy landscape of tomorrow: electrification, CO2 and hydrogen pipelines, decentralisation/distribution, digitalisation, extreme efficiency through new materials, technologies and services, and the related new market design.

The speed of penetration of technologies and building of infrastructure is of concern. Modular technologies such as photovoltaics and wind power have been very successful in massive penetration of the electricity markets. The penetration of industrial decarbonisation technologies will not be that straightforward as apart from international competition concerns that slows innovative environmental technologies, many industrial plants are large and the innovative technologies often are not suited for retrofitting. They also depend on the availability of the infrastructure such as CO2 and hydrogen pipelines or reliable supply of biomass feedstock, which is not in the hands of individual enterprises. Concerted action would be needed at regional level for creating these new business networks along the technological development.

Stranded assets can be created when a major discontinuity in the economic environment in which they operate takes place. The transition to a low-carbon economy is exactly such a major discontinuity. For existing infrastructure and assets, effort must be made to identify innovative solutions for using them – or part of them - in the long-term low-carbon economy. At the same time, an opportunity is rising from the timely replacement of ageing infrastructure and assets with carefully designed ones, which are compatible with the decarbonisation targets.

In many of these sectors, but not in all, competitiveness with regard to international producers is an issue. Moreover there are significant regional differences in Europe in term of the existing industries, the product portfolio and the shares of the various subsectors.

5.5 Non-CO2 and towards a Methane Strategy

5.5.1 Specificities of non CO2 emissions

Increase importance of non-CO2 GHGs

Approximately 18% of the GHGs emitted in the European in 2015 were non-CO2 gases. Historically, non-CO2 gases have reduced faster than CO2, linked for instance to the Member States that joined the EU after substantial reforms in the agricultural sector, and the inclusion of industrial installations with relatively easy to reduce N2O emissions in the ETS as well as the development of EU waste policies. While further reduction is projected to continue in the future, it is nevertheless expected that non-CO2 emissions will be harder to reduce towards zero emissions than CO2, notably those emissions from agriculture.

In a baseline taking into account the objectives of the recently adopted EU Climate and Energy legislation[319], the share of non-CO2 gases could increase to 40% in 2050, and to XX%-YY% in scenarios compatible with a 2°C trajectory, and could constitute up to ZZ% of the remaining residual emissions (before accounting for LULUCF and negative emissions) in a scenario of GHG neutrality by 2050. Non-CO2 GHGs are projected therefore to become the main source of emissions on the pathway towards net zero emissions and need to be addressed specifically.

The basket of non-CO2 GHGs also has a heterogeneous impact on the climate. It includes gases with various properties and characteristics, leading to different times of residence in the atmosphere and potentials in term of climate warming. Methane and Nitrous Oxide are the two main gases, responsible for respectively 55% and 32% of the non-CO2 emissions[320] of the European Union in 2015. The remaining 13 % emissions are comprised of various fluorinated gases belonging to hydrofluorocarbon (HFC) group, and sulphur hexafluoride (SF6), nitrogen trifluoride (NF3) and the group of perfluorocarbons (PFC). Table 4 summarizes the contribution of the different non-CO2 GHGs per sector and major source of emission in 20XX.

Table 4: XXXXXXXXX

Sector	**Major sources**	**CH_4**	**N_2O**	**HFCs**	**PFCs**	**SF_6**	**NF_3**	**Contribution to current EU28 non-CO_2 emissions**
Energy	Energy use (power, industry, residential)	x	x					3.9%
	Transport	x	x					1.3%
	Coal mining	x						2.9%
	Oil and gas production	x						1.5%
	Natural gas transmission & distrib.	x						2.5%
Industry	Nitric & adipic acid, caprolactam prod.		x					1.4%
	Primary aluminium production				x			0.1%
	Semiconductor industry				x		x	0.1%
Agriculture	Livestock: enteric fermentation	x						**21.7%**
	Livestock: manure handling	x	x					**8.7%**
	Agricultural soils		x					**22.3%**
	Rice cultivation	x						0.3%
	Agricultural waste burning	x						0.3%
Waste	Solid waste	x	x					**14.0%**
	Wastewater	x	x					4.2%
Other	AC & refrigeration			x				**11.3%**
	High and mid voltage switches					x		0.3%
	Aerosols			x				0.9%
	Foams			x				0.7%
	Other F-gas uses			x		x		1.4%
	Other N2O uses		x					0.9%

Short-Lived and long-lived climate pollutants

[319] ETS, ESR, EE, RED …

[320] Based on a GWP 100 metric [does this mean 55% and 32% in CO2 equivalent terms? Volume? Or what metric?]

The warming potential of a GHG varies according to the characteristics of the gas. It is mainly driven by the intensity of its (instantaneous) radiative forcing[321] effect and its time of residence in the atmosphere. For example, at same concentration in the atmosphere, methane causes a stronger instantaneous radiative forcing than CO2, but it remains in the atmosphere for a much shorter time (around a decade). Most of the HFCs are also so-called *short-lived climate pollutants* (SLCP). In contrast to HFC[322], PFCs, SF6 and NF3 are GHGs that are *long-lived climate pollutant* (LLCP), staying for centuries or even millennia in the atmosphere. N2O falls between these two categories and stays on average about 114 years in the atmosphere.

Responsiveness of temperature on SLCP and LLCP emissions reduction

If significant reductions in the level of SLCP emissions can be achieved, then these gases relatively quickly reduce in concentration and this can translate into relatively fast temperature decreases. By contrast, even if emissions of LLCPs stop, these gases remain in the atmosphere much longer and warming effect of past emissions stays for a long time present (right hand figure).

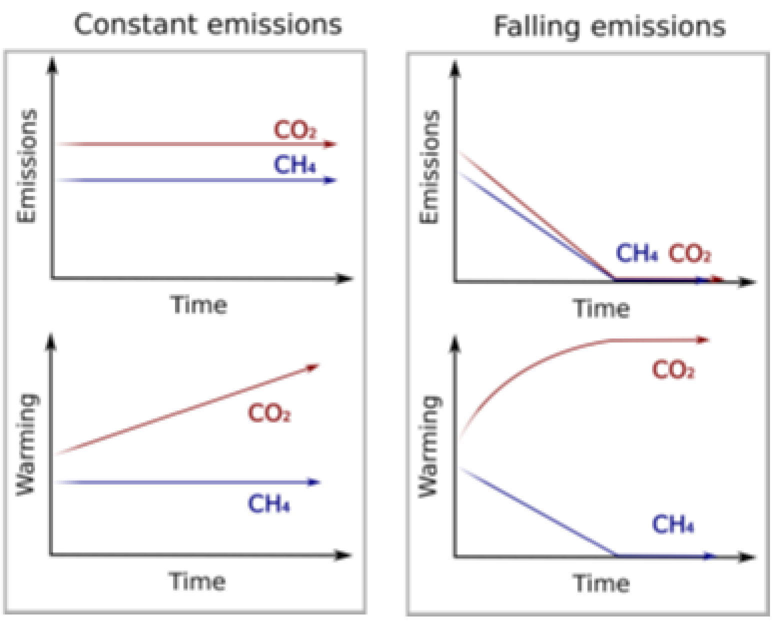


Figure 22: From a presentation of Allen at a JPI workshop, to be adapted

The Global Warming Potential 100 (GWP100) is the metric used most to compare the warming potential of different GHGs over time and is also used in the 4th Assessment Report of the IPCC [to set targets] across a basket of gases. For instance [almost xxx] all countries, including the EU, that took on NDCs with explicit GHG reduction targets under the Paris agreement for a basket of GHGs, have done so using GWP100 as the metric to aggregate the GHG emissions.

[321] Definition radiative forcing
[322] Note explain the very high uncertainty on CO2 lifetime due to biogeochemicals cycles

GWP100 is defined as the sum[323] of radiative forcing over a time horizon of 100 years of one kilogram of a certain gas emitted today, relative to the accumulated radiative forcing of one kilogram CO2 emitted today over this same 100 year time period[324].

In this framework for comparing the climate impact of GHGs, the GWP of CO2 is always one. The cumulative radiative forcing of methane (CH4) is 25 times higher than for CO2, but most of the radiative forcing occurs early in the 100 year time period used for the assessment, while for CO2 it is more constant, even remaining in the atmosphere beyond the 100 year time horizon. If the GWP would be estimated on a shorter period of time, then the relative cumulative radiative forcing of CH4 compared to CO2 would in relative terms be much higher, estimated at 72 for a 20 year period in the 4th Assessment Report of the IPCC (see table below).

Table 5: Lifetimes, radiative efficiencies and GWPs relative to CO2 as presented in the IPCC AR4.

Chemical Formula	Lifetime (years)	RadiativeEfficiency (W m–2 ppb–1)	Global Warming Potential for Given Time Horizon		
			20-yr	**100-yr**	**500-yr**
CH4	*12*	0.00037	*72*	*25*	*7.6*
N2O	*114*	0.00303	*289*	*298*	*153*
Selected number of Hydrofluorocarbons					
HFC-134a	*14*	*0.16*	*3830*	*1430*	*435*
HFC-143a	*52*	*0.13*	*5890*	*4470*	*1590*
Selected number of Perfluorinated compounds					
SF6	*3200*	*0.52*	*16300*	*22800*	*32600*
NF3	*740*	*0.21*	*12300*	*17200*	*20700*
PFC-14	*50000*	*0.10*	*5210*	*7390*	*11200*

Source: Based on IPCC, 4th Assessment report, Working Group I, Section 2.10, table 2.14

As such, GWP100 tends to overestimate the warming potential in the long term of the current emission of a SLCP compared to an emission of a LLCP. But the opposite also applies. GWP100 tends to underestimate the warming potential in the short term of an emission today of a SLCP compared to an emission of a LLCP.

This has policy implications. If the primary concern is to stabilise temperature change in the long term, e.g. by the end of this century, then there is not much difference in reducing annual emissions of SLCPs today or only in a number of decades, as long as this shift to annual emission reductions has taken place by somewhere the second half of the century.

However, this liberty for LLCPs such as CO, with temperature impacts being determined by the cumulative emissions, including the emissions of the past. If too many of them are emitted over time to achieve a certain temperature goal, then only active removal of these LLCPs from the atmosphere could lead to the achievement of a certain temperature goal within the century.

[323] Technically it is rather the integral of radiative forcing over time.
[324] AR4 WGI

That is why many projections require net negative CO_2 emissions in the second half of the century to compensate for too high CO2 emissions in the past.

While these difference in climate warming impacts might result in the conclusion that all focus in the short term should be to reduce LLCPs, rather than SLCPs, so as to avoid as much as possible the need for negative emissions later on, this would also be short-sighted. Three reasons can be put forward to explain this.

First, with temperatures already up by over 1°C, there is a serious risk of overshooting temperature goals. This is certainly the case for the 1.5°C goal, where most projections already assume some level of overshoot of temperatures during this century. Reducing SLCPs as soon as possible can contribute to avoiding these overshoots or limit their size. Second, reducing emissions like CH4, coming from sectors like agriculture, the energy system and the waste management system, will require a sustained effort over time, even potentially requiring behavioural changes that cannot be achieved in the short term. Third, any remaining emissions of SLCP like CH4 will continue to have a warming impact. So the lower they eventually become, the lower their warming impact by the end of the century, but also the larger the remaining allowed cumulative budget for LLCPs becomes.

A number of stakeholders have argued that the GWP should be adjusted towards a 20 year time horizon and to thereby focus more mitigation effort on methane. Such a change would increase the relative importance of CH4 in our policy framework - but would also provide a perverse metric that would downgrade the relative need to reduce LLCPs like CO2. While no metric can perfectly capture the differences in temperature dynamics between GHGs over time, GWP100 is a transparent and well known metric which gives a relatively good fit regarding the importance of the different gases for the achievement of our temperature goals, notably if looked at in the perspective of keeping temperature change this century within the objectives of the Paris agreement.

This section therefore continues to look at non-CO2 gases and the related mitigation potential in the context of a basket of gases, applying GWP100 as the metric to aggregate gases, and evaluating sectoral efforts that can be undertaken to reduce emissions. Nevertheless, given the relative importance of CH4, representing more than 50% of our non-CO2 emissions, the role of methane in our future energy system (see section in **Error! Reference source not found.**), and that methane is also a precursor for ozone air pollution, table xxx in section **Error! Reference source not found.** will also list the type of actions showing largest mitigation potential in the period up to 2050 to reduce emissions for this specific non-CO2 gas.

5.5.2 Baseline

In the baseline scenario, assuming all the current legislation with a potential impact on non-CO2 emissions is respected[325], non-CO2 emissions are projected to reduce by XX% in 2050 compared to 2005 (Figure 23). This reduction accounts for the evolution of activities across the different sectors of the economy but does not include any technological development of non-CO2 abatement technologies. Since most of this legislation targets the pre-2030 period, the level of emissions flattens after 2030.

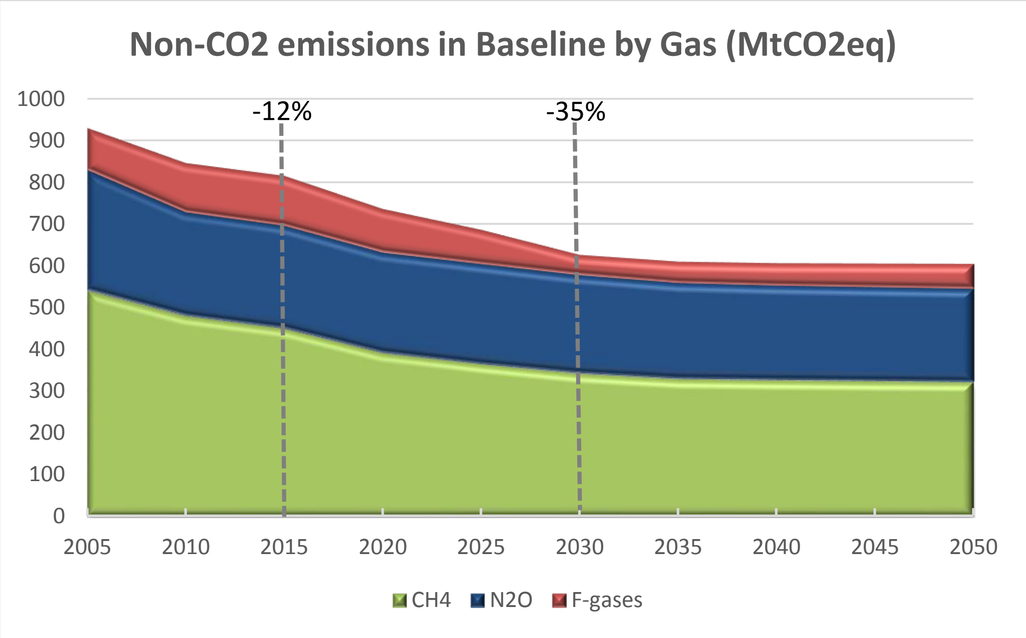


Figure 23: Baseline projections of Non-CO2emissions by gas (GAINS model)

The reduction will be the strongest for methane in absolute terms (aa MtCO2) and significant in percentage of 2005 levels (pp%). F-gas emissions will reduce strongly until 2030 (-50%) thanks to strict rules on Air Conditioning and refrigeration (Figure 24) but are projected to increase again between 2030 and 2050 (explained by activities?). Only a minor reduction in NO2 emissions is expected in 2050 compared to current levels, mainly linked to emissions from fertiliser and manure application.

From a sectoral perspective, most of sectors of the economy that are emitting non-CO2 gases today are expected to significantly reduce their emissions in 2050. With demand for natural gas decreasing as well as coal mining activities reducing, energy related non-CO2 emissions continue to decrease. Similarly full implementation of EU waste legislation would see emission for waste continued to reduce.

[325] See annex for list of legislation

The noticeable exception is the agriculture sector that is projected not to deliver significant further emission reductions without new developments in mitigation technologies and incentives for emissions reduction, or changes in amount and type of agriculture goods produced.

All together, a residual of roughly 600 MtCO2 of non-CO2 emissions remains in the baseline projection by 2050. This is not in line with the ambitions of the Paris Agreement, for which more non-CO2 emissions mitigation is therefore required to be on a trajectory consistent with the EU's objectives.

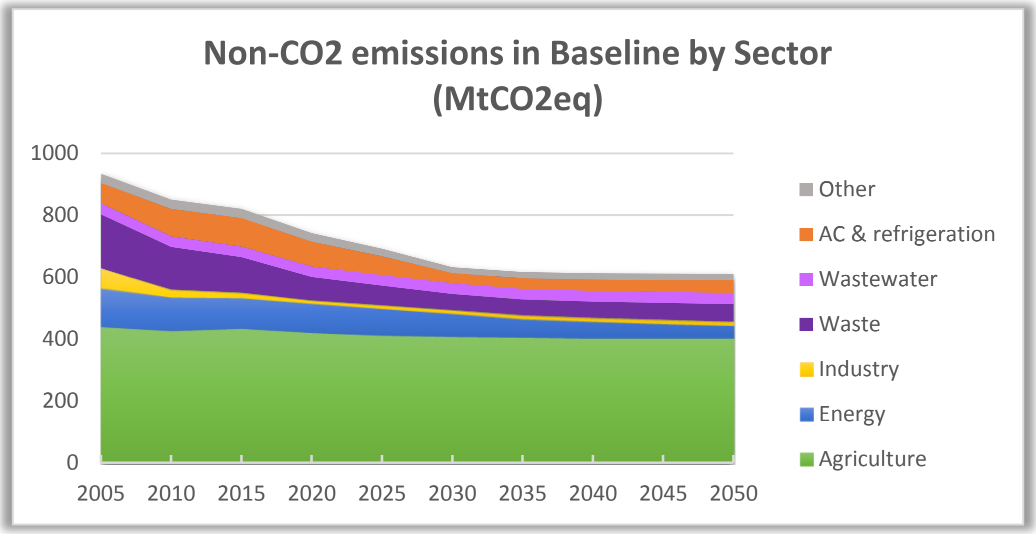


Figure 24: Baseline projections of Non-CO2emissions by sector (GAINS model)

5.5.3 *Reducing non-CO2 GHG emissions in Agriculture*

Mitigation Actions

Mitigating emissions related to production in the agriculture sector is recognised as challenging, but a number of options exist already today and are well known. In aggregate they all show significant total reduction potential. However, large differences remain between studies in the potential for GHG emissions reduction of individual measures. This is illustrated in a study published by RICARDO-AEA[326] in 2016 that presents a meta-review of the main mitigation measures applicable in EU with the range of GHG emission reductions potential reported by various stakeholder at MS levels.

<u>Action to reduce emissions in the livestock sector</u>

[326] RICARDO-AEA report for European Commission – DG Climate Action. Effective performance of tools for climate action policy – meta-review of Common Agricultural Policy (CAP) mainstreaming (Ricardo-AEA/R/ED60006/Mitigation potential, 16/11/2015).

Enteric fermentation

Methane emissions from livestock derive from enteric fermentation during the digestive process in the stomachs of ruminants. Different selective breeding programmes (i.e. the selection of animals with beneficial traits) with different objectives and selection criteria have been shown to effectively reduce enteric methane emissions per unit of production from livestock. Two distinct strategies exist. The first approach aims to enhance the herd's overall health and fertility, while maintaining high productivity, reducing the amount of animals needed. The second strategy focuses on reducing methane emissions per animal, either by selecting to enhance the feed efficiency of the animals, or by selecting animals with low emitting rumen.

Other options exist or are under development for improving feed management, thereby enhancing the GHG efficiency of animal diets, for instance by enriching feed with lipids or adding limited amounts of nitrates, both of which may reduce methane emissions from digestion. This strategy also includes options such as pre-processing of the feed to facilitate digestion, or precision feeding with close monitoring of the composition and timing of feeding.

Anaerobic Digestion

Manure if left untreated will emit methane and nitrous oxide emissions as well as a number of other air pollutants or GHG precursors such as ammonia. Instead, if the organic content of livestock manure decomposes in the absence of oxygen in an anaerobic digester, it will decompose into a gas mixture richer in methane. This so-called biogas can be captured, cleaned and combusted for energy production. However, the way in which the biogas is produced – in particular the inputs to the digestion process in the form of type of manure and eventual additional biogenic material such as crops or food waste – can have significant impacts on the efficiency and cost of the process. A by-product is “digestate”, a nutrient-rich substance that is usually used as fertiliser[327].

Other options exist to reduce manure emissions but do not produce usable energy: Storage management, air filtering and circulation, composting, nitrification-denitrification treatment, acidification, solid separators and artificial wetlands all shown potential to reduce greenhouse gas emissions from manure.

Action to reduce nitrous oxide emissions from agriculture soil

Natural microbial processes in the soil convert ammonia into nitrate and further to molecular nitrogen. While nitrogen is key to plant growth, both processes release nitrous oxide as a side product. Consequently, fertilizer and manure application to soils are the most important sources of nitrous oxide emissions in agriculture. Moreover, mineral fertilizer production is also GHG intensive. Optimizing fertilizer application rates, avoiding excess application and reducing

[327] Other solutions exist to reduce manure emissions but are less advantageous since they do not produce usable energy: Storage management, air filtering and circulation, composting, nitrification-denitrification treatment, acidification, solid separators or artificial wetlands

fertilizer losses, therefore reduces GHG emissions directly. It is also potentially beneficial from an economic perspective for the farmer.

Precision farming refers to technology that optimises the application of nutrients to plants, through reducing fertiliser application only to the extent they need it. It makes use of a number of technologies such as Variable Rate Technology (VRT), Remote Sensing, Global Positioning Systems , and Geographical Information Systems (GIS), linked to farm machinery that applies inputs more precisely. Nutrient management plans are essential tools to provide baseline information on nutrient use by cropping systems.

Nitrification inhibitors refer to chemical additives that reduce the release of nitrous oxide when mineral fertilizer or manure is applied. They slow down the conversion of ammonia into nitrate and give crops a better opportunity to absorb nitrogen, which increases the nitrogen-use efficiency of the fertiliser and reduces nitrous oxide emissions due to mineral fertilisers and manure application.

Organic soils, with their larger amount of available carbon provides “feed” for micro-organisms, including those responsible for the release of nitrous oxide. Fertiliser application on organic soils therefore leads to higher nitrous oxide emissions than corresponding applications on mineral soils. Since the overall area of organic soils under cultivation is relatively small in in EU, *fallowing organic soils* is a simple mitigation option to reduce nitrous oxide emissions related to fertiliser application, with the additional benefit that it would reduce CO2 emissions related to tillage from these soils.

Smaller mitigation options relate to stricter enforcement of the existing ban on open burning of field residuals as well as improved management practices for rice cultivations, both reducing methane emissions.

The below figure gives an overview of the main reduction options as represented in the GAINS model with marginal reduction costs up to €200 per ton of CO2-equivalent, representing in total around 125 Mt mitigation potential.

Mitigation options with highest potential by 2050 are precision farming, breeding for health and fertility as well as nitrification inhibitors. Other studies see less scope for breeding programmes but tend to support a more significant role of feed management. Regarding nitrification inhibitors, interaction can exist between precision farming, with less scope for inhibitors the more fertiliser losses are already limited by precision farming. Relatively small, certainly compared to estimates of other studies[328] are the estimated reduction potential coming from farm scale anaerobic digesters in GAINS, but this is also because in the GAINS projections there is already a significant take-up of anaerobic digestion in baseline projections.

[328] Xxx would be good in general to have some different estimats in this part …

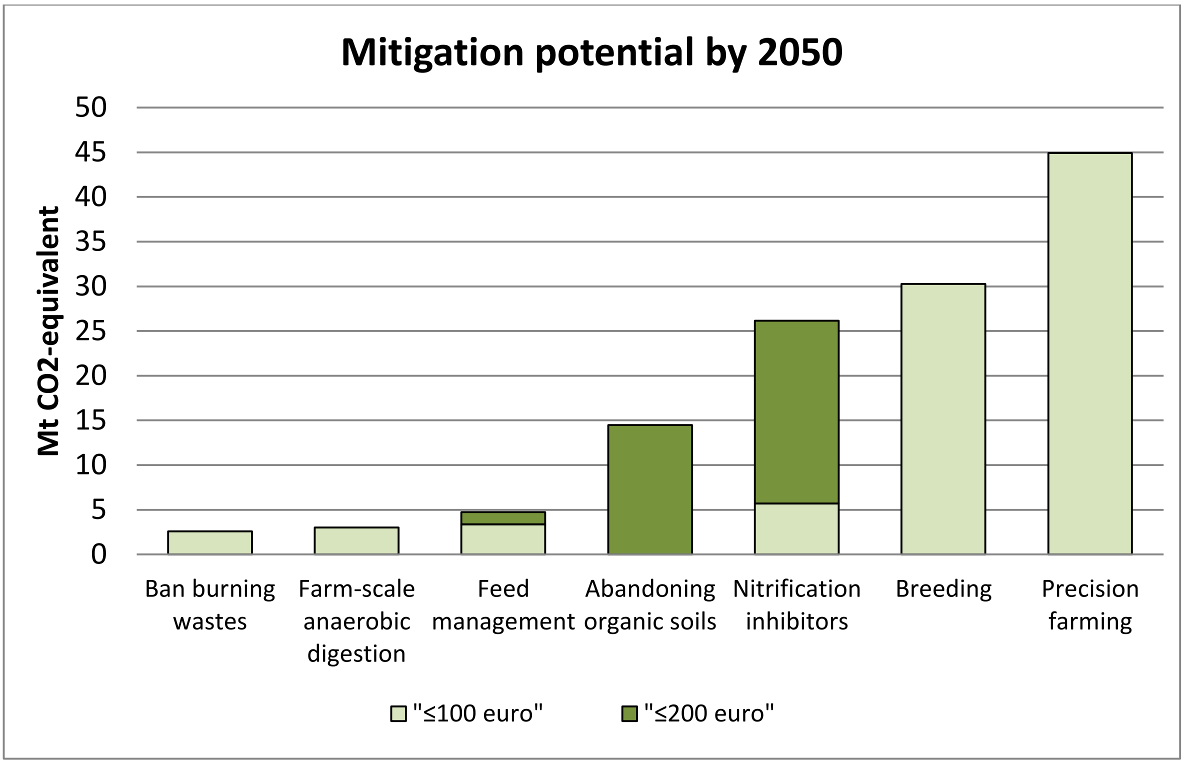


Figure 25: Example of technologies and mitigation potential in the agriculture sector (GAINS model)

A recent EcAMPA[329] study by JRC estimated similar total reduction potentials in the mid-term up to 2030, with a reduction potential for non-CO2 GHG emissions of 72 MtCO2eq in 2030 at a cost of 100 euro per ton of carbon avoided (GAINS has a potential of 64 MtCO2eq in 2030 at a cost of 100 euro per ton). The most significant reduction options in the EcAMPA study are measures addressing enteric fermentation, manure management and soil emissions.

Of note is that many of these measures, such as breeding for health and fertility, or precision farming, increase efficiency of the agriculture sector. Increased efficiency may make the EU agricultural sector more competitive, and thus may lead to rebound effects in that EU agricultural production would expand. This would in part also depend on the cost impact of these measures, and if fully covered by the agricultural sector itself also an opposing impact may happen, with production decreasing in the EU and increased agricultural imports as a consequence. It would depend on the origin of these imports, and the carbon efficiency of the imports to establish what the impacts are on overall greenhouse gas emissions globally.

Consumer preferences on food diet

The technical options analysed in the previous section try to solve the problem of emissions in the agriculture sector from only a supply-side perspective. A complementary approach consists in looking for solutions that affect the demand level from a consumption perspective.

[329] Ref EcAMPA III if possible

For example, the production of meat is very emission intensive and is widely recognised as have major global climate impacts[330]Bovine meat, due to its production by ruminants, emits an average XX kgCO2 per kcal of meat supplied to the food market[331]. This is x times more intensive than the production of pork meat or yy time more than cereals (yy) sector. A reduction in demand for beef at consumer level, with a commensurate reduction of meat production in the EU, would significantly reduce the quantity of methane emitted in EU, require reduced production of feed, which would in turn reduce the emissions of N2O due to reduce overall fertiliser need and potentially free up arable land.

European society has historically had a strong culture of red meat consumption. Statistics from FAO nevertheless seem to indicate that a turning point has been reached in the beginning of the 90s with a steady reduction in the meat consumption at EU28 level since. The deepest cut is on beef consumption with a 33% reduction offset by a +37% increase in poultry consumption. This shift from bovine to poultry is beneficial from a GHG perspective since producing the latter emits in average zz kgCO2/kcal, significantly less than beef. Overall, meat consumption in Europe has been reduced by 8%. In term of calorie intake per capita, that could translate in XXXX try to give an estimate, from a pure consumer perspective of the emissions saving from this shift in the EU population.

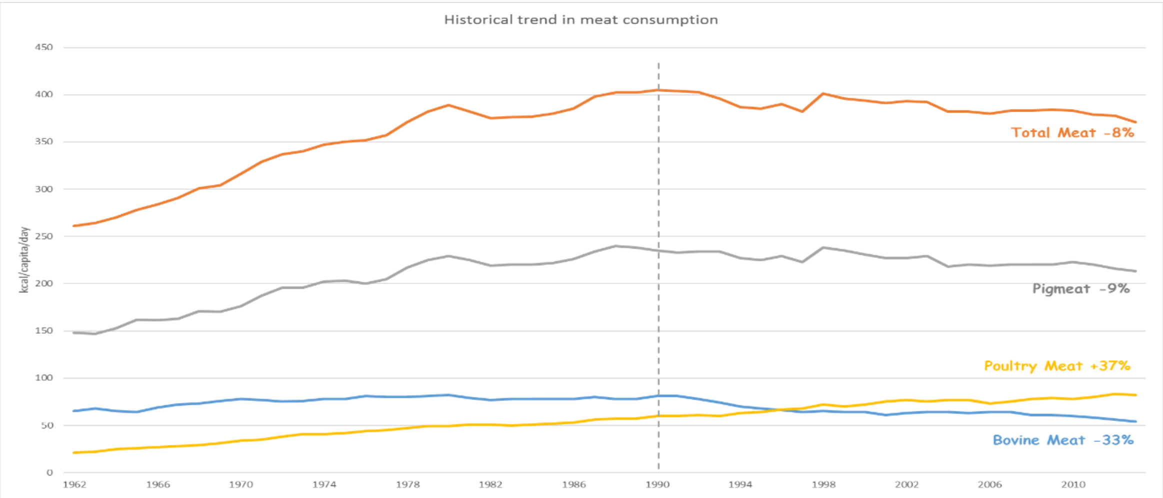


Figure 26: Historical trend EU meat consumption

An analysis based on a detailed representation of 30 different food items has been carried out at the Gothenburg Chalmers University of Technology to estimate the extent to which changes in technology and demand can reduce Swedish food-related GHG emissions necessary for

[330] Reference to Livestock's Long shadow, Steinfeld et al. (2006) FAO, ISBN 978-92-5-105571-7 http://www.fao.org/docrep/010/a0701e/a0701e00.HTM
[331] Use Poore et al., Science 360, 987–992 (2018) 1 June 2018

meeting EU climate targets[332]. It concluded that large reductions in ruminant meat consumption are, most likely, are unavoidable in order to reach emission levels of about 500 kg CO2-eq per capita per year. In contrast, continued high per-capita consumption of pork and poultry meat or dairy products might be accommodated within the climate targets. High dairy consumption, however, is only compatible with the targets if there are substantial advances in technology.

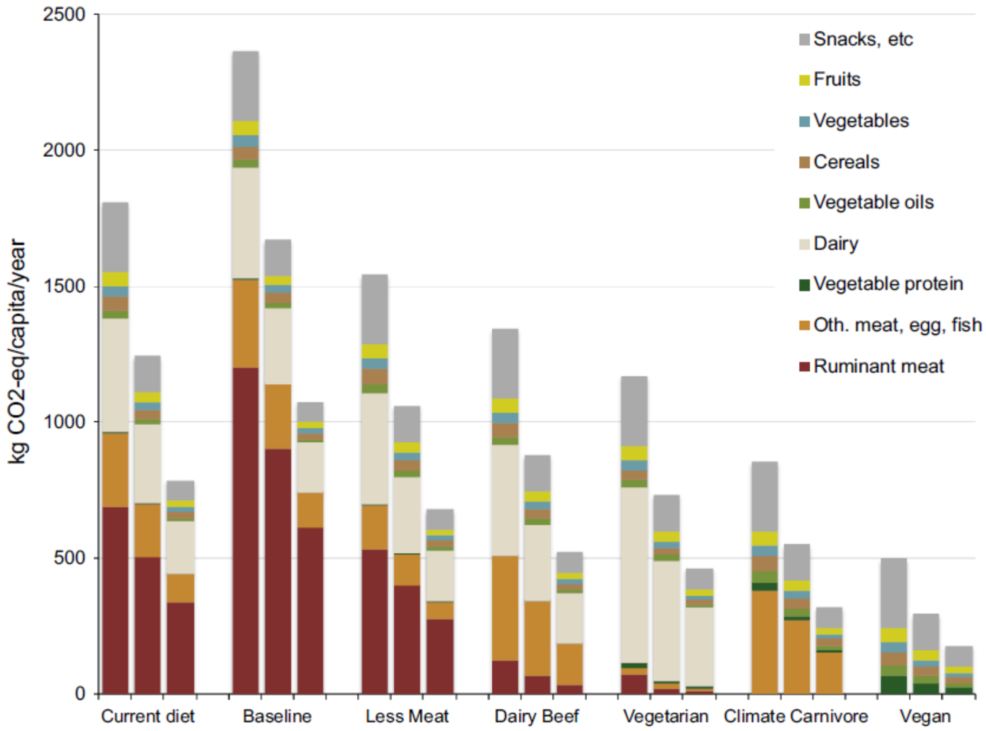


Figure 27: Greenhouse gas emissions per capita and technology level in 2050. For each different diet scenario, emissions are shown for the current technology (left), Moderate technology advances (middle), and Optimistic technology advances (right). Calories intake is constant across all diets, at the same level as baseline projections up to 2050 for the Swedish diet. This Baseline development is specific for this study (source Bryngelsson et al. (2016)[332])

The GLOBIOM and GAINS models have been used to conduct a sensitivity analysis on the possible adoption by the EU population of different diets in the next 50 years. In the baseline GLOBIOM and GAINS models see animal based calorific consumption continue to increase in the EU compared to 2013 levels. This is contradicting the historic trends which actually show a decreasing trend.

Five further scenarios were analysed with variation in the consumption of various meat, milk and egg products that see a reduction of animal based calorific consumption in the EU. Scenario Diet 4 is following the exiting trend as observed in FAO statistics since 1990 in changes in EU diet. The most stringent Diet 5 is consistent with reaching only in 2070 levels of meat

[332] Bryngelsson et al. (2016) How can the EU climate targets be met? A combined analysis of technological and demand-side changes in food and agriculture https://doi.org/10.1016/j.foodpol.2015.12.012

consumption seen as in-line with healthy diets in a number of studies (AgCLIM50-2 project of the JRC[333], the healthy diet scenario of Bajzelj et al. (2014) and Bryngelsson et al. (2016)).

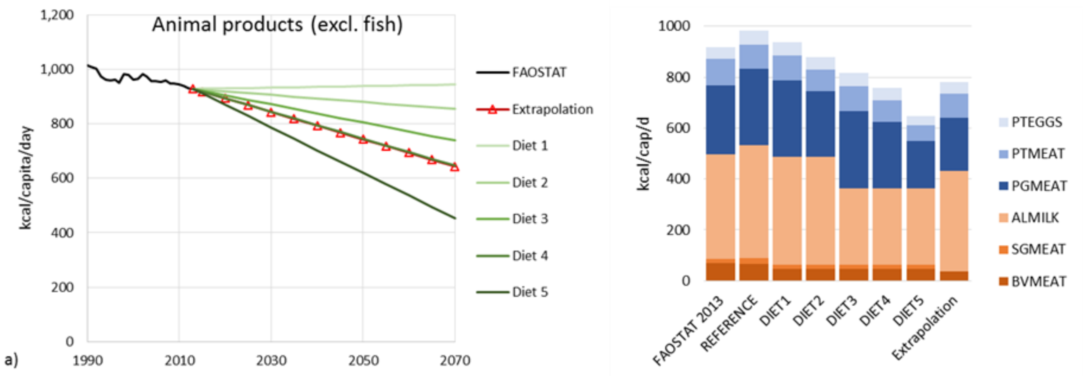


Figure 28: Example of changes in diets, impact on animal based calorific consumption(GLOBIOM, GAINS) XXX to be redone with clearer legend XXX

It is assumed in these assessments that these consumption reductions translate into EU production reductions. For Diet 1 the production of bovine and ovine meat is reduced by 30% in 2050 compared to 2010, the milk production stays at 2010 levels and eggs, pig and poultry meat continue to follow the development of a baseline scenario. The other scenarios are gradually more constrained with around 30% decreases for all the products in the scenario Diet 5 (increasing to -50% in 2070). Table 6 summarizes the characteristics of these scenarios.

2050 EU production compared to 2010	Diet 1	Diet 2	Diet 3	Diet 4	Diet 5
Bovine meat	-30%	-30%	-30%	-30%	-30%
Sheep, goat meat	-30%	-30%	-30%	-30%	-30%
Milk	2010 levels	2010 levels	-30%	-30%	-30%
Pig meat	Baseline	2010 levels	Baseline	2010 levels	-30%
Poultry Meat	Baseline	2010 levels	Baseline	2010 levels	-30%
Eggs	Baseline	2010 levels	Baseline	2010 levels	-30%

Table 6 : Diet scenario analysed with GLOBIOM and GAINS

To complete this sensitivity analysis on behavioural changes on food consumption, a reduction by half in the generation of food waste in all EU Member States was also introduced in the model in all scenarios, translating into a corresponding reduction of agriculture production. This respects the objective of the Sustainable Development Goals adopted by the United Nations Assembly in 2015 where a target was agreed to halve per capita food waste generation at the retail and consumer levels until 2030[334].

The results show that moderate changes in food consumption respecting health recommendations and still allowing ample consumption of all types of food products, even

[333] RefAgCLIM50-2
[334] Ref SDG UN food waste

though in smaller quantities for some of them, can reduce significantly emissions from agriculture production. The effect in 2050 ranges from 34 MtCO2eq with Diet 1 to 110 MtCO2eq with diet 5 and represent approximately 8% to 25% of 2015 emissions from agriculture. In 2050 the transition to the healthy diet is only partially implemented, at full implementation in 2070 the emissions could reduce by 13% to 44% in Diet 5. The impact of Milk consumption is particularly significant.

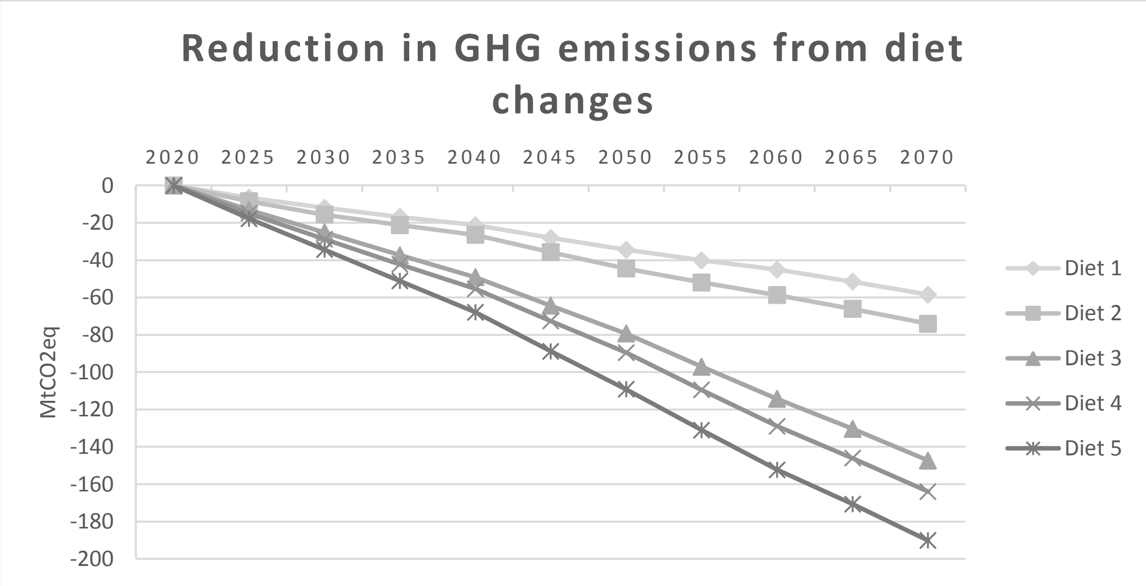


Figure 29: Example of potential impacts on GHG emissions due to dietary changes (GLOBIOM, GAINS)

Potential of GHG emissions reduction

Figure XY (below) gives an example of what the future reductions levels of this sector might be. With current policies in place, projected population stable and no changes in EU diets, the EU's agriculture emissions are also projected to stagnate, basically resulting in a bit more than 400 Mt CO2-eq emissions from the agriculture sector. This represents a bit less than 10% of total 1990 emissions; in other words a significant amount of negative emissions would be needed to get the EU GHG net emissions towards zero. Technical mitigation measures exist to reduce these emissions, and if applied (assuming application of all actions until a cost of 150 € per ton reduce), emissions could reduce by around third to below 300 Mt CO2-eq.

Modelling dietary change alone (and continuing the recent trend in decreasing animal product consumption), shows that demand-side action could reduce emissions from EU agriculture by approximately the same amount, i.e. around 300 Mt CO2-eq.

Moreover, combining both technical supply-side mitigation measures and a demand-side shift in diets, could bring down non-CO2 GHG emissions by almost half, from 434 MtCO2eq in 2015 to 240 MtCO2eq in 2050 or the equivalent of just below 5% of 1990 emissions. Achieving this level of emissions would clearly reduce pressure on the need to generate negative emissions (e.g.

through carbon sinks in soils and forests) to achieve a reduction more in-line with the 1.5°C objective

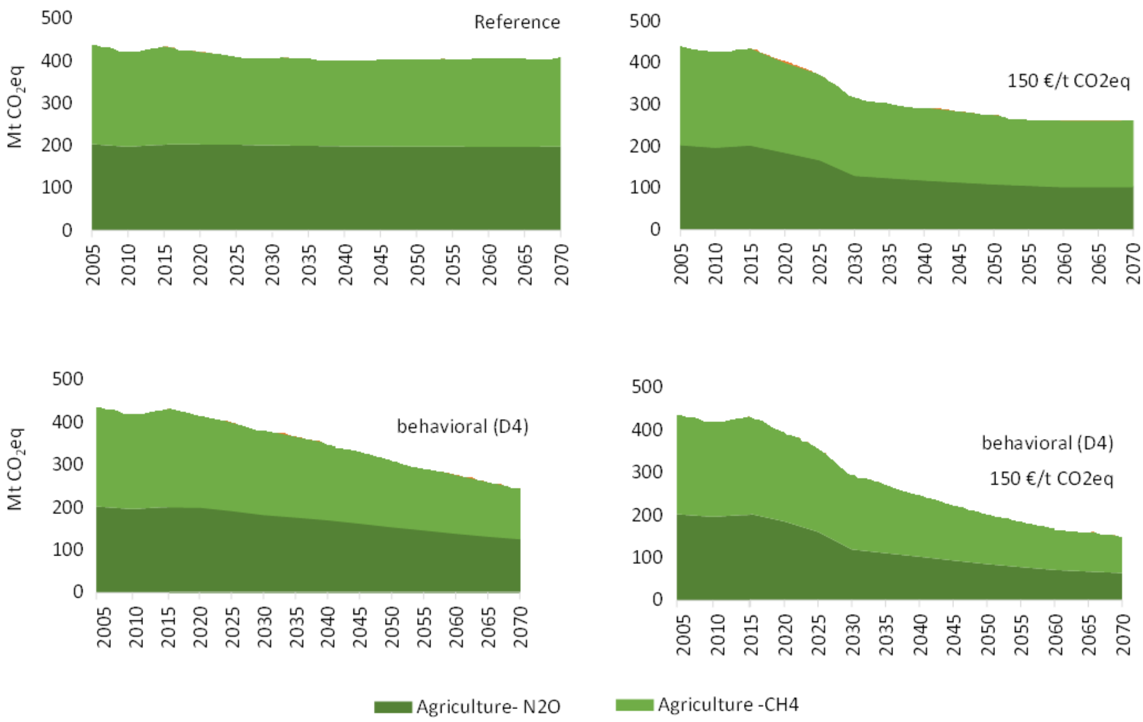


Figure 30: Example of reduction potential in the agriculture sector (GAINS)

5.5.4 Reducing non-CO2 GHG emissions in other sectors

[baseline jus is EUCO30 to which results are compared, to be updated to compare to the real baseline projection xxx]

Non-CO2 emissions form all non-agricultural sectors have and will continue to decline up to 2030 in the baseline projections, after which they stabilize (see Figure I). F-gas emissions from the AC & refrigeration sectors are declining mainly as result of the new F-gas regulation. However, the increase in activity levels after 2030 may lead to a stabilisation in AC and refrigeration emissions. Methane emissions from waste-water are thus far uncontrolled but remain stable over time. Waste legislation led to significant reduction in methane emissions and these reductions are even expected to be more pronounced after 2035 with the acceptance of the new waste legislation mid 2018. The revision of the landfill Directive in 2018 puts a limit of 10% on the amount of municipal waste that can be landfilled from 2030/2035. This will have positive additional effects on methane emissions which are not yet reflected in the figure. Industrial emissions (N2O from nitric and adipic acid production) are covered by the EU-ETS and have declined already significantly. Energy related emissions (methane but also nitrous oxides) decline because of fuel shifts away from fossil fuels combined with a decline in energy consumption. Major sources are electricity and heat production, coal mining and natural gas production, transmission and distribution.

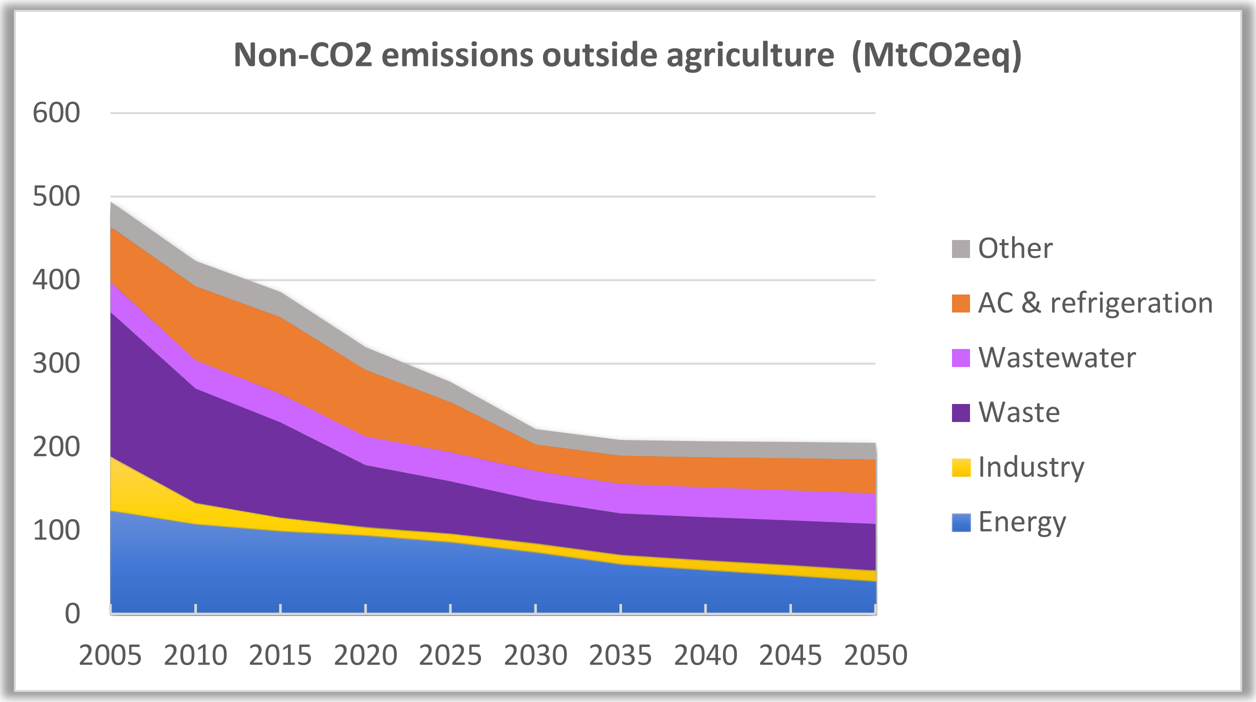


Figure I. Non-CO2 emissions in the EU outside agriculture in the baseline (excludes impact new waste legislation revision June 2018)

Table A shows that the maximum technical potential to reduce methane emissions in 2050 in the EU is around 70% compared to 2005. Solid waste emission and especially waste water emissions could be reduced further using technical measures by 50 to 90% in 2050 compared to 2005. Compared to baseline, solid waste potentials are overestimated since the revised waste legislation of mid 2018 is not reflected in the baseline yet. Methane losses of gas transmission, gas distribution networks and the production of natural gas are expected to decline in baseline but could still be reduced to a limited extent. The potential to reduce emissions from coal is limited if not absent since these fuels are expected to see strong production and consumption reductions already if the baseline (EUCO30) materializes. Technically, a reduction of around 70% would be feasible in 2050 compared to 2005 though in baseline already 60% reductions are achieved (see Table A for details).

Table A. Methane emission reduction potential in 2050 (Mton CO2eq).

Sector	**Activity**	**2005**	**EUCO 2030 Baseline**	**After maximum technological abatement**

Waste	Municipal solid waste	87	31	17
Waste	Industrial solid waste	33	18	11
Wastewater	Industrial wastewater	10	11	10
Wastewater	Domestic wastewater	12	10	6
Energy	Domestic: Gas distribution networks	13	4	4
Energy	Long-distance gas transmission	6	4	4
Energy	Power plants: Gas distribution Networks	3	3	3
Energy	Production of crude oil	15	2	2
Energy	Road transport	3	2	1
Energy	Production of natural gas	3	2	1
Energy	Industry: Gas distribution networks	2	1	1
Energy	Coalmining	36	0	0
Energy	Oil refinery	1	0	0
		224	88	60

Source: GAINS, revised waste legislation mid 2018 not yet reflected.

Table B shows the technical maximum potential to reduce nitrous oxides emissions in the EU28 (other than agriculture). Assuming full implementation of the EUCO30 baseline more than half of the emissions are reduced, with most emission reductions relate to reduced fugitive emissions from solid fuels. There are several big sectors where major reductions are still technically possible non related to changes in energy consumption most notably related to wastewater treatment. All in all nitrous oxides emissions could be reduce technically by 70% compared to 2005 with reductions in baseline already in the order of magnitude of -50%. This would however also require emission reductions also from the smaller sectors.

Table B. Nitrous oxide emission reduction potential in 2050 (Mton CO2eq).

Sector	Activity	Emissions 2005	EUCO30 baseline 2050	After all abatement 2050
Wastewater	Domestic wastewater	15	16	9
Other	Direct N2O use	7	8	8
Waste	Solid waste composting	2	7	7
Energy	Industry: Energy use, other fuels	2	2	1
Energy	Power plants: Energy use, other fuels	16	5	0
Industry	Adipic acid production	12	1	0
Industry	Caprolactam	2	3	3
Industry	Nitric acid production	40	2	0
Energy	Industry: Energy use, gas&other fuel	2	3	3
Energy	Domestic: Energy use, other fuels	3	2	2
Energy	Road transport	10	4	0
Energy	Rail transport	0	0	0
Energy	Other Transport	0	0	0
	SUM	111	53	33

Source: GAINS, waste does not yet reflect the revised waste legislation of June 2018 so solid waste remaining potentials will be lower.

Table C shows the expected technical potential F-gas emission reduction by 2050. It is worth noting in this context that the F-gas regulation is to be evaluated in 2020. All is well that ends well but there is still some limited potential (of around 10Mton CO2eq) to reduce these emissions by another 10 percentage points compared to baseline in 2050. This would achieve an overall reduction of 50% in 2050 compared to 2005. These reduction potentials are spread over a large number of sources but the most important activities where more substantial further reductions are technically feasible are: refrigeration in the commercial sector and high and mid voltage switches.

Table C|. F-gas emission reduction potential in 2050 (Mton CO2eq).

Sector	Activity	2005	Baseline 2050	After all abatement 2050
Industry	HCFC22 production	2	0	0
AC&refrigeration	Refrigeration in industry	4	2	2
AC&refrigeration	Refrigeration in commercial sector	27	25	19
AC&refrigeration	Refrigeration in domestic sector	1	2	2
AC&refrigeration	Refrigeration in transport	8	5	5
AC&refrigeration	Stationary air conditioning	13	7	7
AC&refrigeration	Mobile air conditioning	12	0	0
Other	Aerosols	7	3	3
Other	Foams	7	3	3
Other	Heat pumps	0	0	0
Other	Fire extinguishers	2	1	1
Other	Solvents	0	0	0
Industry	Primary aluminium production	3	1	1
Industry	Semiconductor industry	1	1	1
Industry	High and mid voltage switches	3	3	1
Industry	Magnesium production and casting	1	0	0
Other	Soundproof windows	2	0	0
Other	Other SF6	5	5	5
Industry	Other industry sources	1	1	0
Industry	Semiconductor industry	0	0	0
	SUM	100	59	49

Table D shows the expected development of the non-CO2 GHG emissions for a selection of scenarios

Table D: Non-CO2 greenhouse gas emissions compared to baseline in 2050 in different 2050 scenarios (EU28)(MtonCO2eq.)

2050	**Baseline**	**Circular (3)**	**Combine (7)**	**Combine (8a)**	**Behave (8b)**
Outside Agriculture					
Methane	89				
N2O	53				
F-gases	59				
Agriculture					
Methane					
N2O					
TOTAL					

PLACEHOLDER: scenarios being run.

Apart from the above model-based projections. other studies exist on these issues. In order to reduce GHG emissions from gas transmission lines it is possible to use a methane hydrogen mix instead of gas in the gas pumping units of gas transmission lines. This could reduce the total CO2eq emissions from gas transmission by 30%. The use of methane-hydrogen fuel mix in energy & transport could reduce emission from energy and transport by 25-35%. A transition to an energy based on efficiently technologies to produce hydrogen from methane (gas) may cut emissions by 80% (source: Gazprom, presentation 20/8/2018, Brussels). Evidence from the IEA (WEO 2017) indicates that it is technically possible (at global level) to reduce methane emissions by 60 Mt, half of which could be achieved at negative costs.

XX add other studies.

5.6 Land resources

Land is a precious and finite resource providing good and services essential to the well-functioning of our society and our economy. Europe is one of the most intensively used continents on the globe. It has the highest proportion of land (up to 80 %) used for settlement, production systems (in particular agriculture and forestry) and infrastructure[335]. There is a fierce competition for the use of land, the main drivers being the production of food, feed and fibre, the development of forests and its various services, the supply of bioenergy and other renewable energies and the increasing demand for housing and infrastructures[335].

According to Eurostat statistics, 38 % of the EU land is covered by forest and 22% is cropland, 21% grassland and 7% shrubland (Figure 24). Due to differences in the definitions of land categories, the UNFCCC inventories report a larger share for cropland (28% or 127 Mha in 2016), part of land classified as grassland in EUROSTAT database is inventoried as cropland in the UNFCCC database.

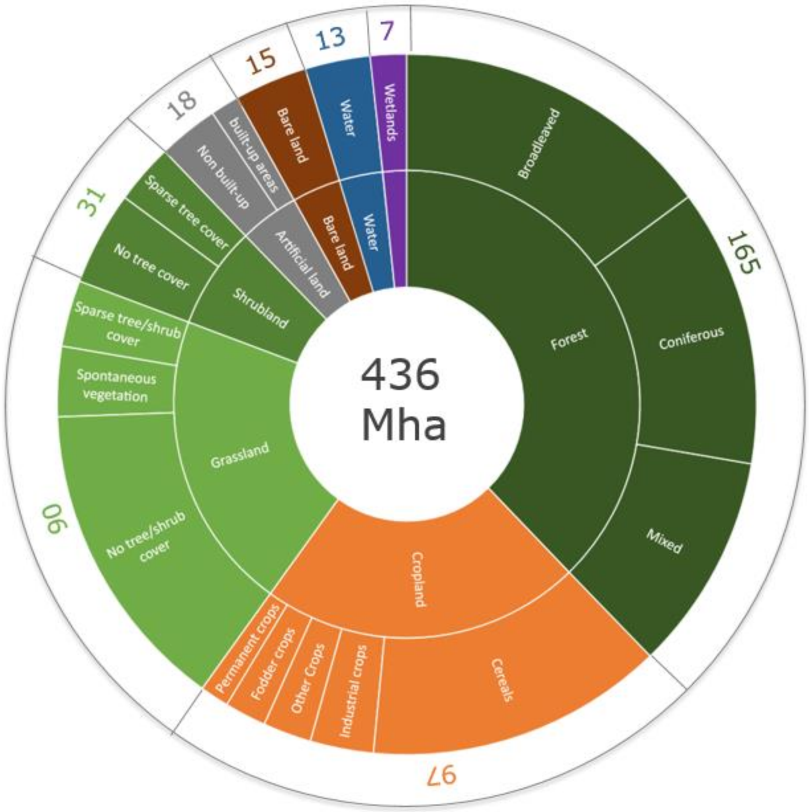


Figure 31: Land cover overview in 2015 (source: Eurostat – dataset an_lcv_ovw)

The current 20% of EU land not used for settlement or production systems includes mainly unused grasslands, abandoned agricultural land and other shrublands/herbaceous vegetation. This constitutes a marginal land reserve of about 70 Mha, however the land left out of production are often the less productive.

[335] https://www.eea.europa.eu/themes/landuse/intro

From a CO_2 emissions perspective, the land use, land use change and forestry (LULUCF) sector covers the emissions and removals of biogenic[336] carbon through land use activities related to forest, cropland, grassland and wetland management, or resulting from land use change between these managed lands.

The LULUCF sector in the EU today is a *carbon sink*, i.e. it removes (or sequesters) annually more carbon than it emits as GHG. According to the information reported by Member States to the UNFCCC[337], the 2016 net balance amounted to 314 Mt of CO_2 absorbed in the LULUCF sector as a whole, with 424 MtCO_2 net removals from forest land offsetting the net emissions of other land cover types, in particular cropland and settlements.

The use of natural resources can substantially affect climate, in positive or negative terms. Climate change interacts with other drivers and further exacerbates biodiversity loss and ecosystem degradation, thus weakening the ecosystems' ability to capture and sequester carbon. Climate change can considerably alter natural availability, structure and function to deliver private goods and eco-system services of natural resources, including their mitigation and adaptation capacity. A sustainable enhancing of the natural resources capacity to deliver, and especially of land as being at the crossroad, will be critical in a decarbonised context.

5.6.1 Preserving carbon from agricultural soils

In addition to the emissions of methane and nitrous oxide, EU agricultural soils release a substantial amounts of CO_2 emissions, YY MtCO_2 in 2016 from cropland and grassland. Slowing down the soil degradation and enhancing the carbon sequestration of EU soils is a win-win strategy for climate and food security that reduces CO_2 emissions and, in the same time, increases the fertility and productivity of EU agricultural land. The international initiative "4 per 1000"[338], launched by France on 1 December 2015 at the COP 21, goes in this direction by encouraging the implementation of some practical actions on soil carbon sequestration and the type of practices to achieve this (e.g. agroecology, agroforestry, conservation agriculture, landscape management, etc.).

The depletion of the soil organic carbon pool is caused by oxidation or mineralization, leaching and erosion. Under the temperate European climate, most soil losses take place during a period of 20 to 50 years after conversion from natural land to arable land, with a new reduced equilibrium only half to one quarter of the original carbon content [339].

Strategies to enhance carbon sequestration in agriculture (figure) aim to increase the soil carbon pool, improving soil biological activity, as such also increasing net primary productivity (NPP), decreasing nutrient and organic carbon losses from erosion and

[336] see footnote above - done
[337] EEA data viewer, not including N20 indirect emissions
[338] https://www.4p1000.org/
[339] Lal, FAO 2010 Thematic Report 4B Soil carbon sequestration, http://www.fao.org/fileadmin/templates/solaw/files/thematic_reports/TR_04b_web.pdf

leaching, and increasing the humification efficiency[339]. Sustainable management practices commonly recommended are[340]

- Reduced till or no-till cultivation practices that minimize soil disturbances, avoid the complete inversion of the soil horizon (i.e. ploughing) and thereby reducing the oxidation of soil carbon. Co-benefits are reduced risk of soil erosion by wind or water, and less energy required for cultivation.

- Crop residues left on the soil surface after harvest. This enables greater carbon retention in soils than removing crop residues (need reference).

- Cover crops are used to reduce the period of time that soil is left bare in order to reduce the risk of soil erosion. Catch crops are grown to reduce the duration of bare soil between harvest and the following spring in order to take up mobile nutrients, such as nitrate, and hence reduce pollution of watercourses.

- Better use of complex farming systems including mixed crop-livestock and agroforestry techniques (inclusion of trees in cropland/grassland) that efficiently use nutrient resources, enhance biodiversity and mimic the natural ecosystems perennial grasses, permanent crops and deep rotting crops

- Limiting or banning agriculture activities on organic soils, and restoring peatlands and wetlands by elevating the groundwater level, in order to reduce the oxidation of the organic material. Reference on how huge the emission per hectare are compared to mineral soils

Organic soils

A very effective way to reduce soil carbon losses and CO2 emissions associated is to limit the use of organic soil and peatlands for agriculture production and prevent the expansion of new agricultural land on these soils. Peatlands are wetlands with a thick layer of organic soil even if they cover only three percent of the global land area, they store 30 percent of the world's soil carbon[341]. In 2012 the Organic soils and peatlands climate change mitigation initiative[342] was launched by FAO, the MICCA Programme and Wetlands International. The initiative is committed to reducing GHG emissions from peatlands and safeguarding other vital ecosystem services that peatlands provide.

In Europe, in the 2018 UNFCCC inventories for the year 2016, the agriculture land with organic soils is emitting in average 16 to 17 tons of CO2 per hectare (less than 1 ton of CO2 in average for mineral soils). Only 1.5% of the cropland is covered with organic soils but that represents 55% of the total soil emissions for cropland (Table 7). For grassland, the 3% area covered by organic soils is emitting as much carbon as the 97%

[340] Ricardo study
[341] http://www.fao.org/in-action/micca/knowledge/peatlands-and-organic-soils/en/
[342] http://www.fao.org/3/a-az616e.pdf

grassland area of mineral soils is sequestrating carbon, making overall grassland near neutrality in term of CO_2 emissions.

Protecting organic soils of intensive use should become a priority of the climate action in the agriculture sector.

Table 7: Agriculture soil emissions in EU according to UNFCCC inventories

	Cropland		Grassland	
	Mineral Soils	Organic Soils	Mineral Soils	Organic Soils
Area (Mha)	125	2	85	3
Total Soil Emission (MtCO2)	-27	-33	41	-41
Implied Emission Factor (tCO2/ha)	-0,2	-17	0,5	-16

Mineral soils

Several studies estimated SOC emissions from mineral soils of arable land and the carbon sequestration potentials at regional and global level using either biophysical SOC models (Vleeshouwers and Verhagen, 2002; Smith et al., 2005; Zaehle et al., 2007; Yu et al., 2013; Lugato et al., 2014) or static SOC sequestration rates (De Cara and Jayet, 2006; Schulp et al., 2008; Thomson et al., 2008). Most studies conclude that European SOC mitigation potential could contribute to reaching emissions saving targets even though estimates have been revised downward (Smith et al., 2005).

Freibauer et al. (2004) identify the carbon sequestration potential for the EU15 to be around 59-70 MtCO2 per year. The PICCMAT project (PICCMAT, 2008) estimated the carbon mitigation potential for several carbon sequestration options. Table 8 gives an overview of most prominent sequestration options from the literature.

Table 8: Carbon sequestration options on cropland and sequestration potential in Europe from literature (MtCO2). Sources: [1]PICCMAT (2008); [2]Freibauer (2004); [3]Aertsens (2013); [4]Dawson (2007); [5]INRA (2013);

Carbon sequestration potential	
Catch crops[1,3,5]	9.7[1]
Zero tillage[1,2,3,4,5]	19.9[1]
Reduced tillage[1,2,3,4,5]	9.6[1]
Residue incorporation[1,2,4]	8.5[1]
Residue management – composting[1,2,4]	1.8[1]
Rotation species, improved rotations[1,2]	7.7[1]
Adding legumes[1,5]	10.6[1]
Agroforestry[1,3,5]	0.63[1]
Grass in orchards and vineyards[1,5]	1.8[1]
Set-aside[2,4]	>2.4[2]
Perennial crops, deep rotting crops[2,4]	4.5[2]
Organic farming[2,4]	3.9[2]
Hedgerows[3,5]	?

However, despite the variety of studies large uncertainties in the magnitude of SOC emissions and mitigation potential prevail. Some studies questioned the feasibility to achieve high emissions saving through carbon sequestration (Powlson et al., 2011). Uncertainties can be attributed to gaps in our understanding of future land use change, quantification of the response of carbon sequestration to land use change (Schulp et al., 2008), future level of adoption of mitigation measures, potential feedback on N2O and CH4 emissions, and persistence of mitigation (Smith, 2012). In addition, there is an ongoing debate about the positive effect of conservation tillage on SOC sequestration and consequently climate change mitigation since most existing studies relied on shallow sampling depth when comparing sequestration rates of conservation and conventional tillage systems. Baker et al. (2007) conclude, that even though conservation tillage may increase surface SOC concentrations, it does not store more SOC for the whole soil profile but solely redistributes carbon in the soil.

5.6.2 Forest Carbon Sink

The current *carbon sink* on EU forest land results from an imbalance in a dynamic forest system. Growth each year in forest biomass (gross annual increment) is larger than the quantity of biomass taken out of forests through natural mortality and disturbances, and human activities (harvests). See figure below. This imbalance results in an increase in net carbon stocks of EU forests, which in turn represents the net absorptions of CO2 from the atmosphere in above-ground biomass. The information reported in the UNFCCC inventories (Figure 32) shows limited changes in the characteristics of the EU forest over the last 25 years. The carbon sink of the total forest is stable since 1990, slightly above 400 MtCO2, with a small increase in the biomass produced but also a small increase of the annual losses in forest biomass (harvest and natural mortality).

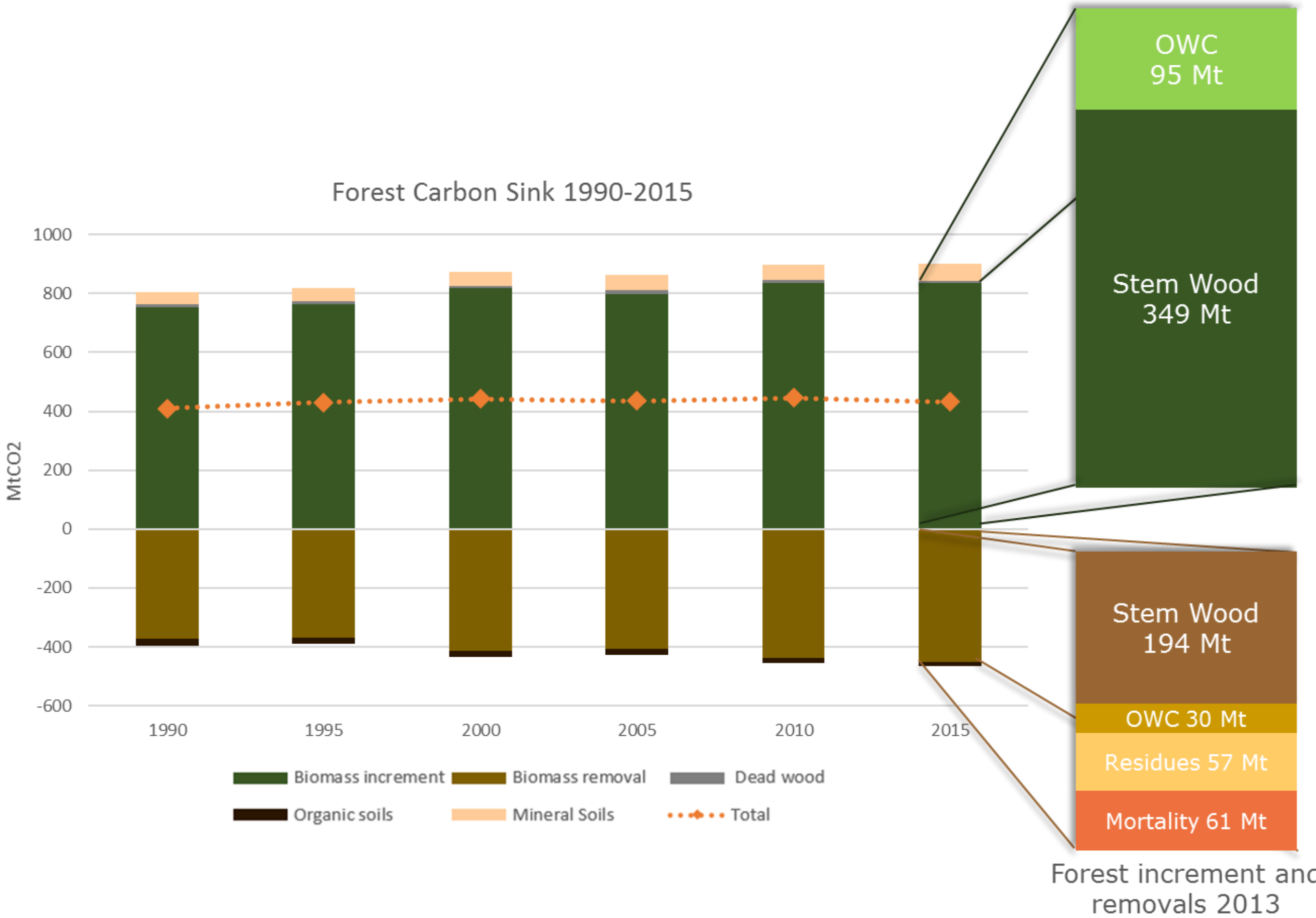


Figure 32: Forest carbon sink evolution between 1990 in MtcO2 (source UNFCCC) and breakdown of forest increments and forest removals in 2013 in Million tons of dry matter (source: JRC biomass study). OWC=Other Wood Components (branches, tops and stumps)

Typically a forest system that has no human intervention (i.e. management) will move over the long term towards a balanced state, with a likely decrease in increment and an increase in mortality, and an upper limit to the carbon stock present in above ground biomass and a limited carbon sink. Optimising the European carbon sink would therefore need action to maintain or intensify the forest system imbalance, through increasing the forest area through afforestation of non-forest land, the carbon density per hectare of forest with other tree species, or through stimulating faster increment by optimising harvests and smarter management practices.

Afforestation and reduced deforestation are obvious options to increase the coverage of EU forests potential together with co-benefits of many other ecosystem services such as biodiversity and reduced risks of soil erosion, floods and water pollution. Land is nevertheless a finite resource and extending forest coverage can, if carried out over large scales, intensify the competition for land with other sectors of the economy. Afforestation for instance may displace agricultural production of food, feed, fibre or energy, and subsequently increase GHG emissions in other GHG sectors. On the other hand, it may be the most productive and viable use of some land in the EU.

Limiting or reducing the amount of wood extracted annually from forests may increase the forest carbon stock and – at least in the short to medium term – the sink. Unfortunately, it comes with the drawback of limiting the supply of biomass for energy and wood product substitution that would otherwise lower emissions in other sectors. Other forest management practices can influence overall carbon stock density. Depending on the forest type and location, intervention may improve the growth rate or health of standing trees, stimulate growth and increase the overall carbon stock. The introduction for instance of tree species with a faster growing rate – i.e. increment – has the potential to increase the carbon density of a forest while preserving biomass flows towards the rest of the economy. Such practices need to be carried out respecting potential negative impacts on biodiversity (and other services) as well as possible increased demand for water resources.

Finally, the use of the harvested wood also matters. In essence, the more it is used for durable goods replacing those produced with fossil materials, such as construction, the more effective it is in reducing the release to the atmosphere of the biogenic (and fossil) carbon. This concept is captured in the LULUCF accounts as Harvested Wood Products. Although in principle this use is only a temporary storage, with eventually the CO2 still being released to the atmosphere, the cascading use can also reduce emissions in other sectors. An example is reduction of production of other building materials like bricks and steel, and subsequently "waste" timber being incinerated, thus reducing emissions from fossil fuels as well.

When looking at how to preserve or enhance the forest sink, it is therefore of key importance to properly assess the interlinkages between the dynamic of the forest sink, the use of biomass in other sectors of EU economy and any associated environmental impact, including indirectly on carbon stocks due to displacement of other land based activities.

Sustainable forest management and afforestation will be critical to achieve the 2050 objectives. Afforestation practices on marginal land and degraded land can enhance carbon sequestration, while also providing woody biomass. However, the possibility to carry out large-scale afforestation programme in Europe is rather limited. The UNFCCC inventories indicate that 7.5 Mha of land has been afforested in the last 20 years, however the forest sink is stagnating slightly above 400 since 1990. Different factors including can explain this stagnation, it includes some deforestation (2.5 Mha) also taking place in the mean time, the ageing of the forest and some increase in the wood harvested from

The Global Biosphere Optimisation Model (GLOBIOM) and the Global Forest Model (G4M) developed and run by the International Institute for Applied System Analysis[343] captures the biophysical and economic complexity of the forest sector and therefore allow a better assessment of the forest potential to sequester significant amount of CO2 in the future. The mitigation options implemented in the models are various, they relate

[343] reference

to the reduction of deforestation, increase of afforestation, change of rotation length, change of the ratio of thinning versus final fellings, change of harvest intensity or change harvest locations. The model results show that in a 2°C baseline scenario, a carbon price of 150 euro in 2050 could increase the forest sink by almost 100 MtCO2 compared to a situation without carbon price applied to the forest sector.

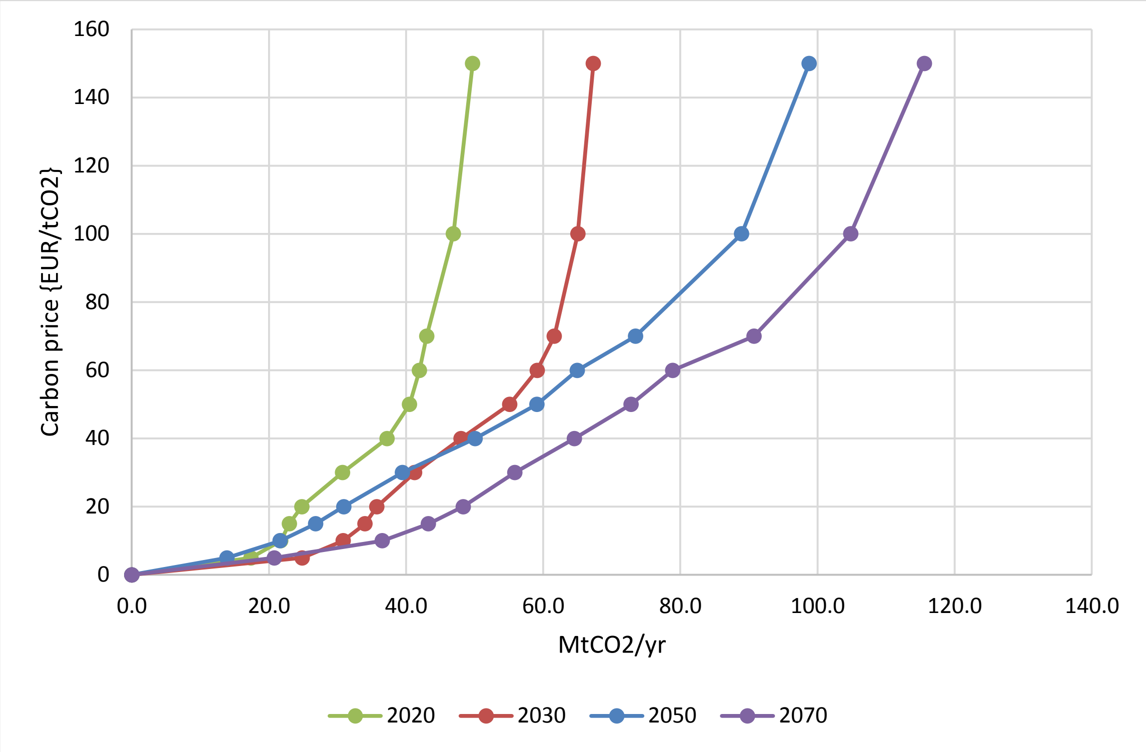


Figure 33: Potential for CO2 sequestration in the forest sector at different carbon price in 2020, 2030, 2050 and 2070

5.6.3 Land to produce substitutes to fossil fuels

Material substitutes

Timber products, paper, bio-chemicals, fertilizer, textiles, elastomers, bio-based plastics, are all products from biomass origins present in our daily life. Some of them have the potential to replace a significant share of fossil fuel-based materials, while performing carbon storage in the case of long-lasting products.

The use of wood in construction of individual houses represents about 10% of the EU construction market and varies significantly across Europe with a market share up to 80% in Nordic countries but very low penetration in Southern Europe countries[344]. The use of wood in buildings of three storey and more is likely to be lower than 1%. Outside the European Union, wood-frames represent about 40% of new constructions in some of the major economy such as the United States or Japan[345]. The ClimWood[345] study concluded

[344] Hurmekoski, E. 2016. Long-term outlook for wood construction in Europe. Dissertationes Forestales 211. 57 p. http://dx.doi.org/10.14214/df.211
[345] CLimwood?

that material use of harvest wood product leads to lower GHG emissions over the whole life cycle than the use of functionally equivalent alternatives by 1.5 to 3.5 t CO2 saved per ton of wood product.

The chemical industry is also interested in the use of biomass as alternative to fossil fuels (see section industry). A large palette of oleo-chemical products produced from biomass are already credible alternatives to fossil fuel based products, e.g. fertilizers, detergents, glycerine, cosmetics, pesticides, coating and colours, lubricants or plastics. Today the global bioplastic production (bio-based and biodegradable plastics together) represents less than 1% of the 300 Mt of plastics globally produced every year. However, this is a fast growing industry and bio-plastics are used for an increasing number of applications such as packaging (40% of bioplastics today), catering products, consumer electronics, automotive, agriculture, toys, or textiles. They could replace in the long term almost all fossil fuel based plastics[346].

Growing demand for bio-based plastics will increase the demand for feedstock, i.e. carbohydrate rich crops such as corn or sugar cane today and potentially lignocellulose crops in the future. If the environmental impact of this growing demand should be carefully and systematically looked at from a lifecycle assessment perspective, the land impact itself is expected rather limited. It has been estimated that replacing the global production of plastic in bioplastic would require about 5% of the total amount of biomass produced and harvested each year[347].

Energy substitutes

In 2014, bioenergy represented 60% of the final renewable energy consumed in the EU[12] and about 10% of the gross final energy consumed. Bioenergy is used mostly for heat, followed by electricity generation, and transport. It provided in 2014 88% of renewable energy in heating, and 19% of renewable electricity. Most of the bioenergy is used in solid form; biogas and liquid biofuels represent smaller shares[348].

Currently, the main sources of solid biomass used in electricity, heating and cooling are EU produced forestry-based feedstocks such as fuelwood, industrial residues (e.g. residues from sawmills or from the paper industry), and forest harvesting residues (such as branches or tree tops). Biofuels are mostly produced from agricultural crops. In 2015, an amount equivalent to 61 % of domestic oilseed production, 13% of sugar beet

[346] European Boplastic – Bioplastics facts and figures (http://docs.european-bioplastics.org/2016/publications/EUBP_Facts_and_Figures_2017.pdf)

[347] Martien van den Oever, Karin Molenveld, Maarten van der Zee, Harriëtte Bos - Bio-based and biodegradable plastics – Facts and Figures. Focus on food packaging in the Netherlands (http://library.wur.nl/WebQuery/wurpubs/519929)

[348] Commission Staff Working Document - SWD(2016) 418- Sustainability of Bioenergy - Accompanying the document Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources (recast)

production and 3.7 % of cereal production were used for the production of biofuels. Finally, while biogas has been produced mainly from annual energy crops (e.g. maize), there is a large potential in producing biogas from agricultural waste, residues, by-products (e.g. manure), sewage sludge, separated household waste, as well as industrial household waste.

5.6.4 Land use projections in the scenarios

All the scenarios analysed in the context of the Long Term Strategy rely on a significant use of biomass in 2050, ranging from 277 Mtoe in the Circular Economy scenario to 337 Mtoe in the Power to X scenario (178 Mtoe in 2020). Most of the biomass use in the 2050 EU economy is produced domestically, the imports are capped at 16 Mtoe in all the scenarios in our analysis.

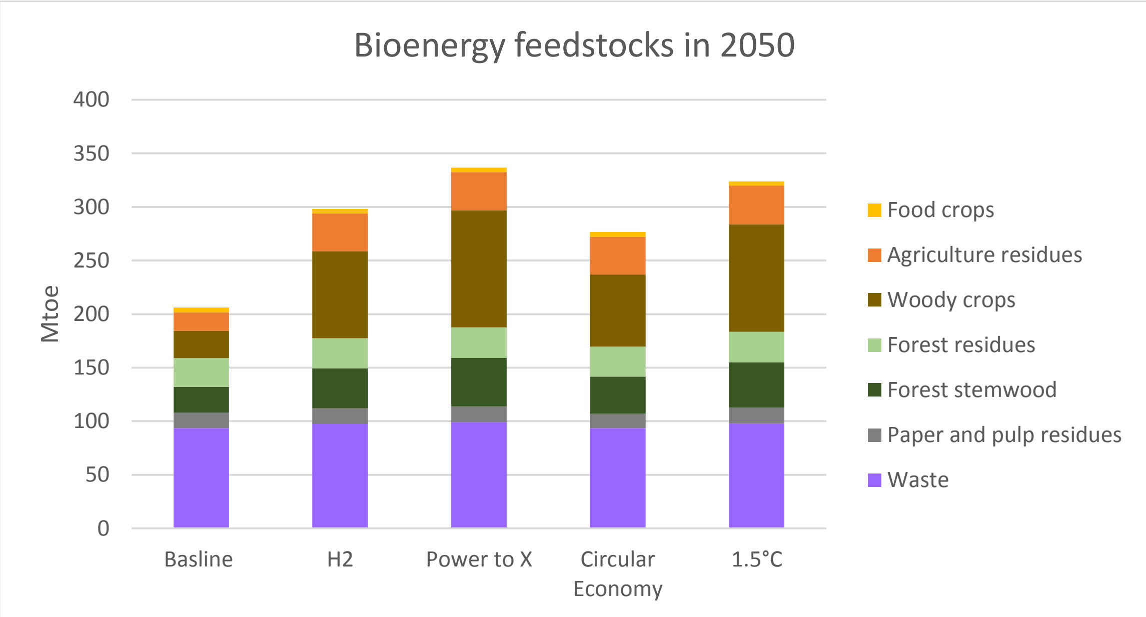


Figure 34: Break down of bioenergy feedstock in 2050

A significant share of bioenergy is produced from approximately 160 mtoe of waste and residues from agriculture and forestry in all scenarios (Figure 34). On the contrary the scenario varies largely in their demand in fast growing woody crops (mainly switchgrass, miscanthus, poplar and willow). In the future, a more important role of these crops is expected if not hampered by upfront investment costs or land availability. If cultivated in a sustainable manner, they could become the main input to the gasification and pyrolysis processes to produce biogas and biokerosene. These fuels would allow to deeply decarbonise the aviation [and maritime xxx] sectors where few alternatives exist. They are also used to replace fossil fuel methane in the gas grid. This is notably the case for the scenario P2X and the 1.5°C scenarios. Figure 35 presents the pathways to produce the different types of bioenergy required in the 1.5°C scenario.

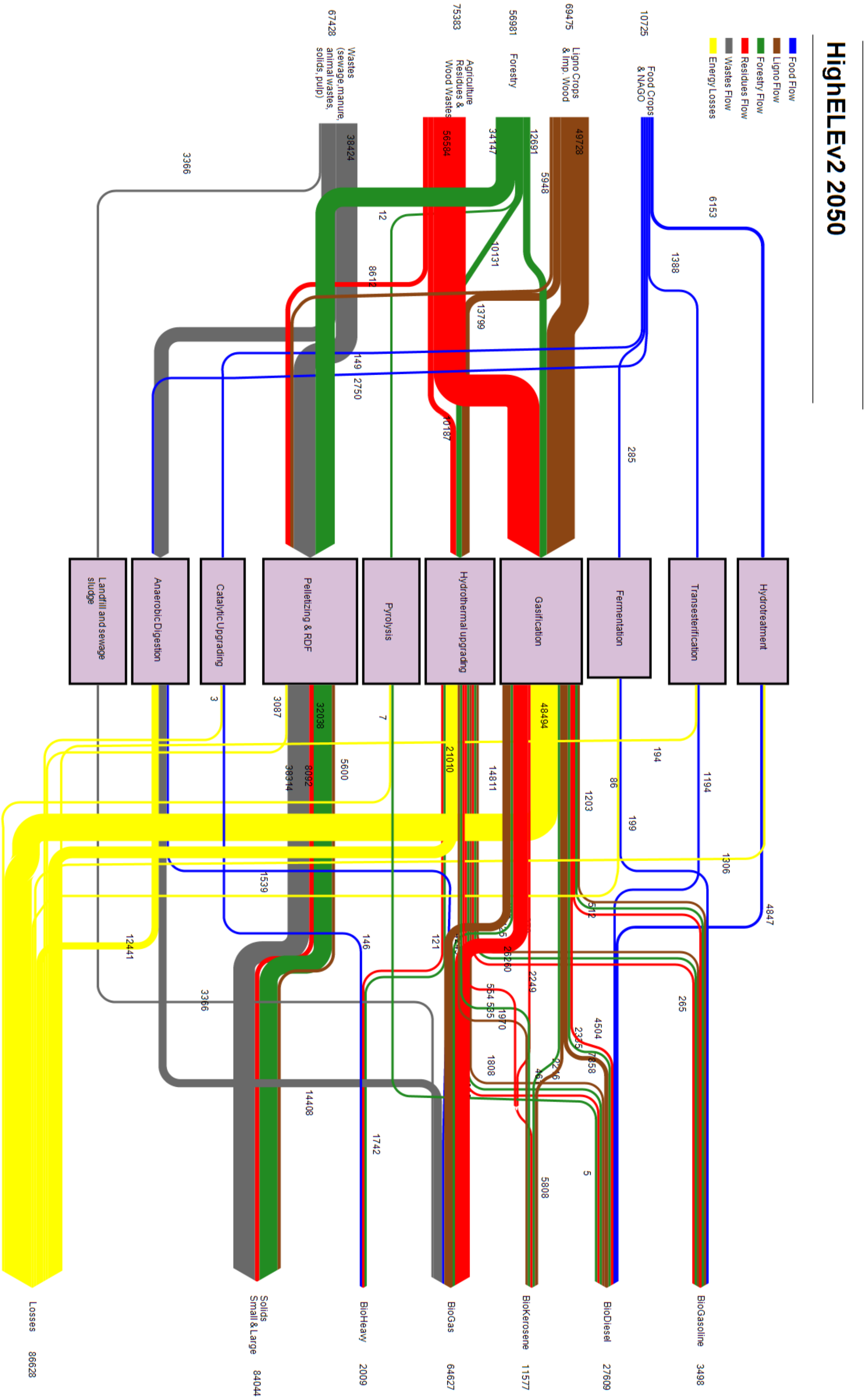


Figure 35: Use of biomass to produce bioenergy in 2050

These large requirements in bioenergy to decarbonise the EU economy have significant impacts on land use changes (and Figure 36). Up to 50 million hectare of land use change is projected to take place in the most impacted scenarios, and 33 Mha in the circular economy scenario. Most of the changes take place within agricultural land with a switch towards woody crops, notably from unused grassland and crops currently used for the production of first generation biofuel. Some afforestation also occurs, in particular on abandoned agriculture land. In the 1.5°C scenario that includes increased consumers choices taking into account their climate impacts, and which includes changes in food diet as discussed in Figure 29 (Diet 4), the reduction in meat consumption[349] frees additional land and allows even for increased afforestation. The P2X scenario has also a relatively large amount afforestation, however, in this case, this is due to the economic incentive to produce feedstock for energy that pushes investements in more forest. [XXX, to be checked with IIASA. XXXX non of the biomass files and LULUCF projections is final]

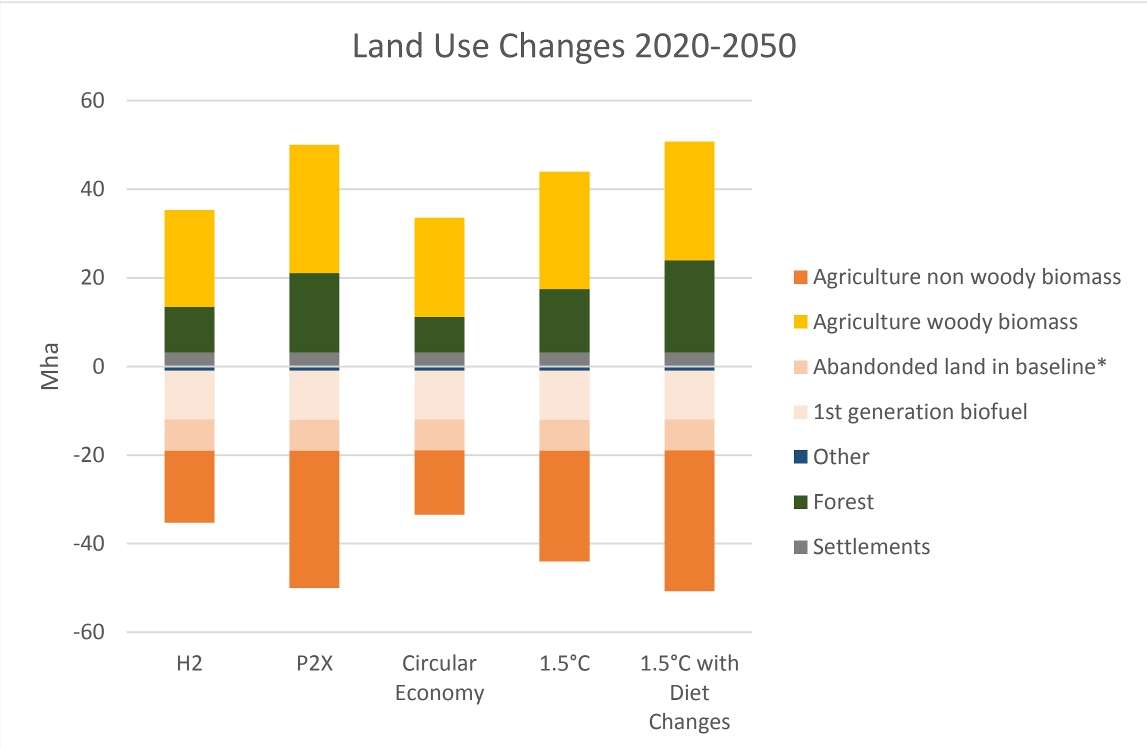


Figure 36: Land use changes between 2020 and 2050 (Globiom modelling)/ Abandoned land in baseline refer to the land currently under agriculture production that is projected to be abandoned in a baseline without any increase in the production of biomass for energy between 2020 and 2050.

[349] Lot of land is required for cattle, meat if the type of food with one of the largest land requirement per calorie.

The need for more urban and industrial areas will represent another important pressure on land but with a smaller impact of 3Mha between 2020 and 2050. XXXX We need to check if this globiom projection is inline with projections of DG regio and others. If information available, I would also add here something about land requirement of wind turbines, solar panels XXXX

In terms of LULUCF emissions, the large use of woody crops instead of stem wood limits the impact on the forest sink and therefore on the net LULUCF sink. Variations across scenarios (Figure 37) show that even an ambitious 1.5°C scenario could maintain by 2050 a net LULUCF sink close to the current level of circa 300 $MtCO_2$.

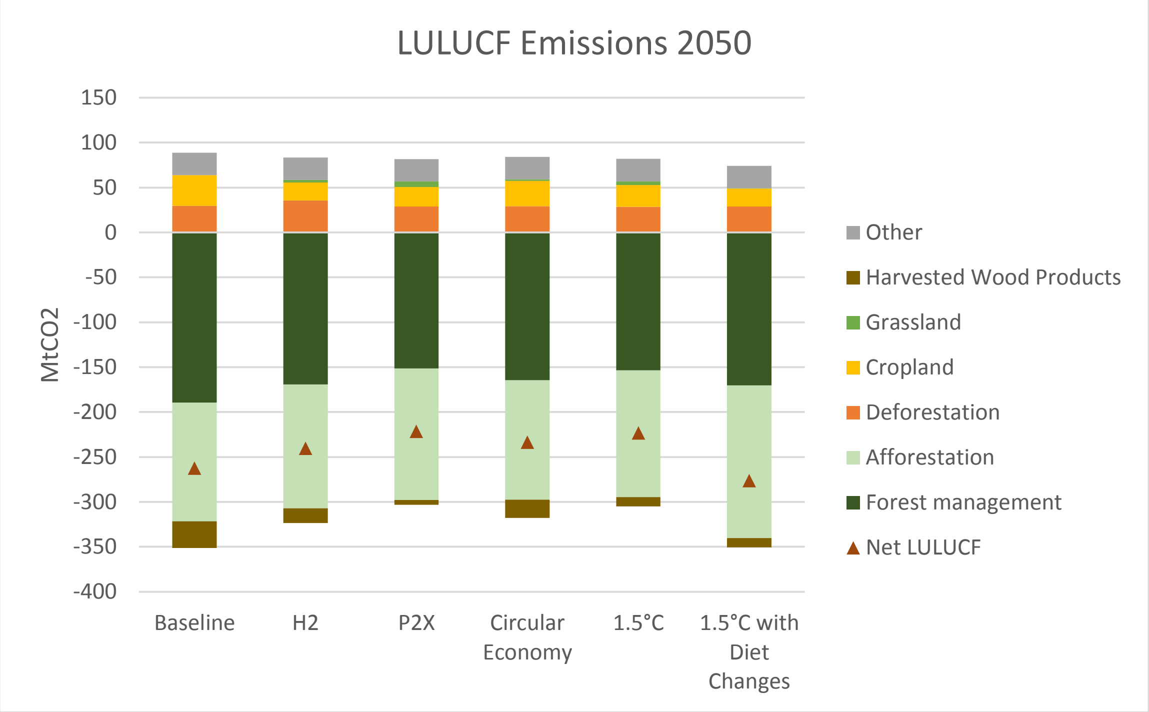


Figure 37: LULUCF emissions accross the scenarios

5.7 Towards negative emissions

5.7.1 Why negative emissions?

Analyses of pathways for keeping global warming below 2°C or 1.5°C (see section 2.1) shows that GHG emissions in the EU need to be reduced by 80% to 100% respectively below 1990 levels by 2050 (and declining to near zero or below by 2100). The absolute priority is therefore to reduce emissions. But emissions can never be reduced to zero. For instance, certain agriculture based non-CO2 emissions cannot be eliminated. The analyses also indicate that reaching the global objectives of the Paris Agreement without measures aiming at removing CO2 from the atmosphere is more than challenging, and could simply be impossible to achieve 1.5°C objective and become impossible to achieve the well below 2°C objective without immediate and very ambitious global action.

Therefore removing the CO2 from the atmosphere has to be considered as an option for a long term GHG reduction strategy. Assessing what its associated challenges are can also inform to what extent the focus has to be on achieving emission reductions as soon as possible, which lowers the need to apply negative emissions subsequently.

Removing CO2 from the atmosphere can be achieved by increasing natural sinks for carbon or by using engineering technologies or a combination. Increasing the natural sink through afforestation, reforestation and enhancing soil carbon sequestration has already been addressed in section 5.6.2.

Other carbon removal options include the use of biomass for energy with carbon capture and storage technologies added to it to store the CO2 emissions underground (BECCS), direct air CO2 capture and subsequent underground storage (DACCS), biochar, enhanced weathering, ocean alkalinisation and ocean fertilisation (Figure 26). We do not consider in this section the removal of other GHG than CO2 even if some technologies exist (de Richter et al 2016, Ming et al 2016, Stolaroff et al 2012, Lomax et al 2015b, Boucher et al 2014)[350]

Providing cost estimates for various options removing carbon from the atmosphere is challenging. Costs from the literature are varies very significantly, reflecting the heterogeneity in the methodologies used for their estimates. These large ranges of possible costs and uncertainties are unavoidable since most of the options for carbon removals are only at an exploratory stage and none of them really mature for large deployment (except Afforestation). The cost estimates reported in a recent and comprehensive review[351] of the current knowledge regarding negative emissions technologies is summarized in Figure 38. According to this review, most of the negative technology options could remove CO2 from atmosphere at a cost below 200 euro/tCO2, in the long term and assuming a removal of the uncertainties surrounding the development and implementation of the technologies involved. The author of the study do not consider any real potential for ocean fertilization.

[350] Ming T, de_Richter R, Shen S and Caillol S 2016 Fighting global warming by greenhouse gas removal: destroying atmospheric nitrous oxide thanks to synergies between two breakthrough technologies *Environ. Sci. Pollut. Res.* 23 6119–38

[351] Sabine Fuss et al 2018 Environ. Res. Lett. 13 063002 https://doi.org/10.1088/1748-9326/aabf9f

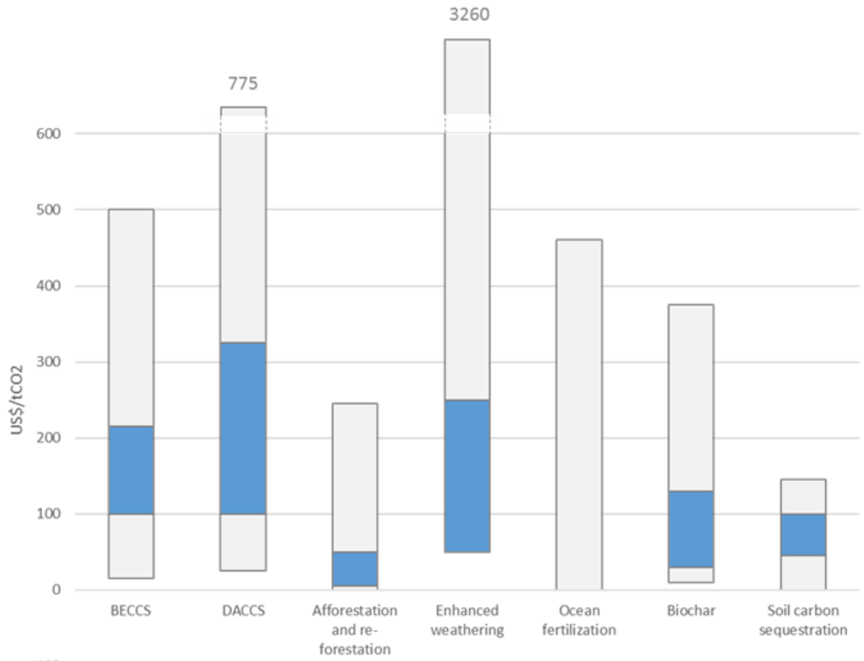


Figure 38: Cost of Negative Emissions Technologies as reported in Sabine Fuss et al.[351]. The full range of costs reported in the literature, the blue colour reflect the part of the ranges the authors of the study consider as the most likely.

5.7.2 BECCS and DACCS

Biomass for Energy with Carbon Capture and Storage

The concept of BECCS lies in the utilisation of biomass as feedstock to generate bioenergy in association with carbon capture and storage technologies (CCS). Together with massive afforestation, BECCS are often seen in the integrated assessment models as one of the main two options for removing permanently from the atmosphere the carbon in exceedance of an emissions budget compatible with the Paris Agreement.

The role of BECCS in the long term will depend on the ability to supply large amount of biomass in a sustainable way and on the development of CCS technologies.

Large deployment of bioenergy raise the question of the quantity of land required for the production of the biomass feedstocks and the competition with other possible use of the land, including the necessity to cover demand in food, feed and fibres. This issue has been addressed in the section 5.6 dedicated to land resources.

Not all bioenergy applications can be linked to CCS. Capital cost of CO2 capture may prohibit the capture of CO2 on small bioenergy installations. On the other hand, the CO2 concentration in the flue gases of some bioenergy installations such as those for production of bioethanol and biogas is very high and thus appropriate for CO2 capture.

Carbon capture and geological storage (CCS) is a technique for capturing carbon dioxide emitted from large point sources such as power plants and industrial installations, compressing it, transporting it and injecting it in suitable storage sites underground. The CO2 emitted from the combustion of the biomass can be stored in geological formations including oil and gas reservoirs, unmineable coal seams, and deep saline reservoirs that have the largest storage potential.

Although all components of CCS are known and deployed at commercial scale, barriers to the uptake of integrated systems exit. The cost of the capture and storage remains important, the capture component being particularly costly for processes emitting flue gas with a low concentration of CO2. The second barrier is the social acceptance for onshore storage in Europe, with the integrity of CCS, and the perceived risk of CO2 leakage, being a concern[352]. Therefore, CCS projects under development at the moment plan to store CO2 offshore, where the public acceptance issue is unlikely to arise, such as below seabed storage, even it correct application of the provisions in the CCS Directive[353] is meant to ensure that the CO2 captured and stored remains isolated from the atmosphere in the long term. Studies estimate that appropriately selected and managed geological reservoirs could retain over 99% of the sequestered CO2 for longer than 100 years and 99% of it for longer than 1000 years[354].

There are a few large CCS projects under development currently in Europe. The Port of Rotterdam PORTHOS project has the ambition to store 2Mt/CO_2 per year from 2020 on going up to 5MtCO2 per year by 2030, which would be about 15% of the Rotterdam's industrial sector emissions. Norway is putting in place a relatively large industrial CCS project: capture from the Oslo waste incinerator and a cement plant, shipping of the CO2 and storing deep under the Norwegian North Sea. There is a small number of other CCS projects and clusters in preparation mostly in the countries around the North Sea but all of them are in rather early stages.

Direct air CO2 capture and storage (DACCS)

Directly filtering CO2 from ambient air, without relying on photosynthesis, and subsequent underground storage is an alternative to BECCS that gets increasing attention in recent years, including from the energy and climate modelling community. DACCS comprises several distinct technologies to remove CO2 from the atmosphere making use of different materials. Contrary to the flue gases of power plants and industrial installations, the concentration of CO2 in the atmosphere is very low (0,04%), it is therefore key to use agents capable of binding efficiently with the few CO2 molecules of the ambient air. Most attempts have focused on hydroxide sorbents, such as calcium hydroxide but today other processes and materials are under investigation, mostly involving amines. Engineering problems involve enlarging the contact surface to increase CO2 withdrawal and dealing with moisture.

The main advantage of DACCS over BECCS is in term of land impact since it does not require biomass and can be deployment on non-productive land in combination with renewable energy technologies such a solar, in the proximity of storage sites. Capturing

[352] E.g. Barendrecht (NL), Belchatow (PL) , Jänschwalde (DE), http://www.globalccsinstitute.com/sites/www.globalccsinstitute.com/files/publications/8172/barendrecht-ccs-project-case-study.pdf, https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1486041390192&uri=CELEX:52016SC0374

[354] Ref 2005 CCS report

100 Mt of CO_2 annually with direct air capture requires between 4 kha and 15 kha, mainly to deploy solar panels, versus 3 to 6 Mha for BECCS and 14 to 33 Mha with afforestation[355] [xxx can these calculation be claried, I assume this mean 4000 hectares of solar panels???].

However, if BECCS delivers energy together with carbon removals, capturing CO2 directly form the ambient air requires on the contrary a significant amount of energy, in particular for releasing CO2 from the sorbent and regenerating the sorbent. Estimates refer to 0.5 MJ per $kgCO_2$[356], others to 300 to 500 MW to capture 1MtCO2 per year[357]. XXX need to check which source NTUA is using for their own assumptions XXX

Research and development on Direct Air Capture technologies is pretty dynamic nowadays, progress can be reasonable expected in a mid-term future. Two direct air capture pilot plants are running in Canada and a third one in Switzerland, providing CO2 for re-use application (greenhouses, carbonated beverages, but also targeting sectors such as Enhanced Oil recovery or synthetic fuel production) with capacities of 300 to 900 tCO2 per year. A Direct Air Carbon Capture and Storage pilot plant has been launched in Iceland in 2017 with the objective to extract 50 tCO2 and store it in basaltic rocks through a mineralisation process also called Enhanced Weathering (see section 5.7.3).

BECCS and DACCS in the scenarios.

XXX need primes runs corrected XXX

Some messages:

NET can dominate the future energy system landscape

BECCS has the first mover advantage

DACCS have more potential for technological development and could be better off in an energy system dominated by "cheap" renewable energy and batteries

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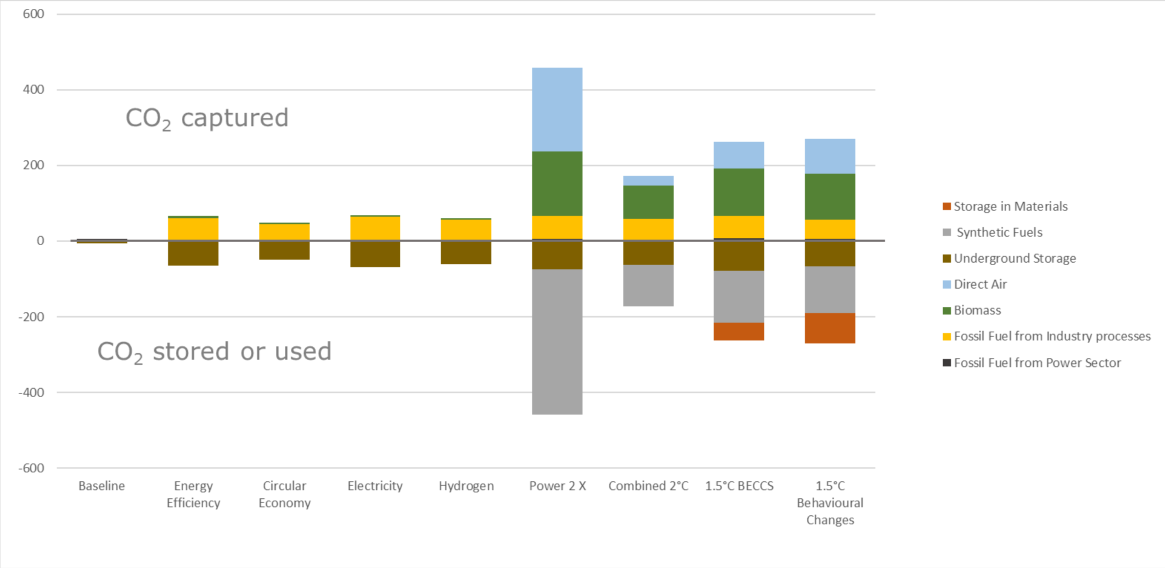
[355] This estimation assume estimates from Smith at al 2016 for BECCS and Smith at al 2016 and information available on Climworks website for DACCS and the implied emission factor from UNFCCC for afforestation (cf section 5.6.2)

[356] American Physical Society Direct Air Capture of CO2 with Chemicals A Technology Assessment for the APS Panel on Public Affairs June 1, 2011

[357] https://www.ted.com/talks/jennifer_wilcox_a_new_way_to_remove_co2_from_the_atmosphere/transcript



5.7.3 Other Options

Biochar, Ocean fertilization, Enhanced Weathering and ocean alkalinisation all still have uncertainties regarding the effectiveness and scalability of their CO2 absorption and storage potential. Further research and large-scale field testing is needed to increase the understanding of the overall effects on CO2 storage, the associated costs and other environmental impacts

Biochar

Biochar is produced from biomass by pyrolysis, i.e. thermal degradation of biomass in absence of oxygen. Added to soil, it can increase the amount of carbon stored with the potential co-benefit of increasing the fertility of the soil and therefor the crop yields. Different processes take place when biochar is added to the soil and some uncertainties remain in the understanding of the overall effects on carbon sequestration and environment. The residence time of biochar into soils is likely to be variable and not well known. Presence of biochar in soils may influence the breakdown of other soil organic carbon which could counteract sequestration of carbon. The interactions between biochar and soils are mostly analysed in laboratories but it is not clear how applicable they are under field conditions[358]. In addition, producing the biomass feedstock for biochar requires land and water and contrary to bioenergy, biochar does not supply energy for the rest of the economy with the pyrolysis that produces biochar being itself energy consuming.

Enhanced Weathering and ocean alkalinisation

Weathering is the process of rock decomposition via chemical and physical processes. Rainwater is slightly acidic due to the absorption of CO2 from the atmosphere that

[358] Ricardo study

occurs in the clouds. When the drops reach the ground they chemically react with rocks and soils and the CO2 content of the rainwater is transformed into bicarbonate and part of it eventually ends up in carbonate minerals in soils or on the ocean seafloor. The efficiency of this natural process depends very much on temperature and climate, characteristics of the rocks, water solution, interaction with the environment and reactive surface area. Enhanced weathering aims at controlling one or several of these drivers in order to speed up the transfer of the CO2 from the atmosphere to carbonate minerals through this process.

One of the most mentioned approach is to pulverize the rocks in small grains to maximise the reactive surface area. The powder made out of this pulverisation is eventually spread over agricultural land where microorganisms help to accelerate further the mineralization process with, as co-benefit, an increase in the soil fertility. The powder can also be spread directly on the surface of the oceans, contributing to a further alkalinisation of the oceans (reducing acidification) and therefore increasing their potential to directly absorb CO2 from the atmosphere.

The main barrier with this option is the slowness of the mineralisation process and the energetic and economical costs associated to the mining and pulverisation of the enormous quantity rocks needed to counterbalance this slowness and remove the CO2 from the atmosphere at a significant rate.

Another option to speed up the process is presently being tested in Iceland[359], where CO2 is injected into underground into basaltic rocks, where this CO2 is mineralized relatively rapidly into stable carbonate minerals.

Ocean fertilization

Increasing the production of phytoplankton in the oceans is another possibility to remove carbon from the atmosphere. Oceans are limited in nutrients and in particular in micronutrient such as Iron. About one third of the oceans could see their phytoplankton production significantly enhanced by injecting relatively small quantities of iron[360]. This can trigger a bloom of algae, of which part ultimately sink towards the ocean floor with part of the carbon sequestered in ocean floor sediments.

Part of the carbon stays in the water column on shorter time scales, limiting the quantity of carbon permanently stored. The acidity of oceans also increases after dissolution of the CO2 due to high recycling rate of organic carbon. Ocean fertilization is expected to alter local to regional food cycles by stimulating phytoplankton production, which is the food cycle's basis.

[359] https://www.or.is/english/carbfix/carbfix-project
[360] Source xxx?

5.8 Macroeconomic impacts of the climate and energy transition

The EU's deep decarbonisation and the energy transition will affect all sectors of our economies, as well as our trade relations with the rest of the world. Deep decarbonisation will not only determine *what* we produce and *how* we produce it, but also *what* we consume and *how* we consume it. At the core of the transition, the structure of our energy system will evolve in fundamental ways, thereby reducing our dependency on energy imports. Deep decarbonisation will not be the only transformative trend that will affect the EU and global economy over the coming decades. Other meta-trends as described in section 2.2 will continue to unfold or perhaps accelerate. For example, the transformation will take place in a context of an ageing EU population and evolving globalisation.

Macro-economic modelling enables an assessment of the impact of decarbonisation on broad economic aggregates as well as the composition of output, employment, international trade and sectoral competitiveness. It faces stronger limitations, however, when it comes to providing deeper insights on the precise nature of the transformation of individual sectors, often not including the required technological representation.

In addition, modelling over very long-term horizons (e.g. 2050 and beyond) should not be seen as forecasts in the sense of short-term economic forecast, which seek to make relatively firm predictions of detailed economic indicators. Instead, long-term modelling is constructed to assess the impact of key factors and assumptions relative to a "baseline" of likely long-term developments. It therefore abstracts from short- or medium-term economic factors that may affect the trajectory of our economies in significant ways, e.g. financial crises, disruptive technological innovation, etc.

All modelling results used in this section operate on this principle and seek to isolate the impact of decarbonisation by focusing on deviations from the baseline. Projections of long-term GDP growth under the baseline rely on the growth accounting methodology used in the European Commission's Ageing Report[361]. The baseline therefore takes into account the EU's expected population ageing and expectations about the growth of total factor productivity.

The Joint Research Centre's GEM-E3 (CGE) model was used to assess a range of scenarios reflecting on macro-economic issues. For this the GEM-E3 model was calibrated in-line with the energy the PRIMES energy system model results for the reference (serving as baseline) and a projection achieving -80% greenhouse gas emissions in 2050 (the high electrification scenario in PRIMES).

At the core of the modelling assumptions are two possible pathways for the EU and the rest of the world: (1) a world where the EU achieves a reduction in GHG emissions of 80% in 2050 relative to 1990 levels while the rest of the world implements the nationally determined contributions as submitted to the UNFCCC, (INDC-80 scenario, in-line with projections by the POLES model); and (2) a global action scenario sufficient to achieve a

[361] European Commission (DG ECFIN), "*The 2018 Ageing Report. Underlying Assumptions & Projection Methodologies*", European Economy Institutional Paper 065; and European Commission (DG ECFIN), "*The 2018Ageing Report Economic & Budgetary Projections for the 28 EU Member States (2016-2070)*", European Economy Institutional Paper 079.

2°C objective, with the EU still reducing its GHG emission by 80% in 2050 (2C scenario, in-line with projections by the POLES model).

Several variations were then used to assess the impact of varying assumptions on the labour market, carbon pricing in the ETS and non-ETS sectors, the behaviour of firms in ETS sectors and the use of carbon-based revenues. However, not all results are reported in all instances below. [In addition, a global action scenario sufficient to achieve a 1.5°C objective was also modelled, whereby the EU reduces its GHG emissions by XX% in 2050.]

The E3ME (Cambridge Econometrics) macro-econometric model was used in parallel to provide as comprehensive a picture as possible. The model was similarly made consistent with the PRIMES results for the baseline and a -80% GHG decarbonisation pathway (the high electrification scenario in PRIMES). As for GEM-E3, the INDC-80 and the 2C scenarios form the core of the modelling [together with a 1.5°C scenario]. [A number of variations were also included regarding carbon pricing in the ETS and non-ETS sectors and the use of carbon-based revenues.]

The GDP impact of decarbonisation is projected to be small. Modelling results vary to a limited extent only and convey a consistent message: the decarbonisation impact on GDP will be if any limited. While GEM-E3 indicates that decarbonisation will entail a small negative effect on GDP by 2050, E3ME suggests that the impact of decarbonisation efforts on GDP could actually be positive. The distinct assumptions regarding market imperfections and whether the economy operates at full capacity are at the heart of these differences. Assuming that the economy has some slack to begin with (E3ME), additional investment in decarbonisation operates as a demand stimulus and spurs additional growth. Instead GEM-E3, which assumes the economy to function at full capacity, sees some limited negative impact due to changes in factor allocation over sectors and the resulting productivity. What is remarkable, however, is that the differences between the two approaches are small.

The negative impact is at most [1.45%] by 2050 under GEM-E3, while the positive impact is at most [1.4%] under E3ME (table x). In turn, the OECD estimated that mitigation policies could have a positive impact of 2.2% by 2050 for advanced fuel-importing G20 countries under a coordinated 2°C scenario, if accompanied by structural reforms and green innovation[362]. These GDP impacts must also be put in the context of economies that are set to continue growing under all circumstances, mainly because of increases in total factor productivity (technological progress and innovation). They should therefore be understood as decarbonisation leading the EU economy to grow by [65.8%] between 2015 and 2050 instead of [68.2%] (GEM-E3), or growing by [73.7%] instead of [71.0%] (E3ME).

Table x: GDP impacts (deviation from baseline in 2050 and growth rate between 2015 and 2050, percent)

[362] OECD (2017), "*Investing in Climate, Investment in Growth*", OECD Publishing.

[xxx table to be added once updated runs become available]

Both models indicate that faster decarbonisation by the EU compared to the rest of the world entails a moderate cost in terms of GDP, either as a more negative impact (GEM-E3) or a smaller positive impact (E3ME). This mainly reflects the negative but limited impact due to international trade exposure (see below), which is on aggregate small. In addition, this does not account for possible first-mover advantages in key sectors (solar and wind energy, electric vehicles or biofuels). Recent modelling results indicate that such a first-mover advantage of around 0.1% of GDP could exist, though that it would likely decrease over time[363].

While aggregate output is unlikely to be affected significantly by decarbonisation, this is not so for the sectoral composition of output, i.e. *what* we produce. The output of sectors related to fossil fuels are expected to contract sharply by 2050, with the reduction in output relative to baseline already significant early in the 2030-2050 period. In turn, output in industrial sectors is expected to remain strong and in some cases above baseline. This reflects both continued demand for industrial products and the competitive position of EU industries globally, certainly in case of global action on climate change. The modelling indicates that transport will be negatively affected, as the sector starts from a high initial reliance on fossil fuels and in certain cases more limited decarbonisation options.

Table x: sectoral output impacts, GEM-E3 (deviation from baseline, percent) with global achievement of the well below 2°C objective[364]. [to be updated and to include also the impact of the run that sees EU increase to 2C but other countries remain at NDC]

	2030	2050
Coal	-24.1	-12.9
Crude Oil	-9.1	-13.8
Oil	-12.7	-45.3
Gas	-10.4	-22.8
Electricity supply	-2.2	8.3
Ferrous metals	1.5	8.5
Non-ferrous metals	1.8	1.5
Chemical Products	1.1	0.6
Electric Goods	2.6	0.1
Transport equipment	0.2	-0.7
Construction	0.9	1.5
Transport (Air)	-0.7	-3.0

[363] European Commission, "*A technical case study on R&D and technology spillovers of clean energy technologies*".

[364] This table is based on the 2C scenario, with no involuntary unemployment, no recycling of carbon revenue, free allocation in the ETS (excluding power sector) reflecting the opportunity cost of allowances in the industrial sector's optimisation behaviour and no carbon taxation in the non-ETS sectors.

Transport (Land)	-0.9	-2.0
Transport (Water)	-2.7	-5.8
Market Services	-0.7	-2.1

The estimated impact on the output of energy-intensive industries differs between the INDC80 and the 2C scenarios more than for other sectors. In addition, modelling results for energy-intensive industries are sensitive to key assumptions, in particular regarding the ETS. Two main sensitivity analyses were thus prepared. The first one is based on full auctioning allowances for all ETS sectors (not only the power sector) instead of grandfathering. The second one is based on a full reflection of the opportunity costs of free allowances in firms behaviour (profit maximisation) vs. not reflecting such opportunity costs (maximisation of volumes or market shares). The latter sensitivity analysis is run as industry firms, particular those exposed to international competition, often report that they are not able to include opportunity cost of free allowances im their price setting.

[The results show that a full auctioning of allowances would have a positive impact on energy industries. This is surprising and needs to be investigated. A negative impact would have been expected, even though it could be small given that the share of allowances allocated for free are set to decline in any case. The results also show that volume maximisation instead of profit maximisation leads to an expected increase in output, though the size of the impact is surprisingly large for ferrous metals. This needs to be investigated as well.]

Table x: sectoral output impacts, GEM-E3 (deviation from baseline in 2050, percent).

[xxx table to be added once updated runs become available]

The impact of decarbonisation on private consumption could be somewhat more significant, though still not very large. Differences between modelling approaches are also more noticeable. The negative impact under GEM-E3 is at most [3.23%]. However, this mostly reflects a sharp drop in the consumption of non-durables linked to durables, i.e. mainly a drop in energy consumption for heating and cooling as well as for transport, falling by close to 30% relative to baseline in 2050. In contrast, consumption of durables could rise by up to around 2% by 2050, while consumption of non-durables would other than energy remain stable or fall by at most about 1.7%. Given that GEM-E3 assumes that the economy operates at full capacity, any increase in investment in one sector must be met by a decrease in investment in other sectors, or a decrease in private consumption through a reallocation of resources (full crowding out). It does indeed appear (see below) from GEM-E3 that decarbonisation entails a shift from consumption to investment, at least during the transition period.

In contrast, the assumption that the economy typically operates below capacity enables an increase in investment for decarbonisation in E3ME without full crowding of other investments or consumption. Under this model, private consumption could increase by up to about 1.0% in 2050 relative to baseline.

Table x: Private consumption impacts (deviation from baseline in 2050 and growth rate between 2015 and 2050, percent).

[xxx table to be added once updated runs become available]

Significant investments will necessarily be required to decarbonise the energy system and industry and to foster research and innovation. To a significant extent, this will mean *other types* of investment than under the baseline rather than *additional* investments. At the aggregate level, it nevertheless remains that additional resources will need to be mobilised for investment, as reflected in the modelling. The crowding out effect assumed in GEM-E3 dampens the impact of the decarbonisation scenarios on aggregate investment, even though a limited shift in aggregate resources from consumption to investment takes place under virtually all scenarios. This shift is persistent during 2020-2050 in most cases, with investment around 0.2% to 0.3% above baseline throughout the period, as reflection of the sustained nature of the investment needs.

The most significant impacts, however, concern the types of investment that take place, with impacts of a similar nature regardless of the scenarios envisaged. As expected, investment in fossil fuels are expected to drop below baseline throughout the period, reflecting the need to accelerate the phasing out of such fuels from the energy system early on (table x). Industrial sectors instead are projected to require significant additional investment to decarbonise for a sustained period of time, while higher reliance on electricity will necessitate a shift of resources to supply and power technologies.

Table x: sectoral investment impacts, GEM-E3 (deviation from baseline, percent)[365] [xxx to be updated once updates modelling become available].

	2030	**2050**
Coal	-25.3	-7.2
Crude Oil	-17.7	-25.6
Oil	-10.8	-45.4
Gas	-11.3	-23.2
Electricity supply	-3.3	6.5
Ferrous metals	2.8	14.2
Non-ferrous metals	2.0	3.4
Chemical Products	1.5	3.1
Electric Goods	2.9	1.9
Transport equipment	0.4	0.3
Construction	1.0	1.9
Transport (Air)	1.0	9.4
Transport (Land)	-0.4	-2.3

365 This table is based on the 2C scenario, with no involuntary unemployment, no recycling of carbon revenue, grandfathering in the ETS (excluding power sector) and in non-ETS sectors and reflecting the opportunity cost of allowances in the industrial sector's optimisation behaviour.

Transport (Water)	-1.8	-3.7
Market Services	-0.7	-1.7
Power Technologies	22.7	65.3

In contrast to GEM-E3, the additional investment needs in E3ME provide a demand stimulus to the economy and does not fully crowd out other types of investment. In aggregate terms, investment is 2.6% higher than baseline in 2050 both under the INDC80 and 2C scenarios. Investment is solidly and consistently above baseline for the entire period up to 2050.

The impact of decarbonisation on aggregate employment is limited. The version of the GEM-E3 model used in this section assumes that wages are flexible and adjust until there is no excess labour supply as well as that there is crowding out of investments. Under this modelling assumption, aggregate employment is not affected, even though the sectoral composition is impacted. If involuntary unemployment is factored in through labour market imperfections (efficiency wages), the total unemployment rate in 2050 increases at most from [8.2%] under the baseline to [9.0%] under the 2C scenario. However, this represents the worst-case scenario, with GDP 1.45% lower than baseline. If carbon revenues are recycled to reduce taxes on labour […].GEM-E3 results that do only assume limited crowding out of finance for investments would see less negative impacts (see also section 6.5). In contrast, E3ME estimates a positive impact on employment of 0.3% (INDC80) or 0.4% (2C) by 2050, equivalent to 628 000 and 973 000 additional jobs. Similarly, the OECD estimates a positive impact on employment of about 0.2% by 2050 for G20 countries, based on the assumption that additional investment and structural reforms to labour and product markets would take place. Overall, this indicates that the aggregate impact on employment is likely to hinge upon factors that relate more to the structure of the labour market than to decarbonisation *per se*. At the sectoral level, however, the employment impacts are expected to be significant. Similarly to what is projected for investment, employment in sectors linked to fossil fuels is expected to fall sharply. In addition, the composition of employment within sub-sectors and in terms of skills is likely to be affected in significant ways that cannot be captured by macro-economic modelling (see also discussion section 6.5).

Overall, macro-economic modelling indicates that: (1) the impact of decarbonisation on broad economic aggregates like GDP, investment, consumption or total employment is likely to be relatively limited under all scenarios and (2) two modelling approaches that differ significantly structurally as well as in their underlying views on the working of the economy and the scale of market imperfections concur on conclusion (1), even though the sign of impacts differ at times.

As far as capital is concerned, decarbonisation will indeed require not only additional investment, but also different kinds of investments than under the baseline. The transition will therefore generate risks of capital misallocations in view of long-term objectives and stranded assets, and the associated risk for the financial sector, either as a result of erroneous business decisions on behalf of investors (a risk inherent to business decisions, but exacerbated in fast-evolving sectors) or potentially also as a result of regulatory uncertainty or instability. Finally, the architecture of the financial system will have to be fit for purpose in order to be in a position to fund the right kind of investments (section 6.2).

As far as the labour market is concerned, the transition will generate significant implications both on labour demand at the sectoral and sub-sectoral level and in terms of skills in demand, with potential impacts on income distribution as well. This is likely to have repercussions at the national level as well as the level of sub-regions, depending on their current specialisation in production. Such implications will need to be managed carefully in the context of a just transition and to ensure that no segments of the population are left behind in the process (section 6.4).

5.9 Co-benefits and interactions with other Sustainable Development Goals

Acting on climate change provides many opportunities to enhance sustainable development. For example, decarbonising energy and transport is associated with improved air quality and health outcomes, especially in urban areas. Similarly, Promoting a circular economy (smarter use of materials such as plastics) can reduce emissions while also contributing to cleaner land and water, and healthier oceans.

However, while some synergies are well understood, knowledge about how climate action interacts with all of the 17 Sustainable Development Goals (SDGs) of the UN is still evolving. Identifying further synergies between climate action and sustainable development will help the EU to be a leader in making the case for ambitious climate action, both domestically and worldwide. As countries pursue climate action and sustainable development jointly, the EU can also show leadership by identifying how to manage potential trade-offs.

The close relationship between climate and sustainable development is recognised through the inclusion of climate action as one of the 17 SDGs[366] adopted by the UN General Assembly in 2015. The EU and its Member States have in turn committed to implementing the 2030 Sustainable Development Agenda in full both domestically and internationally, including through implementation of the Paris Agreement[367].

A growing number of studies investigate the relationships between particular SDGs and climate action. Many use the framework of Nilsson et al.[368] which assesses the positive and negative interactions between SDGs on a scale, with 'indivisible' being the most positive relationship. This system is applied in detail in the IPCC Special Report on 1.5°C[369] which finds that, while there are multiple synergies and trade-offs associated with climate action, the number of synergies exceeds the number of trade-offs in several

[366] https://www.un.org/sustainabledevelopment/sustainable-development-goals/

[367] See Council Conclusions on *the EU response to the 2030 Agenda for Sustainable Development (June 2017)* and on *Climate Diplomacy* (February 2018) as well as the Communication *Next steps for a sustainable European future* of the European Commission (COM(2016) 739 final) which maps out how specific EU policies contribute to sustainable development domestically and internationally.

[368] Nilsson M et al. (2018) Mapping interactions between the sustainable development goals: lessons learned and ways forward. *Sustainability Science*. https://doi.org/10.1007/s11625-018-0604-z

[369] See Chapter 5 and Table 5.3

areas. In some cases (such as the relationship between food security and expansion of bioenergy) synergies and trade-offs co-exist and will need to be carefully managed.

In the energy sector, strategies that focus on limiting demand growth through technology and energy efficiency can reduce emissions while advancing a number of SDGs, (especially those associated with human health via air and water pollution)[370]. Similarly, IEA analysis finds that achieving universal access to electricity by 2030 could reduce global greenhouse gas emissions as well as improve health and gender equality, if smart technologies and efficient appliances are used. In this case, the emissions associated with expanded energy access would be more than offset by reductions associated with use of traditional biomass[371]. McCollum et al[372] also find a strong positive relationship between climate action and the goal of affordable and clean energy (SDG 7), among a number of interactions as summarised in Figure 39.

Figure 39: Nature of the interactions between SDG7 (Energy) and the non-energy SDGs. The relationships may be either positive (left panel) or negative (right panel) to differing degrees. Source: McCollum et al. (2018)

In terms of health impacts, the reduction of GHG is associated with lower emissions and concentrations of air pollutants, in particular fine particles with a diameter of 2.5 µm or less ($PM_{2.5}$), nitrogen oxide (NO_2) and ozone. These pollutants have significant adverse effects on human health and can cause respiratory and cardio-vascular diseases, among others. They are also at the root of premature deaths. In turn, high ozone concentrations negatively affect plant growth. Research to quantify the benefits of climate action associated with improved air quality has progressed in recent years and highlight the significant scale of such co-benefits[373]. Separate research has also developed to better quantify the benefits associated with avoided adaptation costs or the benefits of adaptation strategies themselves.

[370] See for example von Stechow et al. (2016). 2 °C and SDGs: united they stand, divided they fall? *Environ. Res. Lett.* 11 034022 https://doi.org/10.1088/1748-9326/11/3/034022
[371] IEA (2017). Energy Access Outlook 2017. From Poverty to Prosperity.
[372] McCollum et al (2018) Connecting the sustainable development goals by their energy inter-linkages. *Environ. Res. Lett.* 13 033006. https://doi.org/10.1088/1748-9326/aaafe3
[373] See for example European Commission (Joint Research Centre), "*Global Energy and Climate Outlook 2017: How climate policies improve air quality*", JRC Science for Policy Report.

When looking at the specific scenarios for the EU28 we see that climate policy benefits air quality, human health and ecosystems due to the reduction in energy consumption and shift towards less polluting fuels. Both the circular economy and behavioural (aiming at 1.5 degree) scenario have significant benefits (see Table below). The combined scenario has smaller benefits since the reduction in emissions (i.e. PM2.5) is smaller. This is due to the increase in biomass use i.e. in smaller installations that do not control air pollution. [xxx can we check why the combined has less biomass compared to the other, for transport at least the circular has highest biomass use, but probably lower rather in industry]. Mortality benefits are valued using the benefit ranges per life year lost. Improvements in EU air quality also decrease the areas of ecosystems exposed to level of acidification and eutrophication exceeding critical loads (see Figure).

Table Y: Air pollution control costs and benefits in the EU compared to baseline in 2050 (EU28)

2050	Circular (3)	Combined (7)	Behave (8b)
SO2 (1000 ton)	-164	-70	-134
NOX (1000 ton)	-637	-486	-709
PM (1000 ton)	-33	-1	-18
Health impacts (million life years gained due to less PM2.5)	8.1	3.9	7.0
Premature deaths ozone avoided (cases/year)	867	703	1015
Reduced health damage (billion €/year).	467.4-1077.4	223.9-516.1	401.1-924.5
Air pollution control cost savings (€2010 billion/year)	21	25	33
SUM reduced pollution control & damage costs: (€billion/year)	488-1098	249-541	434-958

Source: GAINS model and own estimates for monetary damage based on TSAP values of €57000 to 133000 per life year lost. Impacts on morbidity, materials, buildings and crops are not included.

Research from the Joint Research Centre assesses four types of benefits under various mitigation scenarios: (1) avoided hospital admissions and healthcare costs; (2) reduced number of lost work days resulting from avoided illnesses; (3) improved crop yields; and (4) avoided mortality. The first three benefits can be translated relatively easily into market benefits, i.e. measured relative to GDP. Avoided healthcare costs increase the level of income available for other types of consumption, while the other two benefits translate directly into higher output. Measuring avoided mortality in terms of GDP is also regularly done in the literature by assigning a value of statistical life in monetary terms.

Modelling results under a 2C scenario indicate that illnesses related to air pollution could decrease by 15% to 40% in 2050, depending on the pollutant and illness considered. In the EU, this would translate into a GDP gain of about 0.04%. Increased agricultural productivity would add another 0.04% to GDP. Although these gains may appear negligible, they do not account for the welfare gains that people gain from avoiding hospitalisation. At the EU level, the number of avoided hospitalisations would amount to XXX by 2050.

Most importantly, concerted efforts to limit global warming to below 2°C would significantly reduce mortality across the world. In the EU, decarbonisation could save around 21 000 lives annually by 2030 and 71 000 lives by 2050. Such benefits would also occur across the world, with a total of 346 000 lives saved annually by 2030 and 1.5 million lives saved by 2050.

Finally also significant ecosystem benefits from reducing acidification and eutrophication arise in the EU from the decarbonisation pathways, significantly increasing the areas protected. [xxx to clarify what protected really means]

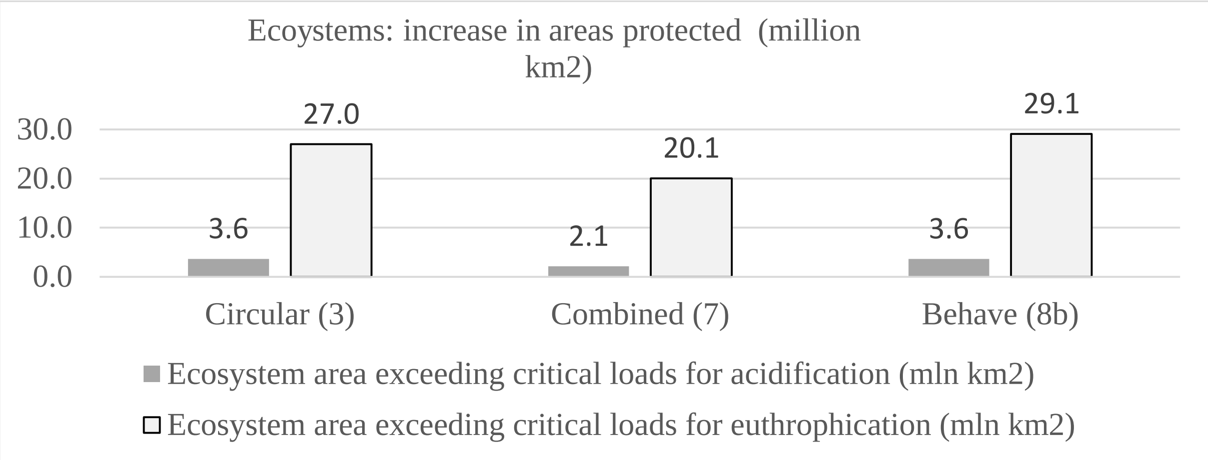


Figure Z: Ecosystem benefits from reducing acidification and eutrophication

6 CROSS-CUTTING FACTORS

6.1 Role of research and innovation

Research and infrastructure and industry leadinnovation (R&I) activities are driving technological progress. This means creating new or improved technologies and solutions. R&I activities are implicitly assumed when designing future scenarios. This is in particular the case if investment costs for a certain technology (e.g. batteries for electric vehicles) are assumed to decrease, or if technical parameters of an existing technology improve (e.g. the fuel consumption of an industrial process) over the time horizon of the analysis. Quantified scenarios often do not explicitly describe the individual measures taken to improve technologies but make assumptions on the expected progress, based on the expected market take-up or on money invested374.

Innovation not only improves individual technologies but may also improve the interaction of different technologies in a system (e.g. the energy system). Enabling technologies, originating from other industrial sectors may allow new functionalities outside of their original sector. An example for this would is the "internet of things", which, in the energy or transport sectors is expected to allow small decentralised units to communicate in real time with the rest of the system. In some cases, the research and innovation lead to disruption in the sense that existing technologies or business models become obsolete in a relatively short time.

6.1.1 Knowledge, research and innovation

Research, innovation and education can be understood as a 'knowledge triangle', a model originally developed for understanding the interaction between universities, research institutions and business around some high tech clusters375. The idea of this concept is that learning, discovering and innovating all go together, as parts part of a system that, if well managed, creates wealth, jobs, growth and social progress. Both private actors (entrepreneurs, SMEs and multinational corporations) as well as different levels of government (ranging from the local level to the European Union) manage the different parts of this system. [add examples of clean tech research clusters in the EU]

Public budgets largely finance education and fundamental research while the private sector is driving applied research and is responsible for product and process level innovation. Therefore, policies and mechanisms applicable to these different sectors (from funding of universities to the competitive environment of SMEs and international corporations) have an impact on the innovation process. The European Commission has acknowledged the importance of innovation in the

[374] For example, industrial learning rate models assume that the cost of a product falls by a certain percentage every time the total number of items produced doubles. While such simplistic relationships often hold over long time periods, the innovation processes behind technology learning are multiple: scaling up production facilities, substituting materials, increasing size, automating production processes among others.

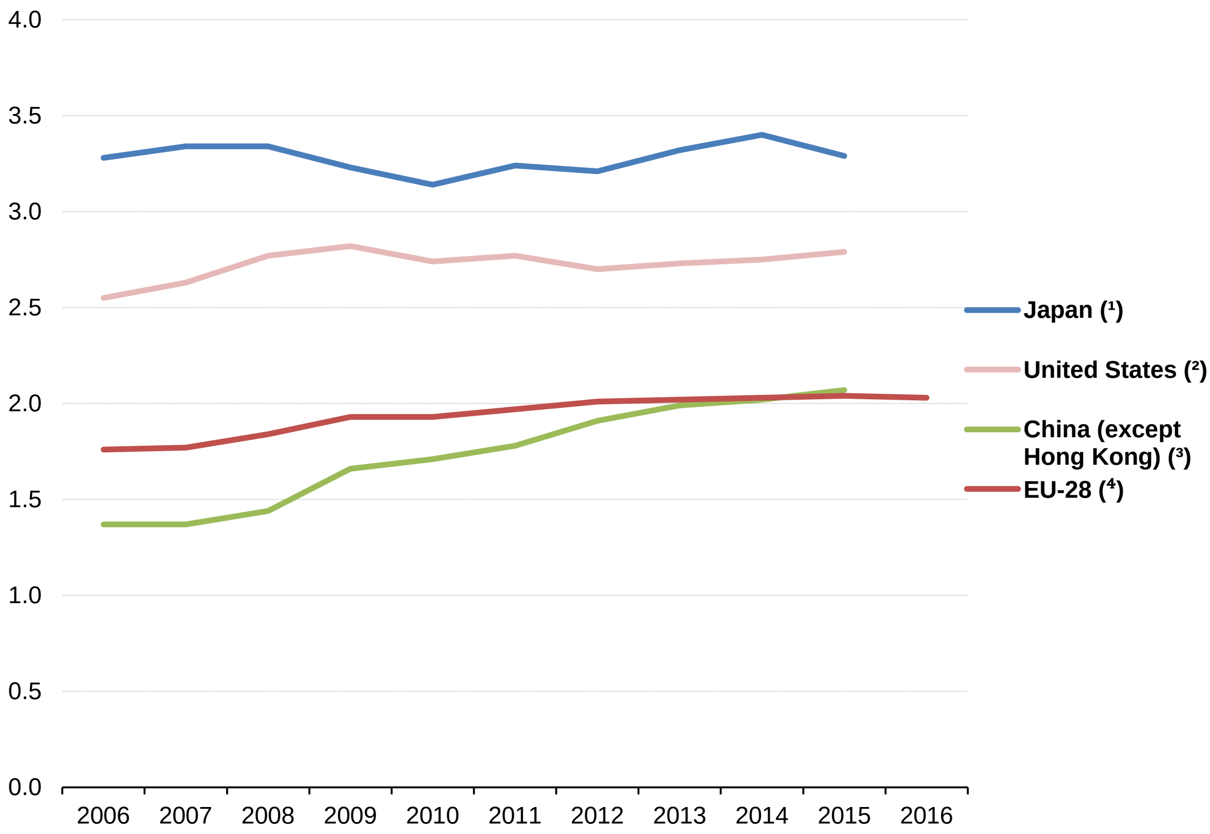
[375] See: "LAB-FAB-APP – investing in the European future we want" http://ec.europa.eu/research/evaluations/pdf/archive/other_reports_studies_and_documents/hlg_2017_report.pdf

Better Regulation Toolbox, requiring its consideration in Impact assessments for new legislative proposals 376.

6.1.2 *Europe in the global innovation landscape*

Europe will need a healthy ecosystem for innovation in order to maintain competitiveness, growth and jobs during the transition to a decarbonised economy. The EU has both strengths and weaknesses within the "Innovation Triangle". Today's global system of higher education and institutional research was born and developed in Europe. Still, Europe is responsible for 30% of all scientific publications and one fifth of global research expenditure377. European based enterprises are responsible for an important share of technological innovation. Yet, Europe is falling behind in two aspects: the EU is spending less on research compared to competing regions and is deriving less industrial innovation.

Research intensity



[376] SWD(2017) 350

[377] Source Open innovation, Open Science, Open to the World – a vision for Europe, https://ec.europa.eu/digital-single-market/en/news/open-innovation-open-science-open-world-vision-europe

Source: ESTAT (http://ec.europa.eu/eurostat/statistics-explained/index.php/R_%26_D_expenditure#Main_statistical_findings)

The ratio of GERD to GDP, also known as R&D intensity, allows comparing research and development investments of economies of different sizes. It includes both private and public money. During the last decade, the research intensity of the EU-28 improved from 1.76 % to just above 2%. Private enterprises are responsible for almost two thirds of the EU's R&D investments378. However, the EU has not yet reached the level of 3.0 % as envisaged in the 2020 strategy. So far, the UE's R&D intensity remains well below the levels of Japan (3.29 %, 2015 data) and the United States (2.79 %, 2015 data). In 2015, R&D intensity in China surpassed that of the EU-28, with Chinese R&D expenditure equivalent to 2.07 % of GDP.

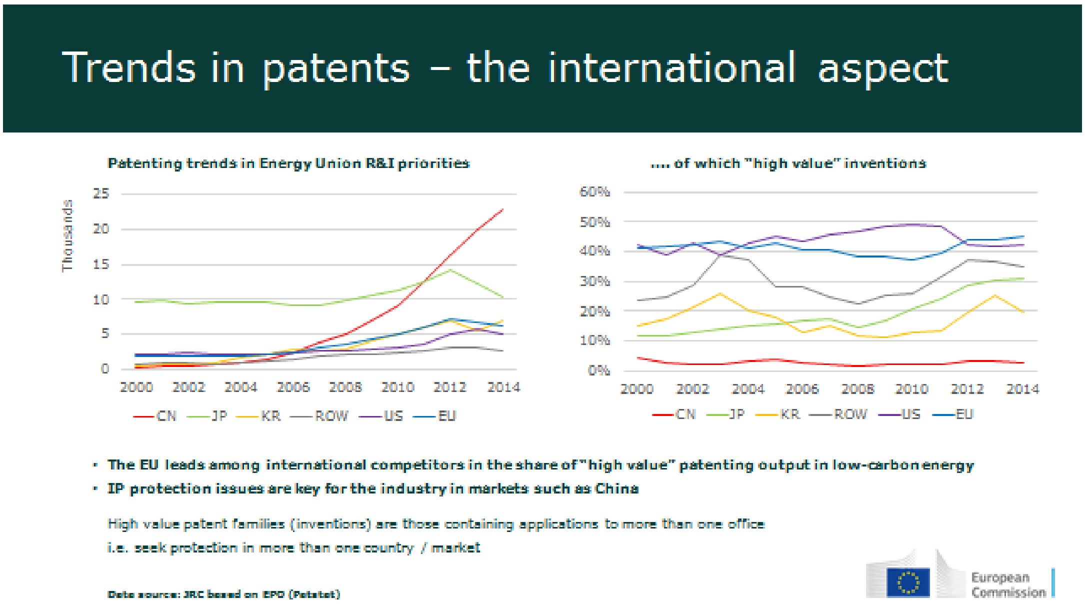
Research spending also differs widely within the EU .In 2016, only three Member States met the 3.0% criterion while nine Member States had R&I intensities of below 1% of GDP. Even larger differences exist on sub-Member State level with research intensities ranging between below 0.5% and 9.5% of GDP379.

Innovation

According to the Community Innovation Survey (CIS)380, more than half of European enterprises regularly innovate in terms of product, process, organisational and marketing 381. Across Member States, this number varies between 13% and 67%. More than half of the innovative companies reported to have made improvements with respect to the environment.

Patent activity can serve as an indicator for industrial innovation. For clean energy technologies in Europe, patenting has been increasing over the last decade but Europe is not leading globally. Japan has consistently outnumbered the EU and, more and recently, China and South Korea have overtaken the EU-28 in terms of the total number of patents filed.

[378] Smarter, greener, more inclusive? — Indicators to support the Europe 2020 strategy — 2018 edition, http://ec.europa.eu/eurostat/web/products-statistical-books/-/KS-02-18-728
[379] ibid.
[380] As set in COMMISSION REGULATION (EC) No 1450/2004
[381] EUROSTAT Innovation statistics, http://ec.europa.eu/eurostat/statistics-explained/index.php/Innovation_statistics



Source (JRC)

On the other hand, European companies leading in terms of patent quality as they seek protections internationally in more than 40% of cases. This proves a growing confidence of their competitiveness in the global energy technology market.

6.1.3 R&I for a low GHG economy

State of the art and needs

The transition to an economy that has moved beyond carbon will technology innovation across all economic sectors. Economic activities related to the production, transformation or usage of energy are of particular concern. According to the IEA, only 4 of more than 30 technologies were on track for a transition pathway compatible with the Paris goals: PV solar (power generation), lighting and data centres (buildings sector) and electric vehicles (transport sector)382. The vast majority of technologies considered require more efforts. Depending on the degree of decarbonisation, efforts are also required in the agricultural sector.

In 2017, public RD&D spending on energy of IEA Member States is at $18 bn. Based on a purchasing power parity; this is still below the peak at the end of the 1970s. Expenditures had been falling until the end of the 1909s but have recovered since. In 2015, the EU spent 0.03 % of GDP on low carbon energy (source: DG ENER,

[382] IEA: Tracking Clean Energy Progress 2017, http://www.iea.org/tcep/

https://ec.europa.eu/energy/en/atico_countrysheets/scoreboard?dimension=Research%2C+innovation+and+competitiveness).

[add information for more sectors]

6.1.4 Closing the gap

With a view to a low carbon transition, a twofold gap has materialised. Firstly, the existing activates on a global scale are not yet sufficient for achieving the Paris goals. Secondly, the European Union is lagging behind other major economies both in terms of total research intensity as well as in the capability of transforming technology into product innovation, growth and jobs.

From a global perspective, the goal is to advance technological innovation for a decarbonised economy making the best use of knowledge, experience, capital and resources wherever available. From a European point of view, it will be crucial to boost domestic excellence in fundamental research, create the necessary conditions to capitalise on the results of this research and reinforce international engagement through science in order to translate climate action into competitiveness.

Encourage applied research and innovation

As innovation is happening within business environments or at the interface between enterprise and research, it will be crucial to create innovation ecosystems. Companies will need to take up research results much faster than today to advance their own technologies. Economic incentives for embracing innovation are required on the firm level. New entrants, often small and medium enterprises, need to be able to compete. This requires open markets free of discrimination, access to capital and a favourable regulatory environment. It is still more difficult for European firms than for their US counterparts to get access to risk capital383. Existing measures and financial instruments for SMEs could be systematically adapted to the challenges of a low carbon economy. Different instruments available on both European and member State level could be streamlined.

Maintaining a constant pressure to innovate would keep existing European enterprises at the forefront of innovation [add historical examples]. This would improve their global market positons and open up export opportunities. Well-functioning global markets with level playing fields would be a prerequisite for capitalising on such an approach through export opportunities.

[383] Open innovation, Open Science, Open to the World – a vision for Europe, https://ec.europa.eu/digital-single-market/en/news/open-innovation-open-science-open-world-vision-europe

An innovation policy that is “open to the world” would help extending innovation ecosystems beyond their current geographic limitations384. Testing new concepts and products on global markets can accelerate the speed of innovation. International collaboration, common standards and the mutual opening of markets will be key. [add examples for EU collaboration with the US and other major economies, standardisation bodies,.etc.]

The global dimension of the low carbon transition has led to a number of international initiatives through which Europe can leverage investments in R&I. Climate finance and the implementation of national commitments are stimuli for global technology cooperation and to create market opportunities for European businesses. E.g., the global Mission Innovation initiative, which was launched at COP 21 combines the ambition to double R&D budgets in the field of clean energy with an approach to collaborate and hare information across countries and with business partners. Private sector players with a similar goal have launched the Breakthrough Energy Coalition.

[add more examples of international clean technology initiatives]

Strengthen fundamental research

Fundamental research requires support on all levels of government. Maintaining excellence in Europe’s higher education and research infrastructure requires action by different levels of government. Prioritising research on both member-state and EU level will be required to meet the challenges posed by a fundamental transition of the European economy. Political actors can expand existing instruments where these have been successful.

Research can strive best when it is “open” in terms of geography and to potentials users of research385. Europe has recently taken initiatives that help ensuring highest standards in research and higher education across the entire EU. [add examples of measure for education and research, e.g. european openScience cloud, Erasmus +,…]

As the world outside of Europe increases its scientific output, the EU will need to ensure access to this knowledge, in particular in the truly global research field of energy and climate. Evidence shows that the quality of research undertaken in international collaborations is higher than average386. Global research cooperation exists for more than 50 years in areas of fundamental research like particle physics or nuclear fusion.

[384] ibid
[385] ibid
[386] ibid

Technology disruption

In a disruptive scenario, technologies may rapidly phase out or business models can disappear due to critical change in costs or functionality. Given to the complexity and the many constituents of the larger economy, it is not straightforward to identify all potential cross-sectoral implications of innovation.

The risks for disruption of technologies or business models is thus inherent in a low carbon transition. As a result, research and innovation paths chosen might become obsolete and enterprises would have to write off investments. Both government and private sector thus need to pursue risk management approaches leaving sufficient flexibility for future adaptations. Policymakers and industry need to find a balance between rationalising R&D expenditures and not putting all eggs into one basket.

6.2 Role of investments and finance

6.3 Impacts for the EU security of supply

Input on PRIMES results:

Trade balance and geopolitics

As one of the five dimensions of the Energy Union Strategy Security, energy supply is a political priority and an important driver for the energy transition. Although the import of fuels is not an energy security problem in every case, the magnitude and nature of, in particular, oil and gas imports (sometimes coming from a limited number of suppliers or via limited number of routes) raise specific energy security and sometimes even wider geopolitical issues. Energy efficiency or other ways of limiting energy demand (circular economy and behavioural change) and switching to low-carbon fuels can contribute to reducing energy imports[387] albeit in the latter case the natural endowment and competitive advantages in production costs could potentially lead to replacing dependency on fossil fuels by dependency on alternative fuels or new materials used for the energy transition.

In 2016, the EU produced 46% of the energy it consumes, while 54% was imported[388], almost entirely under the form of fossil fuels. Oil imports represent the bulk of these imports (about two thirds of the total, more than 90% of oil consumed in the EU), followed by natural gas (about a fourth, more than 70% being imported) and coal (about half being imported). Because

[387] And by reducing the overall scale of imports, the magnitude of potential disruptions of the economy because of supply severance or price shocks is also diminished.

[388] Eurostat (2017): http://ec.europa.eu/eurostat/cache/infographs/energy/bloc-2a.html

of higher volume and higher unit price, oil represents the most expensive energy import cost[389] for the EU, which oscillated since 2005 between 1% of GDP[390] (in 2016) to 2.5% in 2012, (1.2% in 2017), depending to a large extent on the evolution of the oil price.

By bringing significant energy efficiency improvements and increasing the uptake of renewable energy produced on EU soil, the long term strategy will considerably **reduce our dependency on energy imports**. It would stay close to current levels in the first decade, mostly because of the expected reduction of domestic production of oil and gas, which could be halved by 2030 compared to 2010 (more elements / reference?). However, it would reduce strongly afterwards by 2050, from more than 50% in 2030 to 25-35% in the 2C scenarios and less than 20% in the 1.5 C scenarios, and further down by 2070 to 20-25% in the 2C scenarios and below 15% in the 1.5 C scenarios. The lowest dependency ratio go in hand with more domestic resources used, which is the case when new efuels, notably relying upon renewables, are developing more strongly (P2X case and COMBO case).

The remaining limited energy imports would still dominated by oil for about two thirds, followed by natural gas, while **coal imports** virtually disappear from the EU energy system already in the Baseline and in 2050. **Imports of oil** would reduce very slowly without strong decarbonisation of then energy system, where, compared to 2030, they would decrease between 40 and 65% in 2050 and between 55 and 70% in 2070. While **imports of gas** would increase without strong decarbonisation, engaging into the low carbon transitions would bring them, compared to 2030, between 40 and 90% in 2050 and between 50 and 90% in 2070, with the lowest reductions happening in H2 and P2X scenarios because of higher gas consumption (for balancing purposes) in the power sector.

Further than reduced dependency rates, the volumes imported would actually be much lower thanks to generalised energy efficiency reducing total energy demand in the EU (up to a third lower than current levels).

In addition, the import prices of oil, gas and coal are likely to be negatively affected in a global decarbonisation context whereby all regions would move away progressively from fossil fuels[391]. As a consequence, it is expected that the cost for the economy of fossil fuel imports would be much lower than the current levels.

The **net monetary cost of fossil fuel imports decreases in all decarbonisation scenarios**. In the period 2021-30 the value of fossil fuels import bill is projected to amount, on average to €413 bn/year and it continues to grow the Baseline throughout the projection period uniquely due to raising fossil fuel prices (volume of imports decreases as described above). In the decarbonisation scenarios this value in the period 2031-50 is reduced to between €336 bn/year and €274 bn/year with the same performance of the scenarios as identified for absolute volume of imports but only magnified by growing fossil fuel prices. In the period 2031-50, this value is reduced to between €237bn/year and €132bn/year.

[389] EC, EU Crude Oil Imports and supply cost (retrieved 02/08/2018)
[390] WB, GDP (current US$) (retrieved 02/08/2018)
[391] See WEO 2017, figure 1.5 (IEA, 2017), or GECO 2017, figure 28 (Kitous, A. et al (2017))

Based on figures presented above, it can be calculated that in the period 2031-50 the decarbonisation scenarios would bring cumulative (20-year) savings in the fossil fuels import bill ranging from €1.930 bn to €3.172. The savings would be even greater in the period 2051-70 ranging from €4.297 bn to €6.402 again with the same performance of the scenarios as identified for absolute volume of imports but only magnified by growing fossil fuel prices. These savings could be invested in the clean energy transition or other pressing needs of European economy.

By 2030 natural gas imports will thus still be remain an important energy source with all its implications, including the import dependency. The EU will thus have to continue its diversification policy and energy diplomacy towards existing and new gas supply options, including on the promotion of an open and liquid global LNG market. However, over the longer run, with natural gas imports expected to reduce by 60-75% by mid-century in a low carbon context, the long-term use of existing import capacities is an open question. The option to import carbon-free fuels instead, like biomass (in a solid or liquid form), hydrogen or e-fuels are possibilities that cannot be discarded, and that could make benefit from existing energy import facilities. In all cases, international monitoring mechanisms will have to ensure that such imports are carbon-free to avoid carbon leakage to other regions.

At global level, shifting away from fossil fuels will trigger large shifts in the energy trade patterns[392], with possible impacts on exporting regions and international relations. Diversification of their economy, including probably developing other energy sources like renewables, would help producers adapt and prevent political instability.

The challenges to security of supply will evolve over time and existing security challenges are likely to lose importance and new challenges are likely to emerge. Hence, although the energy transition will improve the energy trade balance of the EU, it is likely to **increase the import dependency on other raw materials** used in low-carbon technologies. Current production and resource estimates of some of these are sometimes located in few countries or regions in the world (for instance Lithium is mostly produced in Chili, Cobalt in Congo or Graphite in China), which may require a new assessment of priorities of EU energy diplomacy in a changing geopolitical context[393] to secure access to and supply of scarce and valuable raw materials.

[More elements from DG GROW on initiatives & prospects wrt raw materials]

A secure internal market

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[392] Financial transfers from large energy importing regions, like Europe and Asia, to large energy exporting regions are expected to reduce significantly - see GECO 2016, Table 15 (Kitous, A. et al. (2016), doi:10.2791/662470)

[393] Andrews-Speed, P. et al. (2014). Conflict and cooperation over access to energy: Implications for a low-carbon future. https://doi.org/10.1016/j.futures.2013.12.007

Energy security also includes the dimension of the stability of the domestic energy system, and most notably of the power grid and the role of cyber security.

The decarbonised EU energy system will rely, to a great extent, on locally produced renewables and nuclear[394] which, although relying on fuel imported from outside the EU, provides a well-diversified supply ensured years in advance. However, and as explained in section 4.2.1and section 5, it will also rely on a much greater role for electricity. Energy security also includes the **stable delivery of energy** where and when it is needed, a dimension particularly relevant for electricity which is not an easily storable energy vector, unlike fossil fuels. [more elements]

In the transition towards a low carbon energy system, the increasing recourse to digitalisation and automatization, that will provide better overall efficiency and flexibility to the system, will also enhance the exposure to **cybersecurity** risks. Indeed, the energy system will increasingly rely on devices and processes that can become possible targets of cyber threats, jeopardizing the security of supply (as experienced in UA and other countries over the last years) or the data privacy of consumers. In addition to individual component vulnerability, the increased interconnectivity between the different layers of the energy system (market coupling of electricity and gas, numerous physical interconnections in electricity, gas and oil - section 4.2) can also pose a systemic risk through cascading effects, for critical infrastructures[395] in a number of Member States and across borders. To mitigate this risk, increasing cybersecurity of our energy assets throughout the whole chain (production, transmissions, distribution, and consuming equipment) will accompany the low carbon transition[396,397].

6.4 The international dimension, implications for the EU Long Term Strategy

At a global scale, and looking at the long term, Europe will progressively see its share of global demographics reduce. Similarly its proportional weight in the global economy will reduce, as emerging market economies are expected to continue growing at faster rates. In 2015, the EU was the largest economy in the world, accounting for 22.7% of world output, while the U.S. represented 20.6% and China 13.3%. By 2050, the shares of the EU, the U.S. and China are expected to amount to 15.1%, 15.2% and 19.8% (based on the macro-economic modelling used in section 5.7).

The world has seen an intensification of trade relations, and this has implication for the low carbon transition.

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[394] See COM(2017) 237 final.

[395] Critical Infrastructure Directive (COUNCIL DIRECTIVE 2008/114/EC), review by SWD(2013) 318 final

[396] Cyber Security in the Energy Sector, EECSP Report February 2017, https://ec.europa.eu/energy/sites/ener/files/documents/eecsp_report_final.pdf

[397] Energy cybersecurity is part of the larger cybersecurity policy framework that the EU is putting in place – see the joint communication on "Resilience, Deterrence and Defence: Building strong cybersecurity for the EU" JOIN(2017) 450 final

The most obvious and immediate effect of the low carbon transition on trade for the EU would be the significant reduction in imports of fossil fuels which is expected to occur by 2050. Both the INDC80 or the 2C scenarios as included in section 5.7 would save around EUR 250 billion per annum by 2050 on the import bill of fossil fuels compared to a baseline scenario.

While decarbonisation itself puts potentially pressure on the competitive position of EU industry, with some reductions in EU production in the INDC scenario, global decarbonisation would see a reversal and lead to positive effects on the EU's trade balance for most of the 2020-2050 period.] (see also sections 5.3 and 5.8).

International trade and the globalisation can separate the place of production of emissions with the place of consumption of the goods, besides generation emissions due to transport of traded goods itself, for instance historically strongly contribugin to bunker fuel increases.

GHG reductions and targets (as well as GHG inventories) are typically expressed in relation to domestically produced emissions. This is also typically the case for the NDCs as submitted to the UNFCCC. Inventories don't take into account what the emissions are related to the consumption of goods that are imported by a country, and the resulting emissions from the production of these imported good. This is sometimes referred to as Production-based accounting (PBA).

PBA has been subject to criticism as it does not adequately represent the GHG emissions effect of changing consumption patterns due to trade and globalisation and could potentially open the door to "pseudo-decarbonisation" via the outsourcing of carbon-intensive products to third countries. Some authors have therefore proposed to estimate emissions with a consumption-based accounting (CBA) method, that excluded from a country's inventory the domestic emissions associated with exports but includes the emissions in third countries related to the imports it consumes. Such CBA exercises rely on estimates using multi-region input-output tables and trade flows and have inherent challenges related to date availability[398].

In this context the decarbonisation effort of the EU (typically measured in PBA) has been criticised as being significantly less positive if expressed in CBA[399].

But CBA is itself also open to criticism, as it fails to give credit to countries with export sectors that are more carbon-efficient than the world average and therefore contribute to decarbonisation worldwide via their own exports. Put it differently, if such country would not have exported, but other countries would have produced these goods themselves, global emission would have been higher.

Technologically-adjusted consumption-based accounting (TCBA) seeks to adjust for such differences in carbon efficiency in export sectors, by crediting carbon efficient export countries. By doing so it provides for a more accurate reflection of how trade

[398] Peters G., Minx J., Weber C., Edenhoffer O., "*Growth in emission transfers via international trade from 1990 to 2008*", Proceedings of the National Academy of Sciences of the United States of America, 2010.
[399] Xxx add a numeric example?

impact global emissions than a pure CBA approach. Studies applying this TCBA methodology find for instance more reductions achieved in the EU than compared to a pure CBA approach[400].

For this assessment this type of exercise was redone looking at different impacts of the PBA, CBA and TCBA accounting methods on national emissions. The dataset used was the date available in the E3ME macro-econometric model, as well as projections by the model. GHG emissions considered were only energy related [and process??] CO2 emissions due to date constraints for the non-CO2 and land use related emissions.

The results for the EU was indeed that between 1996 and 2016 emissions reduced more using the PBA basis (-20.3%) than the CBA basis (19.5%), though differences are smaller than what other studies project. Instead the TCBA approach resulted in significantly higher reduction for the EU (-25.3%), which indicates that by 2016 the EU had already contributed significantly to the reduction in emissions of other countries because of the increased trade flow and the improved carbon efficiency of its exports. The absolute level of EU emissions on a TCBA basis are also lower than under a PBA basis because of the carbon efficiency of its exports (figure X).

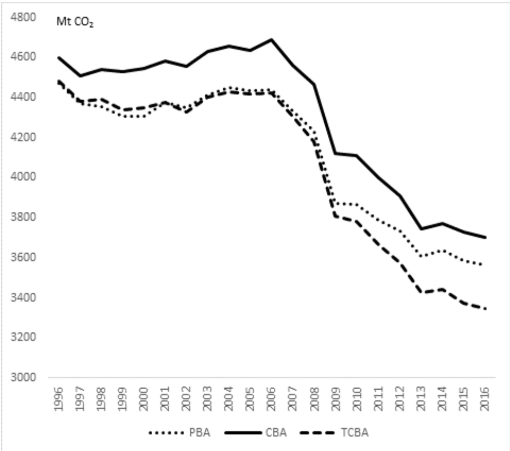

Figure x: EU, GHG emissions on a PBA, CBA and TCBA basis, E3ME

EU trade is thus contributing to the decarbonisation of third-countries via the rising efficiency of its economy. Presently EU exports displace a bit more than 200 Mt CO_2, compared to a situation that EU exports would be produced locally in the importing countries. If the EU would achieve -80% GHG reductions by 2050 and the rest of the

400 Kander A., Jiborn M., Moran D., Wiedmann T., "*National greenhouse-gas accounting for effective climate policy on international trade*", Nature Climate Change, Letters, March 2015. CBA looks at emission per country by calculating the actual carbon content of consumption domestically produced + the actual carbon constant of imported consumption. Under TCBA, the carbon content of exports (i.e. the carbon emissions that are subtracted from the production-based inventory to derive a consumption-based measure) is based not on the actual carbon content of the exports, but based on the carbon content that such exports would entail if they were produced with a carbon efficiency equivalent to the world average for traded product. The carbon content of imports (i.e. the carbon emissions that are added to the production-based inventory to derive a consumption-based measure) is the same for the CBA and TCBA methodology and is based on actual carbon content.

would only achieve the reductions in-line with efforts for their NDCs, with the EU economy seeing its relative carbon efficiency further improve compared to third countries, then the displacement of CO_2 emissions due to EU exports would further increase to Mt 284 CO_2 by 2050. Under a the 2C scenario, this displacement would decrease due to increasing carbon efficiency of other parties' own production, but still be significant at Mt 117 CO_2 by 2050.

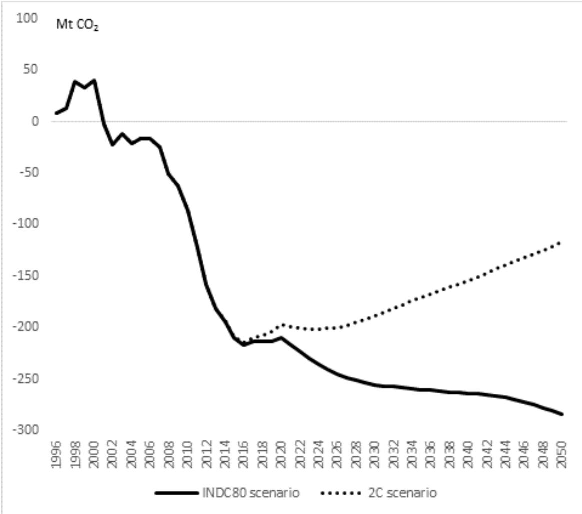

Figure x: Reduction achieved due to EU net exports and imports under a PBA, CBA and TCBA basis , E3ME

The above estimate for CBA based emission reduction of the EU using the E3ME modelling suite is overall more positive than other exercises and it can certainly be further improved, for instance by including agriculture trade and the associated impacts on emissions, including from land use. On the other hand it also confirms that CBA has shortfalls and that it does not recognise the positive impact of EU exports on global emissions. CBA studies sometimes are used to conclude that the EU only achieved GHG reduction due to de-industrialisation. This seems is not correct. The EU has not stopped producing industrial goods and its exports may even be contributing positively to global decarbonisation as the analysis using EME indicates.

Furthermore, if other countries would have achieved emission intensity improvements similar to the EU economy in those sectors with globally traded goods, EU emission reductions using both CBA and TCBA methods would even have further increased. This is of course ultimately the goal of the Paris Agreement, with all countries contributing strongly to the global effort to achieve the temperature objectives under the Paris Agreement. The agreement itself fully recognises this, with a strong transparency framework, and an cyclical approach that sees strengthened of commitments over time by all is important to see action increase beyond current contributions. But it does so by creating a space for a narrative on action not only as an international obligation under the Paris Agreement, but also as a positive agenda towards sustainable development.

On the other hand the role of trade and other internationally relevant policies is also of importance. The ongoing economic transition will necessitate access to a new set of resources, opening new trade routes, and potentially closing others. Global value chains will shift requiring an update of applicable rules and regulations. EU trade policy needs to be aware of this and the EU may contribute to this change itself by setting new standards and re-wiring trade with new free-trade agreements. At the same time the EU needs to be ready to react if global trade of investment rules are being challenged by other players with negative consequences on its competitiveness.

6.4.1 The role of EU security policies

Geopolitical stability and security of supply (ENER)

- Global energy markets fit for purpose

A particular challenge of the low carbon transition is that the economic shift necessarily accompanying the changes will reshape the international framework itself. The changes to global energy markets, for example, will impact on the strategy leverage some states excerpt over other, alter international financial flows just to name few and require economic diversification.

There may be states in this context whose resources or powers are diminished, while there may be others whose significance rises while new dependencies are established. Such shifts will test the established global order particularly within the broad neighbourhood in the EU, potentially increasing migration pressures. The EU needs to anticipate the challenges ahead, and help to accommodate the changes without a breakdown of regional or international stability. Policy actions to address this would be to focus political dialogue and sectoral cooperation on economic diversification, societal, city level and state resilience in vulnerable countries to as to ensure successful transition. Furthermore, long term strategies and climate risks could become standing components of bilateral and bioregional dialogues, agreements and frameworks. Finally, peace and stability can be promoted through local and transboundary environmental resource management schemes and support partner countries in addressing climate-related resource scarcity. Not doing so is not an alternative, because climate change itself will raise numerous similar challenges, affecting resource availability, economic development and eventually migratory flows, which will become significantly larger as the changes expected due to mitigation of climate change.

6.4.1 Cooperation policies with third coun tries

Cooperation projects with fossil fuel exporting countries (CLIMA A1)

Cooperation with G20(CLIMA A1)

Cooperation projects with developing countries

An EU 2050 strategy is likely to serve as a role model to other ambitious countries. It will also raise interest for assistance in similarly decoupling economic growth from greenhouse gas emissions in these countries. One way of doing this is through the EU's intensive cooperation on clean energy and low-carbon projects as well as through technical and financial support for developing countries.

In 2016, the EU and its Member States provided EUR 20.2 billion of climate finance to developing countries. Africa and Europe received around 75% of the climate finance provide by the Commission, including the European Development Fund, and the European Investment Bank. In July 2018, the EIB announced that it has already surpassed its 35% external climate finance target, pledged before COP21 as it provided EUR 2.5 billion in 2017 for climate action investments in developing countries, representing over 40% of its lending in these regions.

Taking one region as example, Sub-Saharan Africa is a strong priority for EU Official Development Assistance (ODA) and, together with the Western Bank and the Neighbourhood, attracts the bulk of EU-level climate finance. Flagship infrastructure projects, especially in renewables, tend to focus on countries with particularly enabling environments such as Kenya, Ethiopia and Ghana. In other countries, smaller scale projects often around EUR 5-10 million are the norm, e.g. under the EU Global Climate Change Alliance+ (GCCA+). In addition, the European Fund for Sustainable Development (a budget of EUR 4.4 billion) under the European Investment Plan became operational and, as of July, mobilised EUR 800 million in guarantees and EUR 1.6 billion in blending, which will translate into over EUR 22 billion public and private investments. Climate-relevant projects[401] for Africa are in the planning or very early implementation phase and are expected to bring tangible climate results in the next years.

Although the EIB presence on the continent is still relatively weak, the EIB has been scaling up renewable energy investments, often co-funded by the EU blending facilities (e.g. Africa Investment Facility) or through the Global Energy Efficiency and Renewable Energy Fund (GEEREF) co-financed by private investors.

With these and other projects globally the EU is trying to pass on knowledge. Capacity building projects are being supported, including model development, to enhance the

[401] These include are *Africa GreenCo* (electricity generation and financing), *DESCO Financing Programme* (rent-to-own solar power kits), *Room2Run* (raise up to EUR 2 billion for new renewable energy projects), *Sustainable Logistics and Interconnectivity Guarantee*, *Boos ting Investment in Renewable Energy*, and *Resilient City Development*.

capacity of developing countries to develop policies, both in the context of NDCs as well as for long term strategies,.

Competitiveness (ENER)

Global leader on clean energy and low-carbon policy (ENER)

6.5 Employment, education and skills

The transition to a low carbon economy has typically been portrayed as a transition towards new growth sectors and employment and overall benign for job creation. But it has also been pictured as potentially being detrimental for a number of sectors, such as coal mining, and thus particularly detrimental for the job market in a number of limited regions with high activity rates in these sectors. This section will assess these dynamics.

Historically, the EU job market has benefitted from climate policies. A review of several studies on the effect of the EU's 20-20-20 targets on jobs concluded that the implementation of these targets leads to an increase in jobs, some estimate putting it as high as 1.0% and 1.5%.[402] Also the International Labour Organisation estimated that by 2030 the low-carbon transition could increase EU jobs by 2 million jobs compared to a business as usual case.[403]

The transition towards green jobs is seen as a positive evolution for the job market. Green jobs are often quality jobs contributing often also to local (non-outsourceable) employment in rural or disadvantaged areas and thus to social reinsertion and territorial cohesion. The EU's green economy has proven itself to be resilient, and has maintained jobs in recent years, including in the recession years. The European environmental goods and services sectors employed 4.1m people in 2015, which is an increase of 47% compared to 2000.[404]

Section 5.8 already discussed the potential macro-economic impacts of a low carbon transition, including the role of taxation, investments and finance and international competitive impacts. Overall it concluded that the low-carbon transition does not lead to significant changes in the total number of jobs in the EU, and in principle may be expected to be benign.

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[402] Cambridge Econometrics (2011) Green jobs: http://ec.europa.eu/social/BlobServlet?docId=7436&langId=en

[403] ILO (2018) World Employment and Social Outlook: https://www.ilo.org/weso-greening/documents/WESO_Greening_EN_web2.pdf

[404] Eurostat (2018) Employment in the environmental goods and services sector: http://ec.europa.eu/eurostat/statistics-explained/index.php/Environmental_goods_and_services_sector

6.5.1 *Sectoral transition*

However, differences will exist between sectors. What is clear is that the low carbon transition will see significant increases in turnover for sectors involved in renewable energy and energy efficiency, with the associated job increases. Previous research concluded that the shift from fossil fuel based energy towards renewable energy deployment increases employment in the EU.[405] The reason for the positive impact of renewable energy deployment is a higher labour intensity in this sector compared to for instance power generation from fossil fuels.[406] Research also showed that the expansion of the workforce in the green energy sector outweighs the compression in the declining fossil fuel sectors.[407] Furthermore, the EU is likely to observe employment gains from a switch to renewable energy since the region is currently a net fossil fuel importer but an exporter of clean energy equipment (mainly wind turbines).[408] Similarly positive employment effects were found for energy efficiency measures.[409, 410] A particular characteristic is that energy efficiency investment is comparatively favourable for local job creation, often associated with activities in the building sector.[411]

In the other sector the picture is more diverse. To give an indication of the impact of climate policies on employment, an assessment was made using the projections as developed for the Clean Energy for All Europeans proposal(EC 2016b IA EE), with energy efficiency improvements between 30% and 35% by 2030, and continuing decarbonisation to -80% GHG by 2050 compared to 1990. Then E3ME and GEM-E3 were used to look at the resulting projections for employment development trajectories up to 2050, with the GEM-E3 version used assuming only limited crowding out. Table 9 presents a qualitative assessment of the drivers of these impacts as well as the results of the modelling exercise ranges for a number of sectors that are potentially affected by the low carbon transition.

The impact of the low-carbon transition on total jobs is estimated overall moderately positive. The low-carbon transition does not significantly impact most sectors. The table shows that the sectors that might experience largest relative change in employment (mining & extraction) account for small shares of total employment. The transition triggers more investments and

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[405] Fraunhofer ISI (2014) Employment and growth effects of sustainable energies in the EU: https://ec.europa.eu/energy/sites/ener/files/documents/EmployRES-II%20final%20report_0.pdf

[406] Wei (2010) Putting Renewables and Energy Efficiency To Work: https://doi.org/10.1016/j.enpol.2009.10.044

[407] UNIDO (2015) Global green growth: http://www.greengrowthknowledge.org/sites/default/files/downloads/resource/Clean_energy_industrial_investment_vol1_GGGI_UNIDO.pdf

[408] Fragos (2017) Job creation related to Renewables: http://www.asset-ec.eu/downloads/ASSET_1_RES_Job_Creation.pdf

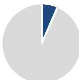
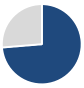
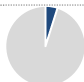
[409] Cambridge Econometrics (2015) Assessing the Employment and Social Impact of Energy Efficiency: https://ec.europa.eu/energy/sites/ener/files/documents/CE_EE_Jobs_main%2018Nov2015.pdf

[410] EC (2016a) The macro-level and sectoral impacts of Energy Efficiency policies: https://ec.europa.eu/energy/sites/ener/files/documents/the_macro-level_and_sectoral_impacts_of_energy_efficiency_policies.pdf

[411] RAP (2016) Costs and benefits of EE: http://www.raponline.org/wp-content/uploads/2016/11/rap-rosenow-bayer-costs-benefits-energy-efficiency-obligation-schemes-2016.pdf

activities in construction, services and agriculture (bioenergy), leading to higher employment. Instead the mining and extraction sectors are expected to contract, as the demand will shift away from fossil fuels. There are also sectors for which the situation is more ambiguous. Power generation benefits from an increase in output, resulting in job increases in the GEM-E3 model [xxx to be checked why E3ME sees negative impacts].

In the manufacturing industries results are more mixed. For these sectors, GEM-E3 projects slight output loses while E3ME expects increases (see also discussion section 5.8 on the differences in modelling approaches). Certainly the energy intensive sectors will face significant changes in their production processes in the future due to the transition towards a low-carbon economy (see section 5.3). If successful this should not be negative for employment in these sectors. Particular the circular economy is often associated with job increases in the de value chain supplying the energy intensive industries[412]. Furthermore also in the overall manufacturing sector the picture is diverse, with for instance a European automotive manufacturing sector that has to switch from internal combustion engines to electric drive trains. This development is expected to accelerate with a reduction in battery prices.

Sector	Qualitative assessment of impacts of a low-carbon transition	Share of total jobs in 2015	Range of change in jobs by 2050 in the E3ME and GEM E3 results
Construction	• Direct benefits from investments related to the low-carbon and climate-resilient transition (e.g. renewable energy technologies, energy efficiency, and adaptation measures) • Job-impact strongly dependent on investments in the sector • Workers need to up-skill to handle innovative building materials	 **6.5%**	⇗ **0% to +4%**
Services	• The business services and distribution & retail sectors are indirectly influenced as they depend on corporate and household demand • Digitalisation will grow in importance in the long-term due to the low-carbon transition • The transport sector is expected to undergo a substantial transformation that might lead to a change in skills requirements • In the non-business services sector, the skills profile of procurement-related jobs might change due to a shift towards green procurement	 **73.7%**	⇗ **Around +2%**
Agriculture	• Bioenergy production has a positive effect • In the long-term, decarbonisation policies help to protect jobs that depend on eco-system services	 **4.9%**	⇧ **+1% to +9%**
Mining & extraction	• Automation and global competition have led to a continuous contraction of the workforce in the mining sector • A low carbon transition will continue to shifts away from fossil fuels with significant impact on employment in the mining and extraction of fossil fuels	**0.4%**	⇩ **-46% to -2%**
Power generation	• Energy efficiency measures lead to a reduced demand in energy in the mid-term but electrification will increase the demand again • The higher labour intensity of renewable energy technologies has a positive impact on employment but not all jobs are created in the power generation sector	**0.4%**	⇨ **-11% to +19%**

[412] Xxx reference?

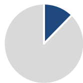
Sector	Qualitative assessment of impacts of a low-carbon transition	Share of total jobs in 2015	Range of change in jobs by 2050 in the E3ME and GEM E3 results
Manufacturing (energy-intensive industries)	• Risk of carbon leakage depends on measures that allow EU industries to remain competitive and if there is a unified global decarbonisation ambition • Faces structural changes to existing production processes due to decarbonisation needs, opportunities related to the circular economy. • An increase in investments in renewable technologies or energy efficiency measures would lead to an increase in demand in upstream sectors to the construction sector, such as the manufacture of iron, steel or cement	**1.9%**	**-4% to +3%**
Other manufacturing	• Benefit directly from higher investments triggered by climate policy (increase in demand for clean energy products produced by some sub-sectors) • Benefits indirectly in upstream sectors to other growing sectors, for example construction • Automotive manufacturing will face structural changes due to electrification	 **12.3%**	**-2% to +2%**

Table 9: Impacts of a low-carbon transition on different sectors (E3ME, GEM-E3)

To evaluate the magnitude of the employment impact of a low-carbon transition on the different sectors, it may be of interest to compare this to other megatrends (see also section **Error! Reference source not found.**).

EU population is ageing. The table below gives an overview of employment numbers in the sectors as represent in the modelling exercise as represented in Table 9. In the baseline scenario in this projection, these sectors would see by 2030 9 million jobs being added. Due to decarbonisation this increases by 0.3% compared to baseline projections, or the equivalent of 700000 thousand additional jobs. On the other hand these sectors have 66 million people active today in the age class of 50 to 64, of which many will retire by 2030. Decarbonisation is a positive, all be it a limited, driver for total employment. Finding replacements for retiring labour and candidates for new jobs overall in the EU economy, is a big challenge to which decarbonisation will rather add (see section 6.5.3). For specific sectors that see a decline in jobs due to the low carbon transition, even in the pessimistic 'worst case' scenario, a part of these job losses can be absorbed through retirements.

Million	Total employment (2016)	2016-2030 change in baseline	2030 change due to decarbonisation (lower end of the projected range in Table 9)	2016 labour in the 50-64 years age bracket
Sectors represented	224.2	8.8	0.7	-65.9
Construction	14.5	0.8	0.3	-4.0
Services	165.3	11.6	1.0	-48.6
Agriculture	10.9	-1.9	-0.2	-3.8
Mining & extraction	0.9	-0.1	-0.1	-0.2
Power generation	0.9	-0.1	-0.1	-0.3
Manufacturing: Energy-intensive industries	4.2	-0.4	0.0	-1.3
Other manufacturing	27.5	-1.3	-0.0	-7.7

Table 10: Need to absorb employment changes

6.5.2 *Regional implications*

While the challenge posed by a decline in employment at economy and even sectoral level appears manageable, it is clear that a low-carbon transition can entail significant economic and societal challenges for regions. Particularly challenged are regions whose economies are largely made up of sectors that either are expected to decline or will have to transform in the future. An assessment was made on what which regions might be in this situation in the EU. Table 11 show which sectors and sub-sectors were included in the two different categories in this assessment and the respective NACE codes.

Sectors expected to decline	Sectors expected to transform
• Mining of coal and lignite (B05) • Extraction of crude petroleum and natural gas (B06) • Mining support service activities (B09)	• Manufacture of chemicals and chemical products (C20) • Manufacture of other non-metallic mineral products (C23) • Manufacture of basic metals (C24) • Manufacture of motor vehicles, trailers and semi-trailers (C29)

Table 11: Sectors shown in the heat maps

To visualise the regional impact of a low-carbon transition, the below heat maps (Figure 40) show the relative share of employment in sectors that are expected to decline and in sectors that will have to transform.

Three EU regions (NUTS-2 level) have employment shares of more than 1% in sectors that are expected to decline. The region with the highest share (11.3%) is North Eastern Scotland in the United Kingdom because of high employment in extraction and support service activities, focussed on oil and gas . Similarly but with a focus on coal and lignite, Silesia in Poland and Sud-Vest Oltenia in Romania have a share of 5.3% and 1.8% % of overall employment in mining activities and support services.

When considering the industries that will have to transform, it becomes apparent that many more regions will be affected. Out of the EU's 28 Member States, 24 have regions where more than 1% of the work force is employed in such a sector, with higher share in Member States with lower GDP per capita levels. The regions with the highest exposure are Strední Cechy in the Czeck Republic (10.4%), Közép-Dunántúl in Hungary (9.7%), and Vest in Romania (9.3%).

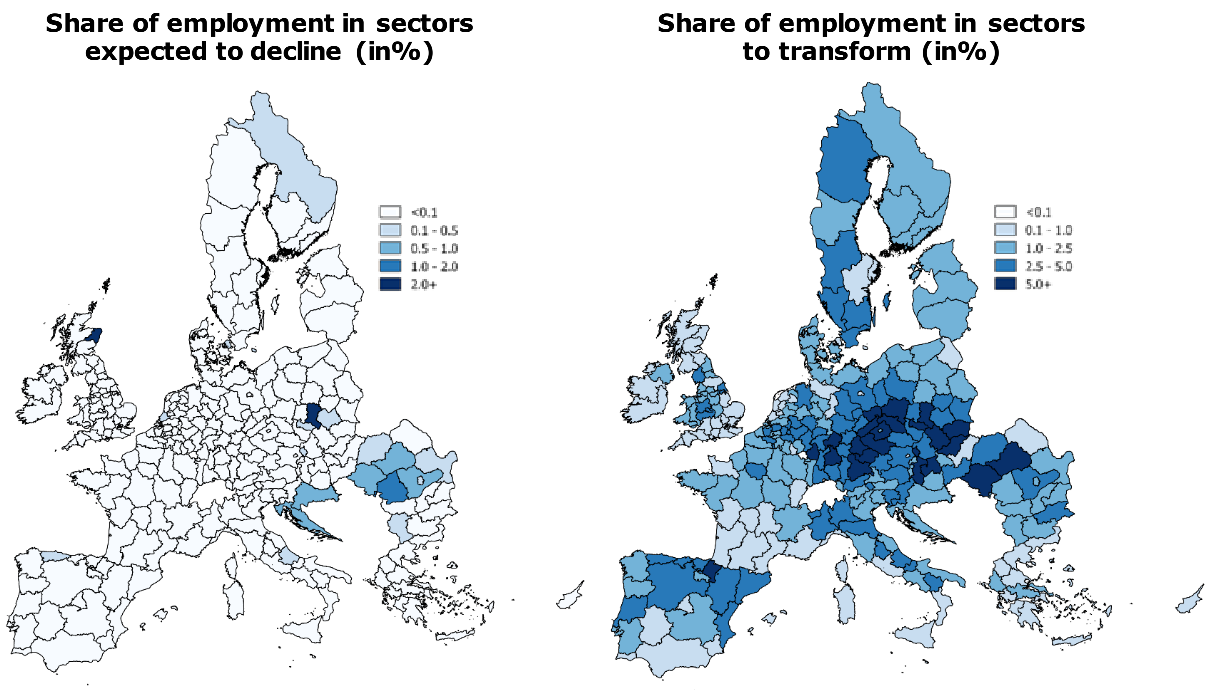


Figure 40: Regional exposure to sectors that will decline (left) and transform (right)

It becomes clear that the effects of a low-carbon transition will remain unevenly dispersed across EU regions. The transition requires significant changes and, for some regions would come with a social challenge linked to the move away from traditional sectors. A conclusion of the above analysis is that only a few regions highly depend sectors that will decline. Much more regions depend on sectors that will have to undergo low-carbon transformations.

6.5.3 Implication for education and skills

The impact of decarbonisation on the employment market is rather one overall to add to capacity constraints in the labour market. While overall gains more than offset losses between and within sectors, resources released by a declining sector are not perfect substitutes for those required by an expanding sector. A low-carbon transition is expected to increase the capacity constraint in the labour market, also because skills needed during a transition might be in short supply.

This issue was analysed in a study recently commissioned by the European Commission[413] using the E3ME model and GEM-E3-FIT, a version of the GEM-E3 model. The study analyses the differences between a decarbonisation scenario compatible with a 2°C trajectory and a business as usual scenario based on the Reference 2016 scenario developed by the European Commission and looked at the impact of level of qualifications needed.

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[413] Tender ENER/A4/2015-436 "A technical analysis on decarbonisation scenarios - constraints, economic implications and policies", https://ec.europa.eu/energy/sites/ener/files/documents/technical_analysis_decarbonisation_scenarios.pdf

Table 12 shows results from the E3ME model of the implications of a low-carbon transition on the level of qualifications[414] of workers. Large shifts already occur in reference from low- and medium- to high-level qualifications and reflect the trends observed over the past two decades. The decarbonisation scenario increases employment by around 1.4 million compared to reference by 2050 with nearly all occupations having more jobs than in the Reference scenario. Largest increases compared to reference are in the medium and high skill categories (strongest in skilled manual building workers and ICT occupations). The analysis confirms that Europe will be faced by a substantial skills challenge with decarbonisation adding to this challenge[415]. Therefore, the transition needs smoothing and the clearest way to do this is through supporting skills profiles and retraining.

Scenario	Qualification level	2020	2030	2050	2020-50
REF	Low	40,877	33,199	19,646	(51.9%)
	Medium	109,346	104,658	81,898	(25.1%)
	High	79,128	94,153	118,255	49.4%
	Total	229,350	232,011	219,800	(4.2%)
2DEG	Low	40,890	33,273	19,800	(51.6%)
	Medium	109,380	104,857	82,450	(24.6%)
	High	79,150	94,309	118,944	50.3%
	Total	229,420	232,438	221,194	(3.6%)
Difference	Low	13	73	154	
	Medium	35	198	552	
	High	22	156	689	
	Total	69	427	1,394	

All figures in '000, if not otherwise stated

Table 12: EU28 jobs by broad qualifications level for the Reference and decarbonisation scenarios, E3ME model.

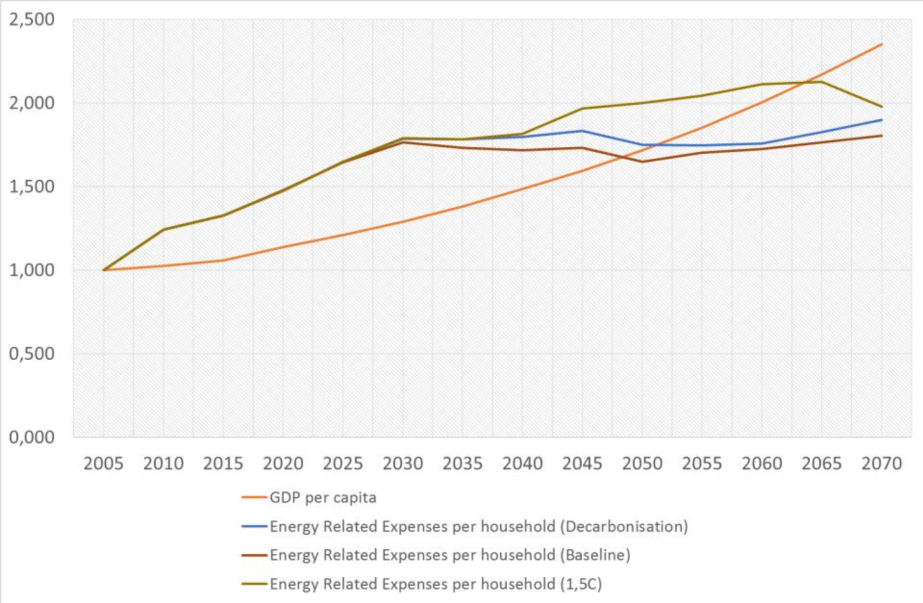
6.6 Social aspects

The energy transition will increase the cost of energy services. Energy related expenses per household increase in both the Baseline and in Decarbonisation scenarios. Between 2020 and 2030 cost per households in decarbonisation scenarios are the same as in the Baseline. After 2030, the higher climate ambition of Decarbonisation scenarios increase the costs compare to Baseline, but the trends remain similar. The rate of increase is higher between 2020 and 2030. After 2030 Energy related expenses per household reaches a plateau. The higher the climate ambitions the grater the costs increase. Figure 41 shows the trend in energy related yearly expenses per households in the Baseline and in Decarbonisation scenarios with different ambitions. The trend in GDP per capita is also reported.

[414] Low: up to and including lower secondary education; Medium: upper secondary and post-secondary non-tertiary education; High: tertiary education.

[415] CEDEFOP (2010) Skills for green jobs: http://www.cedefop.europa.eu/files/3057_en.pdf

Figure 41: Energy related expensive per households in different scenarios, normalised to 2005.



There are several reasons for this trend. The decarbonisation effort is slightly stronger in the first part of the transition. Moreover, a great share of the emissions reduction will be achieved with technologies that are projected to become cheaper in the coming decade. Deploying such technologies will be cheaper in 2030 than it is now. Finally, energy efficiency gains are expected to continue in the long term reducing energy consumption and, therefore, expenditures over several decades.

Up to 2030, the cost increase for households will be significant. In 2030, on average, every household is expected to spend for energy services 950€ per year more than in 2015. This corresponds to a 35% increase and is comparable to the increase experienced over the 2000 – 20015 period. However, after 2030 cost increase is projected to be moderate. With the assumption of continued, moderate economic growth, rising living standards will quickly compensate for higher energy costs. Shortly after 2030, the ratio of energy expenses to GDP per household will return to the 2015 level. Since the 2030 energy and climate targets are already part of the Baseline scenario, up to 2030 the Decarbonisation scenarios follow the same pathway as the Baseline. Therefore, the cost increase experienced by households will be, for the most part, the same in the Baseline and in Decarbonisation scenarios.

The cost increase experienced by consumers will, on average, amount to few percentage points of the disposable income. However, the European Union must step up its effort to mitigate the social costs of the transition. Guaranteeing continued economic growth and rising living standard is most important measure to offset the projected cost rise. However, it will be particularly important to protect vulnerable consumers. Most of the effort should take place in the next decade.

6.7 Natural resources

The use of natural resources can substantially affect the climate. In its turn, climate change can considerably alter natural resources structure and function to deliver private goods and eco-system services, including their mitigation and adaptation capacity. A sustainable enhancing of the natural resources capacity to deliver, and especially of land being at the crossroad, will be especially critical in a decarbonised context with no considerable technological breakthrough.

There are strong links between GHG emissions and natural resources. Soil, nutrients, water, oceans, minerals and fossil raw materials are the main resources involved in this interaction. The way we manage natural resources has a direct impact on climate change, influencing emission levels and storages of GHG.

Soil, nutrients and water, all part of the land ecosystem, and are among the main resources involved in the primary sector for the delivery of a number of public goods and ecosystem services such as food, wood, and biodiversity and providing habitats for a variety of species, as well assuring water storage and filtration. The land-based sectors in particular, while can produce GHG emissions, can also have the ability to sequester and store carbon through photosynthesis while providing other economic sectors with raw materials to substitute fossil-based products.

Oceans can help to provide resource-efficient food, energy medicines and other resources without impinging on diminishing land and freshwater resources. Non-energy fossil raw materials, in terms of GDP, jobs or trade, are relatively small, but are the key enablers of all EU value chains and for some key mitigation technologies. Access to these raw materials can be a competitive advantage or a bottleneck and could affect mitigation actions.

Land use is part of the "problem" - i.e. generating GHG emissions, mainly throughout Agriculture and tropical deforestation - and part of the "solution", i.e. globally forests remove more than 30% of anthropogenic GHGs. Agricultural greenhouse gas emissions in the EU account for 10.13% (436.74 MtCO2e, 2015) of total EU emissions, after energy, transport, residential and commercial sectors. The agriculture sector has decreased its GHG emissions by 21% since 1990, performing relatively well compared to other sectors. Land use Change and Forestry sectors (LULUCF) are helping in removing CO2. It removed 7.1% (304.8 MtCO2e) of all EU emissions in 2015, or about 70% of the agricultural emissions. Since 1990, the sink-function in the land use sector increased by 16%.

Globally, instead, LULUCF is a net emitter of GHG. Deforestation alone contributing about 10% of global greenhouse gas emission. It also contribute seriously to land degradation.

Long-term GHG emission perspective in the land use sectors

Given the lower mitigation potential of Agriculture and the multiple objectives and food security, this sector may become the most important source of EU GHG emissions in 2050. A compulsory mitigation target of -20 % without subsidies for mitigation technologies would result in the EU-28 beef cattle herd decreasing by 16% and beef production by 9%. Emissions reduction is very costly in agriculture, with consequences for food productions (EcAMPA 2). Approximately 95% of agriculture emissions come from agricultural soil management, manure management and enteric fermentation.

Mitigation technologies for reducing emissions from fertilisers without compromising the yields exist already, although their uptake is currently limited. A more widespread use of nitrification inhibitors, precision farming, recycled nutrients, can technically help to reduce these emissions. The use of surplus renewable energy to produce fertilisers can also help. Manure management emissions can also be reduced by a more widespread use of biodigestors and precision farming in their distribution. Very important would be technologies that could process/extract nutrients economically.

The emissions from the enteric fermentation will remain the most difficult to reduce considerably. An improvement in yields per unit of animal, through a generalised higher enhancement of productivity, health and resilience, can still deliver a substantial reduction in emissions; few other still controversial technologies exist today in the market that can curb these emissions. A technological breakthrough would be key in this area. Bovine production should however be seen in a more holistic way, together with land used in producing feed.

Anyway, with the currently available technology and practices, it is foreseen that agriculture emissions cannot be fully eliminated (unless a scientific breakthrough emerges), also due to growing demand of food, feed, fibres and public goods.

This residual emissions will have to be compensated by the sink in the LULUCF sector, whose relative importance in compensating emissions of Agriculture Non-CO2 residual emissions will considerably increase.

Increasing the sink potential of LULUCF

Agriculture emissions remaining in 2050 can be compensated through C sequestration and storage in soil and biomass.

Carbon sequestration into the soil are largely determined by the land use, with forest systems tending to have the largest sequestration into the soil (inputs all year round) and often this material is also the most recalcitrant. Grasslands also tend to have large inputs, though the material is often less recalcitrant than forest litter and the smallest input of C is often found in croplands which have inputs only when there is a crop growing and where the C inputs are among the most labile. The smaller input of C to the soil in croplands also results from removal of biomass in the harvested products and by tillage which increases SOC loss by breaking open aggregates to expose protected organic C to weathering and microbial breakdown, and also by changing the temperature regime of the soil.

C tends to be lost when converting grasslands, forest or other native ecosystems to croplands, or by draining, cultivating or liming highly organic soils. SOC tends to increase when restoring grasslands, forests or native vegetation on former croplands, or by restoring organic soils to their native condition. Where the land is managed, best management practices that increase C inputs to the soil (e.g. improved residue and manure management) or reduce losses (e.g. reduced impact tillage, reduced residue removal) help to maintain or increase SOC levels. The most effective mechanism for reducing C loss globally would be to halt land conversion to agriculture, especially deep peatland, but with the population growing and diets changing in developing countries, more land is likely to be required for agriculture. To meet growing and changing food demands without encouraging land conversion to agriculture will require productivity on current agricultural land to be increased. In addition to increasing agricultural productivity, there are a number of other management practices that can be used to prevent C loss or increase C sequestration.

A limited increase in C content of soils has a big potential in terms of C sink. However, the economic C sink potential of agricultural soil is still debatable. Moreover, it cannot be neglected that soil C sinks are not permanent and will continue only for as long as appropriate management practices are maintained. If a land-management or land-use change is reversed, the C accumulated will be lost, usually more rapidly than it was accumulated. The rate at which C is removed from the atmosphere becomes smaller with time as the soil C stock approaches a new equilibrium. At equilibrium, the sink strength will decrease to zero. Moreover, if an ecosystem currently acts as a sink, its possible lack of adaptation to the future climate will mean decreasing its mitigation potential. At the same time, increase in temperature can cause that soils will emit carbon.

In this case, “win–win” and "no-regret" strategies should be applied. Mitigation measures that also improve food security, profitability and resilience, would be more favourable than those which have no economic or agronomic benefit or could prevent the application of ling term adaptation actions. A small increase in the soil carbon pool can provide a significant contribution to improving soil fertility and agricultural production.

In addition to the soil, biomass is also an important C-sink; it can absorb C from the atmosphere, replace fossil energy and store C for long time by replacing fossil materials. Permanent crops have the advantage to provide biomass and increase C stored into the soil. On agricultural land, short rotation coppice and agro-forestry could play a role depending on economic factors. For the latter, more practical research is needed to improve its economic convenience.

Sustainable forest management and afforestation will be critical to achieve the 2050 objectives. As for afforestation, in Europe there is a limited possibility to carry out a large scale afforestation. Afforestation practices on marginal land and degraded land can enhance carbon sequestration, while also providing woody biomass. Most of the potential is in forests. The capacity of EU forests to sequester is however decreasing, due mainly to aging and to the effects of climate change. It is important to improve their resilience and adaptation to the changing conditions.

Moreover, through the right incentives and interventions promoting sustainable forest management, there is potential for forests to achieve higher mitigation impacts. Forest restoration should also be seen as an important strategy to improve the amount and rate of carbon accumulation in degraded or abandoned landscapes.

In this respect, an expansion and a more resilient forest could help to reduce pressure on natural resources and land in particular. It could contribute to the fight against land desertification and degradation, with retention of water and creation of a favourable micro-climate. Several other ecosystem services are associated to forests, such as water protection and filtration, biodiversity, reducing soil erosion, increasing albedo, evapotranspiration and water condensation. Forests can have a positive impact on the surrounding areas, such as increasing the probability of rainfall and water storage.

The LTCS could identify the most promising "climate-smart" agriculture and forestry actions. National forest programmes and strategies should also include the climate component to “maintaining or increasing forest carbon stocks, while producing an annual sustained yield of timber, fibre or energy from the forest, will generate the largest sustained mitigation benefit” (IPCC AR4). We should not forget the important function of forests and woody biomass as source of income for rural areas, jobs and growth. Countries should be less focused on the forest biomass sink strength and consider a mitigation strategy (adapted to national circumstances) to maximize the sum of all the possible components: carbon sequestration in forest biomass, soil and wood products, and the effects of energy and material substitution of woody biomass.

It is worth noticing however that most of the potential to increase C sequestration in agricultural soils and reduce losses of C stored in peat soils and forests biomass (deforestation) is outside the EU, most likely Africa, South America and Asia.

Enhancing circular economy and the substitutional function of natural resources (biomass and raw materials)

Analysts agree on the fact that the "climate mitigation case" for the circular economy is large, although solid evidence is missing regarding its exact magnitude. Promoting circular economy strategies can mitigate by about half the emissions gap between national climate mitigation commitments for 2030 and the 1.5-degree trajectory and reduce pressure on natural resources.

Agriculture and forest, in particular, can be real suppliers of bio-based materials replacing fossil fuel-based materials and fuels, while performing C storage in the case of long-lasting products (harvested wood products) and supporting their use, such as wood in construction.

Production of energy at farm level will also compensate emissions with the substitutional function replacing energy produced with fossil resources. Rural areas offer several possibilities to produce energy. Research and innovation would provide the most effective technology on the base of locally available renewable energy sources (soil, wind, biomass, manure biodigestions, etc).

The link of renewable energy to substitutional effects might be also found for nutrients. N fertilizers can already be produced by using residual electric energy from wind power for the synthesis of NH3. The production of organic fertilisers and phosphorous extracted from manure and urban wastewater, replacing the already depleted mineral phosphorous, as well as alternatives for industrial production of fertilisers through Haber-Bosch process are all part of a circular economy approach.

On raw materials, the most recent study in this area, led by Material Economics, the European Climate Foundation and SITRA , places the climate mitigation potential of the circular economy in the ballpark of -56% of the EU's industrial emissions by 2050 based on four material streams (plastics, steel, aluminium and cement). While the EU is at the forefront of the circular economy transition increasing the use of the secondary raw materials, a lot remains to be achieved in order to make the economy truly circular. In addition, these high recycling rates for a number of materials cannot cover the demand for these metals due to long product life-cycles (e.g. in buildings), although in some cases (e.g. steel) relatively large quantities of used material are being made available due to the introduction of these materials in the economy several decades ago. Moreover, for most of the raw materials needed in renewable energies or high tech applications, such as rare earth elements, indium, gallium or lithium, secondary production only represents a marginal contribution (often only around 1% or less) in meeting fast growing materials demand.

According to Material Economics, the European Climate Foundation and SITRA, some of the major opportunities associated with the circular economy are "demand-side measures", such as material recirculation through the economy's loops, product material efficiency, in particular reducing the amount of materials used for production which are not strictly necessary and new circular business models, notably sharing models of assets such as cars or housing.

Contribution of oceans to GHG emission reduction and substitutional functions

It can be expected toward 2050 an increased use of sea space. Aquaculture has already overtaken capture fishing in terms of tonnage on a global level where it grows at 8% a year. We expect this trend to continue and European industry to have a significant role in the inputs (feed) and outputs (processing). In addition, electricity generation replacing fossil fuel from floating wind farms in areas too deep for tethered, tidal and wave energy will play a significant role in Europe's energy mix, together with algae as biofuel and feedstock. Commission's Group of Scientific Advisers believe that oceans have capacity to provide far greater proportion of human food intake than it does now

All above mentioned functions will contribute to reduce the pressure on land for the provision of the growing demand of public goods.

A circular economy for a plastic-free ocean will lower the need for feedstock.

In any case, competition for seas-space will require careful planning and sharing of platforms, also ensuring that natural habitats are protected in order to maintain biodiversity.

Policy considerations

In a long term perspective, several trends bring to an increase pressure on natural resources and especially on water and land. Demand for natural resources and land in particular would increase while their accessibility and availability would be reduced and their capacity to deliver threatened by climate change. Most of this pressure is in developing tropical countries where also is most of the potential and opportunity costs for actions. An increase in population would raise demand for food, feed, fibres as well as water and other eco-system services; climate change would induce more frequent crop failures, water scarcity, and desertification and land degradation; urban concentration would increase irreversible land consumption while depriving rural areas from skilled people; land will also be demanded for more C-sequestration (into soil and biomass) to balance the residual emissions (at least) in agriculture and produce biomass as substitute of fossil materials.

Natural resources and land in particular would be therefore called to carry out multiple functions. Therefore, to ease the pressure, the optimisation in the execution of these different functions and of the synergies between them will be crucial. Each type of agriculture and forest land should perform at best the function(s) is more adapted for. Eg marginal land could be used mainly to produce carbon into soil and biomass (afforestation); fertile land could produce in synergy food and C–sink into soil; improvement of grassland in marginal areas could represent a C-sink while producing biomass for ruminant. Improvement of yields sustainably in all these functions would also be crucial to save natural resources and land. In this respect, research and innovation will be key. A more dynamic sustainable forest management associated to a circular economy and substitution would increase biomass production and C sequestered and stored for long time in goods.

Another way to ease the pressure on resources and land would be to reduce waste or irreversible uses of land (soil sealing), desertification, land degradation including the availability of water. Afforestation and forests in this respect play a positive role by protecting water and regularise raining, providing biomass, stopping desertification and degradation. All of these resources and functions are however affected by climate change.

On the demand side, behavioural changes of consumers and processors could help by reducing waste, increase efficiency in the use of raw materials. A more balanced diets would go in the same direction. Oceans and seas can also contribute to the supply of food and feed (especially proteins) by therefore easing pressure for land-based sectors.

The key in all the above is however adaptation, research and innovation. Without an improved resilience of the eco-system, the various pressure listed above would be exacerbated and cause serious damages to the capacity of natural resources to deliver. Research and innovation will be key to improve the efficiency and synergies of the multiple functions requested from natural resources while improving also their resilience to climate.

Focus on Research&Innovation

Research and innovation will be key for reducing emission reduction costs further, improve resilience of the natural resources systems and the primary economic sector, while increasing sustainably their efficiency and capacity to deliver. Particularly important also in pushing ahead the circular economy, developing bio-based materials, alternative sources of food nutrients, renewable energy production and all potential synergies.

Support research and innovation aimed at cost-effective production, substitution and more efficient use of raw materials for decarbonisation, starting from key /most sensitive areas, including also alternative sources from the sea and lands.

As regards C-sink into soil and biomass, R&I will be crucial to increase sustainable productivity of private and public goods, food in particular, and C-storage.

Adaptation, stop desertification, forest fire and reverse degradation

An increase in resilience of natural resources systems and related economic sectors would be critical for the success of any mitigation strategy. The eco-system risk not delivering if put under increased pressure from the demand side and at the same time threatened by a changing climate. Adaptation action is therefore key. Measures to be implemented should be those that can improve resilience with a potential to keep or even increase the productive potential of the resources. Special attention, because of the extent of their irreversible damages, should be paid to the eco-systems eroded by the desertification, forest fire, and degradations.

Human resources in rural areas

A sustainable management of natural resources requires keeping a sufficient number of skilled people on the land. With an increasing concentration of urban areas, depopulation can only be stop by enhancing the economic dynamism of rural areas. The two aspect reinforce each other.

Safeguarding agriculture land, its improved productive potential and optimal use

Land will become under pressure from several sides and required to carry out multiple functions. This calls for a strategy that would safeguard as much as possible and enhance the capacity of land to produce goods and ecosystem services. Losses of land, especially the most productive ones, should receive a special attention. Soil sealing should be more cautious, while actions to reduce/stop desertification, water scarcity, and land degradation should be a priority in e.g. land planning depending on local context and climatic scenarios, in a way to increase the local resilience. In this respect, potential of forests should be recognised. Sustainable intensification of agriculture, in association with an enrichment of SOC of the soil and improved animal productivity and health, should be pursued especially for the more fertile areas.

Contributing to the supply of food, feed and bio-based products by alternative sources

The cultivation of sea and oceans can be valuable alternative sources. Supply from these sources of oils and proteins can contribute considerably to reduce pressure on land and possibly deforestation in tropical areas. Sea and oceans can also be sources of renewable energy.

Promoting afforestation and use of forest biomass

Through the right set of incentives and intervention there is potential to stimulate afforestation and sustainable forest management, to achieve higher mitigation impacts and a well-functioning C sink. Progressive aging of EU forests should be slowed down and reversed to avoid a weakening of their C sequestration capacity, productivity, and strength to face the growing adversities of a changing climate. Forest must reach the 2050 fit for the purpose, implying the need of starting now for a more dynamic sustainable forest management with wood used for substitution of fossil materials. Afforestation is also an efficient C sink and appropriately done, key to reduce desertification, erosion, water protection and increase rains.

Forest restoration should also be promoted as an important strategy to improve the amount and rate of carbon accumulation in degraded or abandoned landscapes.

Improve the implementation and effectiveness of nature-based solutions to reduce GHG emissions (mitigation side) and disaster risks (adaptation side) in urban areas (green spaces) and peripheries (green infrastructure network).

Stopping deforestation and conversion of C rich soils

Contrary to the EU where Lulucf LULUCF is a net C sink and forests are expanding, globally thereis a huge loss of C caused by deforestation and land conversion (especially peatland), and soil degradation. The reversal of this trend has a large potential for mitigation and for the health of our global eco-system. For this trend reversal, substantial and quick progress in economic and social development is paramount, together with forest protection laws and enforcement, and sustainable intensification of agriculture. EU external policies and interventions should be aligned with the EU priorities and embed these principles and goals.

Mutually reinforce low-carbon economy and circular economy

Adopt an integrated approach whereby the circular economy and the low-carbon economy mutually reinforce each other, starting with investing in circular economy measures with a high climate change mitigation potential; it relies on the EU's raw materials policy to help ensure secure, sustainable and affordable supply of raw materials for the EU manufacturing industry.

Proactively implement the new rules applying to waste management (2030 and 2035 targets); fully reap the potential of demand-side circular economy measures such as material recirculation, product material efficiency and circular business models; looking at possible additional measures on industrial and commercial waste; scaling up the use of Green/Circular Public Procurements.

Determining with Member States the fitness of their raw materials policies and frameworks for domestic productions, and identifying best approaches to improving regulatory framework and incentivising exploration and extraction.

Support research and innovation aimed at cost-effective production, substitution and more efficient use of raw materials for decarbonisation.

Remove regulatory barriers to the development of the circular economy in the biological cycle.

6.8 Climate change and its impact, how to increase resilience and adaptation

Climate change is already occurring and impact are already felt. Most change will be gradual. But science also continues to warn for the possible occurrence of tipping points beyond which climate impacts accelerate. They are also interconnected: reaching a tipping point affects the likelihood of triggering another one[416].

Melting of the Greenland and the West Antarctic ice sheets, complete bleaching of coral reefs, glacier melting in the Alps or ice-free summers in the Arctic Ocean may occur already between 1ºC and 3ºC global warming, though will have very different time scales for completion[417]. Recent evidence points at the first ever observed disintegration of the oldest and thickest Arctic ice north of Greenland in 2018[418] with an Arctic is warming much faster than the rest of the world. Melting of Arctic sea ice could shift the jet stream southwards, which may lead to colder European winters and extreme droughts in Southern Europe. The disappearance of alpine glaciers would change seasonal run-off patterns and freshwater supplies with major implications for irrigation and hydropower plants. The melting of ice sheets in Greenland and Antarctica would eventually radically reshape Europe's coastal regions, though occur on much longer time scales[419].

6.8.1 The need to adapt in the EU

In Europe, land temperatures in 2007-2016 were around 1.6°C warmer than in pre-industrial times. Particularly high warming has been observed since 1960 over the Iberian Peninsula, in mountain areas across central and north eastern Europe and over southern Scandinavia. The Pyrenees region is already 1.5ºC hotter than in 1960. Winter temperatures have increased the most in northern Europe, while higher summer temperatures have affected southern Europe. In addition, there has been a substantial increase already in climate-related extreme events in recent years, some of which can be attributed to climate change. There are also slower on-setting impacts like coastal erosion caused by sea level rise, or drought caused by changes to precipitation patterns. Climate change impacts in third countries can also have spillover effects on Europe, for example by affecting trade routes and patterns and triggering climate-induced mobility migration.

The observed changes in global and regional climate are already affecting EU ecosystems, economic sectors and human health and well-being. Successful mitigation

[416] 2016. Risk of multiple interacting tipping points should encourage rapid CO2 emission reduction - Yongyang Cai1,2†, Timothy M. Lenton3*† and Thomas S. Lontzek4*†

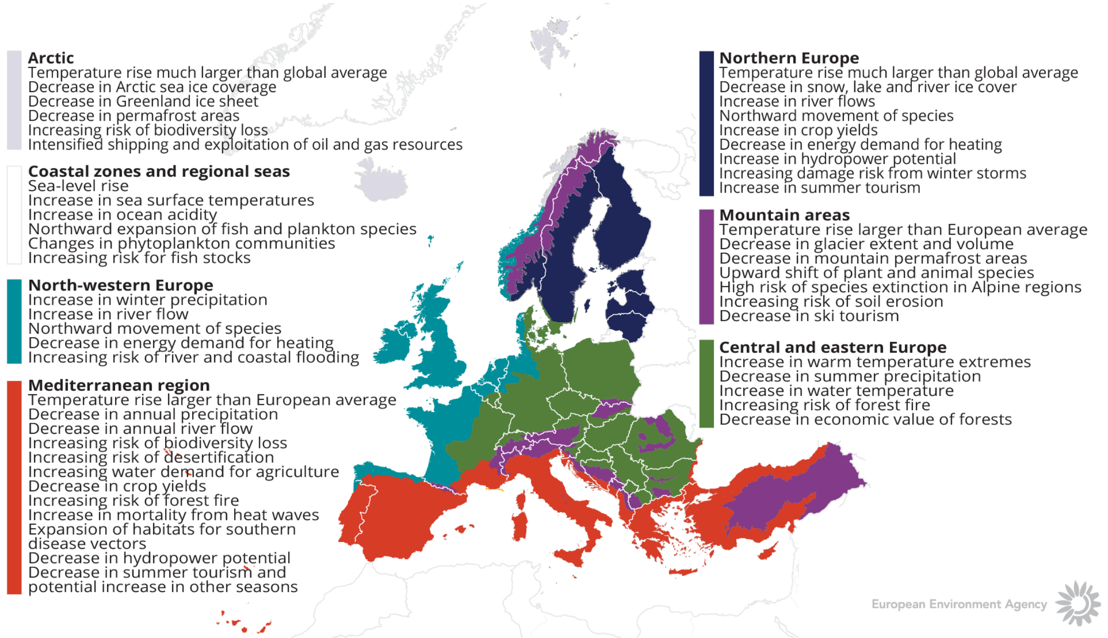
[417] Steffen et al 2018 - hothouse

[418] https://www.theguardian.com/world/2018/aug/21/arctics-strongest-sea-ice-breaks-up-for-first-time-on-record

[419] Levermann et al. (2012),, Joint Research Centre PESETA II (2014).

action is the first necessary step to reduce the risk of climate change. But the EU economy as a whole must prepare for and adapt to the risks associated with the negative consequences of climate change and already committed emissions with long-term effects (e.g. sea level rise). Any future path of economic output is expected to be undermined by the damages caused by climate change itself. This needs to be a central consideration of any economic analysis of climate policies.

The European Environment Agency has outlined a geography of main impacts in Europe:



By the end of the century, one estimate looking at a high emissions scenario and no action to adapt and enhance resilience to climate change, found that the EU could endure an annual welfare loss of around 2% of GDP per year, i.e. €240 billion per year from 6 impact categories assessed. In addition, an additional 20% of losses would come from impacts in the EU of climate inaction in third countries, conveyed via trade[420]. Policy insights from ongoing research on high-emission scenarios convey a clear message: conventional and incremental approaches that do not consider long-term sustainable development, focus on single sectors, geographical scales, or adaptation or mitigation separately will not deliver the Paris Agreement[421]. More emphasis on 'transformational' adaptation actions as a complement to 'incremental' adaptation may be required[422].

[420] PESETA III. Caveats for this figure: the PESETA economic assessment is based on simulating what would be the impact of future climate change occurring on today's economy for 6 impact categories (residential energy demand, coastal floods, inland floods, labour productivity, agriculture and heat-related mortality).

[421] HELIX policy brief

[422] EEA 2017 climate vulnerability report

Integrating emission reductions planning and adaptation is the most effective and efficient course of action because:

a) **Adaptation provides economic and social stability** – climate change will interact with other socio-economic developments such as the ageing of the EU's population, increasing urbanisation, projected decreases in population size in Eastern Europe, and narrowing of the economic gap between Eastern and Western Europe[423]. It can be expected that climate change adaptation projects or the impact of extreme events such as floods or droughts will involve a higher level of public intervention than today[424]. Public resources may be severely drained if the climate reaches certain thresholds or "tipping points"[425]. In contrast, early integration of adaptation concerns in mitigation pathways will be a crucial enabling factor for decarbonisation, enhance a balanced development and build a resilient European society.
b) **There are co-benefits and trade-offs between mitigation and adaptation** – so both policies must be developed together as components of any long-term climate action. Vulnerability to climate change is one of the risks to be taken into account in mitigation activities, for instance to ensure renewable electricity networks are climate-proof, that hydroelectricity and bioenergy can be produced in a water-stressed world, or that forests can withstand climate change and continue to perform their sink function.
c) **Urban transformation requires the right mix of adaptation and mitigation** – urban areas concentrate population, economic and cultural assets. As a result, they concentrate the transformative power to become engines of European economic development as well as European decarbonisation. On the other hand, urban areas are also vulnerable to adverse climate impacts.

Europe will warm more than the global average, i.e. much of Europe may experience **more than 2°C of warming** (relative to pre-industrial levels) even if the 2ºC global goal of the Paris Agreement is achieved. At 2°C globally, the Iberian Peninsula and other parts of the Mediterranean could experience 3°C of warming in summer, and Scandinavia and the Baltic could reach 4°C of warming in winter[426].

Under a business-as-usual emissions scenario, **weather-related disasters** could affect about two-thirds of the European population annually by the year 2100 (351 million people per year)[427],

[423] EEA 2017 Report climate and vulnerabilities Europe.
[424] Daniel Bailey (2015) The Environmental Paradox of the Welfare State: The Dynamics of Sustainability, New Political Economy, 20:6, 793-811, DOI: 10.1080/13563467.2015.1079169

[425] Steffen et al 2018, hothouse earth
[426] Impact2C 2015 [xxx include more detailed reference!]
[427] Forzieri et al Increasing risk over time of weather-related hazards to the European population: a data-driven prognostic study

compared with 5% of the population between 1981-2010; if no adaptation measures are takenthis would increase the related fatalities per year by fifty times by the year 2100 (from 3000 deaths per year presently, to 152 000 deaths per year by 2100).

In 2013, the European Commission published an EU Adaptation Strategy to tackle climate change risks to the EU economy. The Adaptation Strategy focuses on developing better knowledge and understanding of climate impacts, climate proofing of specific sectoral policies and the promotion of action by Member States and cities through non-legislative means.

The evaluation of the 2013 Adaptation Strategy[428] highlighted the urgency for action because of the important risks facing the EU[429]. Global temperatures have risen by around 1ºC but the average annual temperature for the European land area for the last decade (2008–2017) was between 1.6 °C and 1.7 °C above the pre-industrial level, which makes it the warmest decade on record. Europe experienced extreme heat waves in 2014, 2015 and 2017[430]. 2018 clearly will be added to that with temperatures in Lapland being 5°C above usual in July this year[431]. There is no certainty that the world will achieve the climate objectives (see also section 2). And a certain amount of further warming is already locked-in. It clearly makes sense to enable early (but flexible and "adaptive") adaptation to address for Europe.

Both in terms of likelihood and impact, two adaptation-related risks are currently among the top-five risks identified in the 2018 Global Risk Report[432]: extreme weather events and failure of climate change mitigation and adaptation policies.

The total reported economic losses caused by weather and climate-related extremes in Europe over the 1980–2016 period amounted to over €436 billion. Many of these events are increasingly being associated with climate change.

In Europe, considerable increase in river flood risk, even under a 1.5º C warming scenario, calls for effective adaptation plans to compensate increasing risks[433]. In the absence of adaptation action and in a high emissions scenario, coastal floods alone may cost EU countries up to €961 billion per year by the end of the century, with the UK and France showing the highest absolute increase in flood damage. By the end of the century, under a high emissions scenario, about 200 airports and 850 seaports of different size

[428] Ref to future evaluation package, scheduled for adoption sept-oct 2018.
[429] Ref to future evaluation package, scheduled for adoption sept-oct 2018.
[430] https://www.eea.europa.eu/data-and-maps/indicators/global-and-european-temperature-8/assessment
[431] http://en.ilmatieteenlaitos.fi/press-release/610918514
[432] World Economic Forum, 2018, The Global Risks Report 2018, 13th Edition. The Global Risks Report is an annual study published by the World Economic Forum ahead of the Forum's Annual Meeting in Davos, Switzerland. Based on the work of the Global Risk Network, the report describes changes occurring in the global risks landscape from year to year and identifies global catastrophic risks. Sources for the report include an assessment by several major insurance and reinsurance companies and focus workshops, interviews and a survey of internationally recognised experts.
[433] Alfieri et al, Climate **2018**, 6, 16; doi:10.3390/cli6010016

across the EU could face the risk of inundation due to higher sea levels and extreme weather events[434].

In specific sectors such as agriculture, the OECD includes four Member States (France, Spain, Italy and Greece) as countries at risk because of water shortages[435]. Droughts in some EU regions in 2018 have already triggered calls, in some Member States, for financial aid to cover agricultural losses[436]. At EU level, the prolonged drought of 2018 has triggered higher CAP advanced payments and derogations from greening requirements.[437] Nearly 65% of arable land in Poland has been affected by drought this year[438].

The Mediterranean region as a whole will endure less water availability year-round and extreme drought events. Water stress will certainly increase in Southern European regions[439], and it may well cause tensions between different users of dwindling reservoirs and aquifers. Member State vulnerability assessments reveal that water and agriculture are the most frequently covered areas, followed by biodiversity, energy and forestry[440]. Consequently, the recent CAP proposal by the Commission aims to strengthen the conditions for receiving agricultural income support, including protection of carbon-rich soils, and to implement more ambitious farm-based mitigation and adaptation strategies.

Beyond agricultural demand of water, 41% of European companies acknowledge exposure to water-related risks that could generate a substantive change in their business and operations[441].

Risks concerning freshwater at global level have very recently been studied[442]: simulations of four climate models to drive two global hydrological models have revealed a differentiation: the incremental impact between 1.5°C and 2°C on high river flows would be felt most by low income and lower middle income countries, but the effect on soil moisture and low flows most by high income countries, e.g. those of the

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[434] peseta 3. See also Climatic and socioeconomic controls of future coastal flood risk in Europe Michalis I. Vousdoukas, Lorenzo Mentaschi, Evangelos Voukouvalas, Alessandra Bianchi, Francesco Dottori & Luc Feyen

[435] OECD 2018 Study on Water Water Risk Hotspots for Agriculture

[436] https://www.reuters.com/article/us-germany-harvest-drought/german-farmers-seek-1-billion-euros-in-drought-aid-report-idUSKBN1KK0RZ

[437] Commission Press release – "Commission offers further support to European farmers dealing with droughts", Brussels, 2 August 2018. http://europa.eu/rapid/press-release_IP-18-4801_en.htm

[438] , according to state news agency PAP

[439] peseta 3

[440] 2018 EEA national climate change vulnerability assessment report.

[441] CDP (2017). Extracted from: https://www.cdp.net/en/research/global-reports/cities-infographic-2017

[442] Petra Döll et al 2018 Environ. Res. Lett. 13 044038

EU. Soil moisture in Europe shows a marked decreasing trend over the 1979-2017 period and all seasons of 2017 showed below average values[443].

Soil moisture decrease is a crucial factor to understand the severity of recent forest fires across the world. The danger of forest fires in Europe will increase, with longer seasons, higher intensity and wider reach. Danger is high in Spain and Portugal[444] but, as wildfire during the 2018 summer have shown, Northern countries will also be at risk.

Yet, research suggests that forest fire risks could be substantially reduced if adaptation measures are introduced, including appropriate forest management to increase the structural diversity of forest ecosystems, prescribed burning and use of fire breaks, as well as behavioural changes[445]. Unfortunately, the fact that forests are multi-functional means several administrative departments are co-responsible for policies that concern forests. This creates a significant challenge to policy-makers to ensure a systematic approach, to avoid conflicts and to enhance sustainability and synergies between different policy domains[446].

Furthermore, specific risks (e.g. hurricanes, sea level rise, heat) threaten to unravel EU efforts to support its nine Outermost Regions, most of them small islands. The impacts of hurricanes Irma and Maria on the Caribbean, and notably on St-Martin, Guadeloupe and Martinique (three of the EU's outermost regions) came as a stark warning of the potential impacts such regions face. The importance of adaptation to minimise potentially crippling losses for these communities cannot be underestimated, as both extreme and slow-onset climate change erode long-term socio-economic development. If there is no adaptation, heatwave-related excess mortality is expected to increase the most in tropical and subtropical areas where most of these regions are located[447]. The Commission channels efforts to support adaptation in the Outermost Regions via the new partnership adopted in 2017[448], helping to strengthen and mainstream adaptation into their specific socio-economic contexts, as well as offering solidarity when disasters occur[449].

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[443] Copernicus Climate Services (C3S): European State of the Climate 2017: https://climate.copernicus.eu/climate-2017-european-wet-and-dry-indicators

[444] Peseta 3

[445] Khabarov, N et al., 2014, Forest Fires and adaptation options in Europe, Regional Environmental Change 16)1, 21-30 (doi: 10.1007/s101130-014-0621-0); and European Commission, Modelling the impacts of climate change on forest fire danger in Europe Sectorial results of the PESETA II Project, 2017.

[446] EASAC 2017 multi-functionality and sustainability in the EU's forests

[447] 2018 guo et al

[448] Communication from the Commission to the European Parliament, The Council, the European Economic and Social Committee, The Committee of the Regions and the European Investment Bank: A stronger and renewed strategic partnership with the EU's outermost regions, COM(2017) 623 final.

[449] http://europa.eu/rapid/press-release_IP-18-722_en.htm

6.8.2 Mitigation and adaptation: co-benefits and trade-offs

Adaptation can contribute to mitigation targets. Conversely, failure to adapt can undermine mitigation efforts. Adaptation and mitigation are sometimes perceived as coming from different people operating at different spatial and temporal scales, which hampers the analysis of their interrelation[450]. Efforts must continue to combine mitigation and adaptation in balanced global and national climate action. A recent OECD report[451] highlights that climate investments and projects must consider the links between adaptation and mitigation so as to minimise climate risk: the greater the perceived risks of a project, the higher the returns investors will demand, and the higher the costs passed onto end users and government sources of funding. The report provides a summary of potential synergies and trade-offs between adaptation and mitigation measures:

	Positive for mitigation	**Potential trade-off with mitigation**
Positive for adaptation	Reduced deforestation: sequesters carbon and provides ecosystems services Agricultural practices (e.g. no till) that can sequester carbon while boosting farmers income Wetland restoration: carbon sequestration and reduced flood risk Renewable energy – wind and solar: lower water use than thermal generation	Desalination: addresses water shortage but is energy intensive Increased irrigation: helps farmers manage variable precipitation but can be energy intensive Construction of hard defences: reduces the risk of extreme events, but greenhouse gases are embodied in the construction Air-conditioning: reduces the impact of high temperatures and help, but is energy intensive
Potential trade-off with adaptation	Inappropriate expansion of biofuels: could exacerbate food price shocks if biofuels displace crops Hydropower: could increase the complexity of managing water resources	N/A

In some areas, the potential to maximise the interdependence between adaptation and mitigation should guide long-term EU efforts to decarbonise and climate-proof the economy. Examples for land use (in particular agriculture and forestry), energy and cities are mentioned below.

[450] Amica-literature-review - project
[451] 2017 investing in climate investing in growth,

Land and coastal ecosystems

Land restoration, reduced and avoided degradation in forests, wetlands, grasslands and croplands is crucial to achieve long term temperature goals.

Forests offer a good example of the co-benefits that can arise from coordinated adaptation and mitigation. Indeed, EU forests absorb the equivalent of 7% of total EU greenhouse gas emissions each year. Their effects on temperature, water purification and hydrology mean they also play a crucial role in adaptation to climate change by limiting locally not only the effects of heatwaves, but, through their water retention capacity, also of floods and droughts. Recent case-studies in Ireland, Spain and the Czech Republic have shown that adaptation measures and good forestry practices enhance the role of forests as carbon sinks[452].

Yet forests are under pressure from climate change. Extreme weather conditions such as extended heat waves, drought, and strong winds will affect many of Europe's forests more frequently and more severely. Forest fire seasons are longer and more devastating year by year. Failure to take into account climate adaptation of forests will leave them increasingly vulnerable to pests and diseases, storms and forest fires, in turn jeopardising forests' role as carbon sinks.

It is crucial to design and implement a long-term strategy to manage forests. The long life span of trees warrants adaptation planning today to withstand tomorrow's climate changes. Forests planted today in certain European regions will be exposed to a changing climate.

Ecosystem services provided by healthy terrestrial and marine ecosystems are crucial for mitigation (carbon sequestration) and adaptation (flood and water regulation, air quality, etc.). These services should be climate-proofed as much as possible if they are to continue delivering benefits. Future EU adaptation policy should:

Energy

A number of observed and projected climate change impacts are pertinent to certain European regions. For instance[453]:

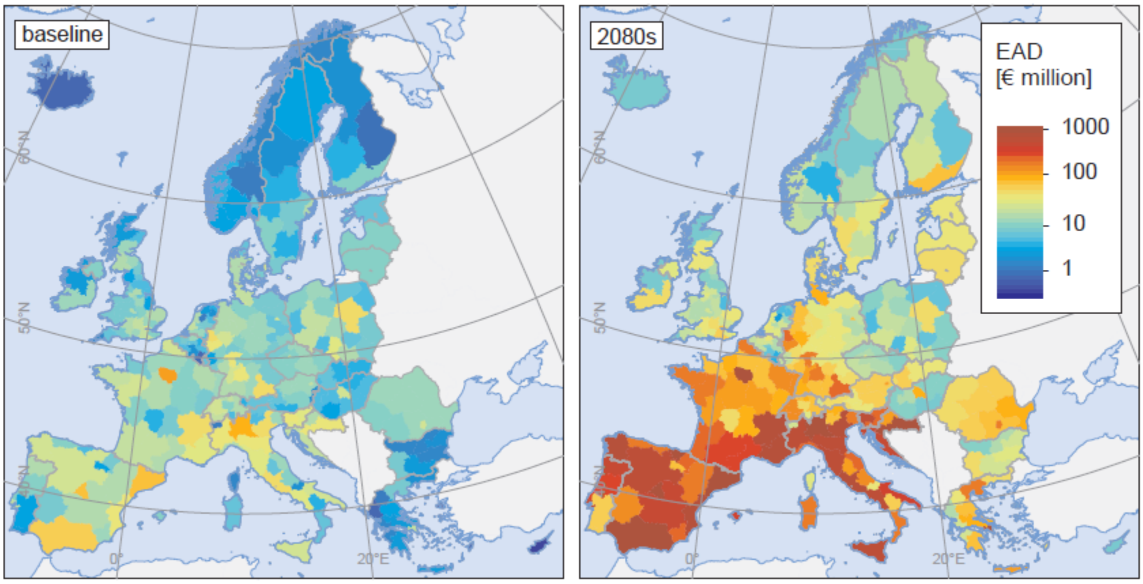
- Decrease in energy demand for heating in the Atlantic and Northern regions.
- Increase in energy demand for cooling in central Europe and the Mediterranean.

[452] European Forest Institute – 2018 https://www.efi.int/publications-bank/climate-smart-forestry-mitigation-impacts-three-european-regions
[453] 2017 EEA Climate vulnerability and impacts in Europe report

- New opportunities for the exploitation of natural resources and sea transportation in the Arctic.
- Increased hydropower potential in the North.
- Decrease potential for energy production in the Mediterranean.

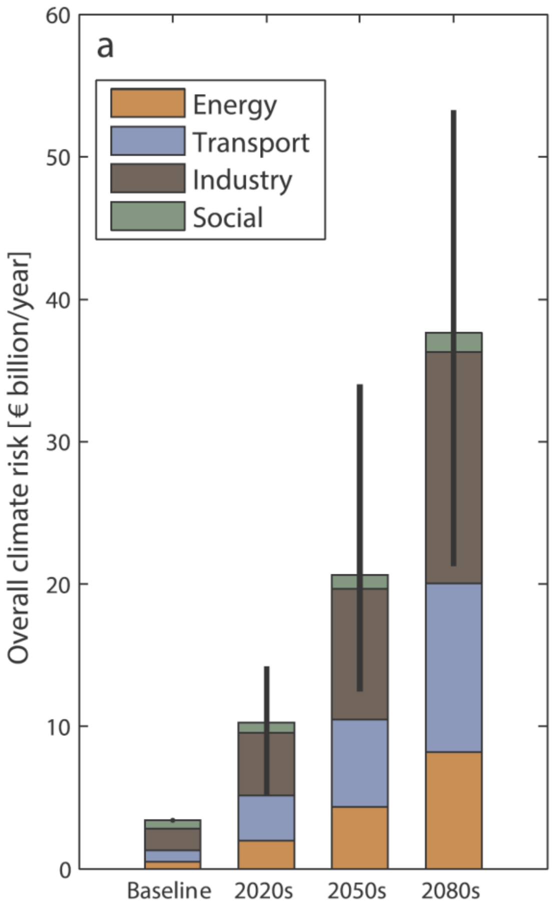
Due to climate change alone, and in the absence of adaptation annual damage to Europe's critical infrastructure could increase ten-fold by the end of the century under business-and-usual scenarios[454], from the current €3.4 billion to €34 billion. Losses could be highest for the industry, transport, and energy.

Expected annual damage (EAD) to critical infrastructure in European regions, due to climate change, by the end of the century (million €)



Source: Forzieri et al, Global Environmental Change 48 (2018)

454 Forzieri et al, Global Environmental Change 48 (2018) 97–107, "Escalating impacts of climate extremes on critical infrastructures in Europe"



Source: Forzieri et al, Global Environmental Change 48 (2018)

The risks associated with the negative impacts of climate change will have increasing effects on energy supply, notably on hydroelectric generation, but also on wind, solar, biomass, and thermal power (nuclear and fossil)[455].

Electricity production may be affected in most EU countries and for most sources. The impacts are limited in a 1.5ºC world, but almost double under a 3ºC warming. As regards sources, hydropower and thermoelectric generation may be under pressure because of their water cooling needs: they may generate up to 20% less under a 3ºC scenario; 15% less in a 2ºC world. In general, Southern Europe will generally be more strongly impacted than Northern Europe.[456] Another study finds that thermal electricity generation will suffer from water stress in the near term across the EU in a diverse regions set of regions (Mediterranean, France, Germany and Poland)[457].

[455] See COACCH 1st synthesis report.
[456] 2018 Tobin et al – vulnerabilities and resilience of European power generation
[457] Behrens et al (2017): Climate change and the vulnerability of electricity generation to water stress in the European Union

Current energy models can integrate changes in heating and cooling demand brought about by temperature projections, as is done in the PRIMES projections. On average, higher temperatures are expected to raise electricity demand for cooling in Europe (notably if retrofitting or new dwellings are not adapted to recurrent heatwaves), to decrease demand for heating, and to reduce electricity production from thermal power plants.

One of the greatest challenges is how to assess impacts which may occur as a consequence of the projected increase in the intensity of extreme weather events, as research gaps include economic modelling of extreme events and vulnerabilities of transmission infrastructure[458].

But rising thermometers may also affect supply, which is often not included in economic projections.

Renewables play a key role in limiting greenhouse gas emissions. This is the case, for instance, of hydropower production. The main mechanisms through which climate change can affect hydropower production are changes in river flow, evaporation, and dam safety[459]. For Europe, most studies show a positive effect of climate change impacts on hydropower for northern Europe and a negative effect for South and Eastern Europe[460]. The extent to which climate change affects hydropower in Europe as a whole differs among the studies from almost no effect[461] to decreases of 5-10% by the end of the century or before[462].

As regards to solar and wind energy, there are studies that indicate that production might be negatively affected on some regions in the EU[463,464,465].

While the magnitude of the impacts is not expected to jeopardise Europe's long-term decarbonisation path, it may entail higher costs and different regional energy mixes,

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[458] Chandramowli, S.N. & Felder, F.A., 2014. Impact of climate change on electricity systems and markets - A review of models and forecasts. Sustainable Energy Technologies and Assessments, 5, pp.62–74. [CF2014]

[459] Mideksa and Kalbekken, 2010

[460] Hamududu and Killingtveit, 2012; Mideksa and Kalbekken, 2010; Lehner et al., 2005; Van Vliet et al, 2016; Teotónio et al., 2017; Turner et al., 2017.

[461] Zhou et al., 2018; Hamududu and Killingtveit, 2012

[462] Lehner et al., 2005; Turner et al., 2017; Chandramowli and Felder, 2014

[463] Southward shift of the global wind energy resource under high carbon dioxide emissions

Kristopher B. Karnauskas 1,2*, Julie K. Lundquist 1,3 and Lei Zhang 1

[464] To cite this article: Isabelle Tobin et al 2016 Environ. Res. Lett. 11 034013

[465] The impact of climate change on photovoltaic power generation in Europe
Sonia Jerez1, Tobin et alWild4

unless adaptive measures (such as improved technologies or more efficient use of water resources) can be deployed.

Another perspective to adaptation in the energy sector is the effects of climate impacts on energy cooperation between Member States. For example, hydropower production in the river Tagus, which runs through Spain and Portugal, will be affected by more frequent and intense droughts in the Iberian Peninsula and may impact. Diminishing Tagus flow to Portugal under certain climate scenarios may impact cross-border cooperation enshrined in the Albufeira Convention between the two riparian countries, which specifies the amount of water should be discharged from the Spanish section of the river into the Portuguese section[466]. The evaluation of the EU's Adaptation Strategy[467] suggests that national adaptation strategies are not very effective in identifying and addressing macro regional and cross-border climate risks.

In spite of the above-mentioned risks, gaps remain on the losses caused by extreme weather events on fossil fuel based as well as renewable energy sources and thus overall on energy security. Efforts are also required to project the rise of cooling demand and to analyse costs and benefits of adaptation options for cooling[468].

Private stakeholders in the energy system and EU and national policies should reinforce the right market framework to ensure that the climate impacts do not jeopardise the EU's stability and security of energy supply. In particular, current and planned renewable investments in the EU (hydropower, wind, solar, biomass) should be climate-proof to ensure they can deliver their full clean energy production capacity.

As part of the EU Adaptation Strategy, the Commission issued guidelines for infrastructure project developers, launched a review of infrastructure standards and is promoting climate resilient investments in infrastructure[469] and related knowledge base. For example, the Commission proposal for the Connecting Europe facility (CEF) for the period beyond 2020 recognises that infrastructure, in general, and energy infrastructure in particular, is vulnerable to long term climate change impacts and therefore seeks that most projects supported by the CEF are climate proof: in budgetary terms, 60% of the future CEF investments should be climate-related. In the cohesion funds proposed for 2021-2027, the Commission also envisages climate-proofing virtually all EU-funded infrastructure.

Existing evidence, while insufficient, suggests that energy providers will have to incorporate climate projections in the management of their assets: the past will no longer

[466] See EU-funded research project IMPRESSIONS: http://www.impressions-project.eu/. POLICY BRIEF On The IBERIAN CASESTUDY.
[467] Xxx evaluation SWD reference, when available.
[468] COACCH 1st synth report.
[469] Climate change and major projects: https://ec.europa.eu/clima/sites/clima/files/docs/major_projects_en.pdf

provide a reliable strategy. They should also envisage adaptation measures such as climate-proofing traditional technologies while, in parallel, diversifying renewable energy portfolios in accordance with regional climate scenarios[470]. For example, Member States most affected by water scarcity in the future, such as Spain and Portugal, have an additional interest, beyond mitigation, to switch to renewable sources of electricity: solar and wind are more resilient to climate impacts in those countries.

Cities

The need to interweave adaptation and mitigation pathways is most apparent in the transformation of cities that is to ease climate pressures. European cities are home to 360 million people, i.e. 73% of Europe's population. They account for 80% of the continent's energy consumption and concentrate 85% of the EU's GDP[471]. Yet, only around 40% of EU cities with more than 150.000 inhabitants have adopted adaptation plans to protect citizens from climate impacts.

Urban areas are densely populated and concentrate multi-layered infrastructure: they concentrate around 70% of the EU CO_2 emissions[472]. These are strengths for emission reduction efforts and planning, but densification becomes a weakness as regards vulnerability to climate impacts. Cities, for example, also suffer from higher temperatures than the surrounding areas, due to the concentration of built environment ("heat island effect"). Experts estimate that, unless action is taken now, economic costs from extreme weather events to EU cities could reach over €190 billion annually by 2070.

Therefore, there are opportunities to optimise climate action when developing joint mitigation and adaptation in urban planning, also considering the holistic approach of SDG 11: Make cities inclusive, safe, resilient and sustainable, and in particular is Target 11.b[473]. For example, urban green spaces and green infrastructure can deliver adaptation benefits such as cooling, storm-water drainage and social areas, while also contributing to mitigation by reducing cooling energy use through shade. Nature-based solutions for cities are cost-effective because they reduce energy needs and disaster risk, and at the same time they increase energy efficiency, carbon sequestration and air quality. The participation and buy-in of local stakeholders is critical for the successful implementation of ecosystem-based adaptation and the implementation of natural solutions[474]. In

[470] Bonjean Stanton et al (2016): A systematic review of the impacts of climate variability and change on electricity systems in Europe
[471] HELIX
[472] HELIX.
[473] By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, **mitigation and adaptation to climate change**, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels.
[474] Sgobbi 2017

addition, cities will be major clients for climate services. Emerging business may provide solutions to city planners that combine optimal mitigation and adaptation ideas. Cities that prioritise resilient urban development will enjoy a competitive advantage and increase their attractiveness for investments in the future[475].

The Commission already promotes an integrated approach to urban mitigation and adaptation in cities through the Covenant of Mayors for Climate and Energy. Today, more than 1,000 Covenant signatories in Europe are committed to developing sustainable energy and climate action plans for 2030. A 2018 analysis of the Local Climate Plans of 885 EU cities (both Covenant and non-Covenant cities) highlights that about 17% of the cities have joint (mitigation and adaptation) plans. Countries without national legislation requesting compulsory local climate plans (all Member States except Denmark, France, Slovakia and the United Kingdom) are found to have nearly half as many urban mitigation plans, and five times fewer urban adaptation plans, than countries with such legislation.

6.8.3 The global context: adaptation, security and migration

There is a need to translate into policy the growing evidence that there are transboundary climate risks[476] arising from the risks of unmanaged climate change impacts in countries outside the EU. Lack of mitigation globally as well as for adaptation locally in third countries will propagate to Europe via people displacement, financial flows, value chains and trade. The importance of each of these risk-pathways and the range of risks facing the EU in the future will vary depending on future socio-economic pathways[477], as well as on the level of future climate change. Economic and climate intelligence on global value chains and trade flows will be crucial to prioritise support for the adaptive capacity of fragile partners[478] that may see their development, stability and security jeopardised by growing impacts.

The European Environment Agency finds Europe is particularly vulnerable to certain cross-border climate risks coming from third countries[479]:

- Economic effects through climate-caused global price volatilities.
- Disruption to transport networks such as ports.
- Changes in the Arctic environment, including new shipping routes.
- Agricultural commodity trade shocks in Mediterranean countries.

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[475] UNDERFUNDED, UNDERPREPARED, UNDERWATER? CITIES AT RISK e3g
[476] adaptation strategy SWD.
[477] also known as shared socio-economic Pathways (SSPs) under the IPCC nomenclature.
[478] E.g. third countries with which the EU has signed trade agreements: http://ec.europa.eu/trade/policy/countries-and-regions/negotiations-and-agreements/
[479] 2017 EEA Climate vulnerability and impacts in Europe report

- Non-agricultural commodity trade shocks in small, open and highly developed European economies.
- Increased "strategic importance" of North Africa (particularly the Sahel and Maghreb) and Middle East in terms of climate-induced human migration flows and geopolitical and security considerations.

Multiple security risks are set to arise from impacts already foreseen even under the most optimistic climate predictions. European vulnerability to cross-border climate change risks is expected to increase in the coming decades, primarily in relation to European Neighbourhood countries (e.g. as regards energy imports), but also elsewhere. Links between the EU and the rest of the world should be considered in long-term adaptation planning because cross-border risks may be as significant as those from direct impacts[480].

Today, this is an immature research area with few quantitative assessments and unstable terminology. In the IPCC Fifth Assessment Report, cross-border impacts of climate change are mentioned as "cross-regional phenomena" that can be "crucial for understanding the ramifications of climate change at regional scales"[481]. The EU Adaptation Strategy has identified this field as a new knowledge gap to which research efforts should be channelled.

In one of the few efforts to quantify cross-border impacts conveyed via trade[482], available only for some sectors[483], climate losses arising from trade with third countries may increase EU climate losses by up to 20%.

By definition, national vulnerability assessments focus on national territory, populations and economic sectors. The amplification of climate risks brought about by the global economy might be underestimated or just downright ignored[484].

Risks to domestic and international food production and trade are one of the six priorities identified by the 2017 UK Climate Change Risk Assessment[485]. The recognition in Member State vulnerability assessments of impacts coming from abroad is growing but requires further attention[486]. Similarly, the US Third National Climate Assessment[487]

480 IMPRESSIONS

481 Hewitson, B., Janetos, A.C., Carter, T.R., Jones, R.G., Kwon, W-T., Mearns, L.O., Schipper, E.L.F., van Aalst, M.K. (2014). Regional context. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [eds. Barros VR et al.]. Cambridge University Press, Cambridge, United Kingdom and New York, USA, pp. 1133-1197.

482 Peseta 3

483 Agriculture, labour productivity, river floods and energy.

484 Climate risks across borders and scales Andrew J. Challinor*, W. Neil Adger and Tim G. Benton

485 https://www.theccc.org.uk/tackling-climate-change/preparing-for-climate-change/uk-climate-change-risk-assessment-2017/ how

486 2018 EEA national climate change vulnerability assessments report.

highlighted in 2014 the cross-border risks for neighbouring countries with shared water resources.

As regards climate and migration, recent findings confirm a relationship between climate change and fluctuations in asylum applications in the EU: asylum applications could increase by 28% by the end of the century (an average of 98,000 additional asylum applications per year)[488].

Because of all these transboundary effects of climate change, the EU's external policy has shifted to focus on structural, long-term but flexible approaches to climate resilience. In the 2016 Global Strategy[489], the EU recognises climate change as one of the global challenges facing the EU, and in doing so recognises that climate-induced fragility exacerbates conflicts and undermines Europe's security.

7 ACTIONS AT THE NATIONAL AND REGIONAL LEVEL

7.1 Role of Member States

The Commission's proposal for the EU Long Term Strategy presented in this paper was scheduled for the adoption by the Commission for November 2018, ahead of COP 24 in Katowice largely overlapping with the delivery of the NECPs (scheduled, in the politically agreed text of the Governance Regulation, for December 2018). At the same time, the support of MS for the Commission coming up already in 2018 with the proposal for the European Long Term Strategy was very strong. MS were looking towards the Commission setting an example for preparation of their national LTS and all parties hoped that tabling the proposal early will enable constructive discussions and taking on board the positions and visions of all MS before delivering the final EU strategy to UNFCCC. Some MS have already delivered their national LTS, some work intensively on them so they will be well positioned to discuss the Commission's proposal.

The Commission endeavoured to make the preparation of the LTS a truly **inclusive exercise** involving citizens, stakeholders and Member States (via public consultation, public events and dedicated meetings) clearly steering away from a top-down exercise based uniquely on own analysis. The **consideration of national perspectives** in this exercise was also the explicit wish of the Heads of State as reflected in the European Council conclusions from March that invite the Commission to: *(...) present by the first quarter of 2019 a proposal for a Strategy for long-term EU greenhouse gas emissions reductions in accordance with the Paris Agreement, taking into account the national plans.* Consequently, several meetings were organized in 2018 to enable exchanges with MS, obtain feedback on the key issues to be considered in the EU LTS and encourage them to speed up the work on their NECPs.

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[487] https://www.globalchange.gov/browse/reports/climate-change-impacts-united-states-third-national-climate-assessment-0

[488] Missirian et al., Science 358, 1610–1614 (2017), "Asylum applications respond to temperature fluctuations".

[489] **: *Shared Vision, Common Actions*** (EU, 2016).

At the meetings organised in 2018, MS representatives expressed explicit their desire for the strategy to identify already now the vision **for not only the GHG abatement but also for the entire economy**. Such vision, spanning all sectors of economy as well as land use is presented in this SWD and meant help MS to identify where to invest scarce resources, how to focus RDI effort, how to train young people and what the right tools and enabling conditions for all these actions are. MS emphasised that **such vision must be realistic** and this is why the vision presented in this SWD is firmly grounded in the economic analysis considering broad range of evidence and using state of the art projections based on latest available scientific evidence.

Several MS signed the declaration[490] to achieve net zero emissions at latest in 2050 pushing for the **ambitious goals** in the Commission's proposal. On the other hand, other MS underlined **different starting points, potentials and vulnerabilities**, not only on the national but also regional level, which need to be taken into account. This is why the Commission analysed, in a very transparent manner a range of pathways with different levels of ambition but all of them credible and costed. Unlike in 2011 roadmaps the analysis of the Commission is much broader than energy system and land use modelling, it looked not only on abatement to be delivered by technologies but also at changes in the lifestyle, it assessed not only EU-28 economy and society-wide impacts but also national and sectoral ones.

While the range of pathways analysed is very diverse, there is a common starting point of them: the proposal for the EU LTS starts from the achievement of the 2030 targets as politically agreed in June 2018. While the governance process will be set in motion with delivery of the critical mass of NECPs, the EU LTS can only assume that this process will be successful and will deliver the 2030 objectives.

At the time of the preparation of the LTS only Swedish and (TBC BE, FI and LU) NECPs were delivered to the Commission. Clearly XX and YY that are put forward in these Plans are considered in the proposal for the EU LTS as illustrated by ZZ.

Most importantly, t**he adoption of the proposal for the EU LTS** by the Commission should not be seen as the end of a process but **a beginning of the road towards the submission of the EU LTS to the UNFCCC by 2020**. MS will now discuss the LTS in the Council.

Importantly, the **MS will need to deliver their own LTS to UNFCCC by 2020**. National differences notwithstanding, they Commission wanted to lead this process by example by tabling the EU LTS early on. While the national circumstances are very different and even 2030 starting will be different, **MS are strongly encouraged to follow the Commissions' example by setting up a truly inclusive example, robust analytical framework and analyze a broad range of credible pathways for the entire economy**.

Last but not least, in the Governance Regulation, there are strong safeguards (notably Article 14) for ensuring consistency between NECPs and national LTS. The 2030 national objectives

[490] Ref.

will play a key role for the national LTS and the decarbonisation perspective will play a key role for the NECPs. Also, both Governance and UNFCCC processes will interlink and influence each other in the future through updates. This internal consistency on national level will allow for the internal EU LTS and 2030 targets consistency.

Should article 14 also require that NECPs are aligned with EU LTS one should describe it here.

The consistency of the visions set out by MS and LTS will enable coordination of efforts and effective implementation of the strategy. Setting the strategy early and an inclusive manner will enable to have support of other actors and most importantly of citizens. Using transparent analytical framework will enable to identify the challenges, notably in terms of investment and finding the smartest solutions.

7.2 Role of regional and local authorities

- Regional, local, city planning efforts

Achieving the EU's climate objectives will require contributions from every part of the economy – industry, business, farming and forestry – and from all as individual citizens. Hence the policy process at all levels is key to regulate and achieve that change – at the same time a "grand coalition" of all stakeholders to take their responsibility seriously will have to be formed. This includes cities, regions, civil society and of course and importantly the private sector, which complement and inspire the action and ambition of Parties.

In preparation for the EU's proposal, the Commission has carried out a public consultation in the summer of 2018, seeking input from citizens, stakeholders and authorities on the EU’s long-term strategy. Strong participation and ownership will not only help accelerate the implementation of current commitments in the EU, but can also help strengthen global efforts in the short, medium and long term.

City governments have a particular, important and increasing role to play in implementing and enforcing climate mitigation and adaptation policies. This may even extend into the upstream, as a recent study by the Potsdam Institute for Climate Impact Research (PIK) showed for a variety of cities, Berlin New York, Mexico City, and Delhi.[491] Greenhouse gas emissions caused by urban households’ purchases of goods and services from beyond city limits are much bigger than previously thought. According to the study these upstream emissions may occur anywhere in the world and are roughly equal in size to the total emissions originating from a city’s own territory. This in turn means that local policy-makers may have more leverage to tackle climate change, since the two main sectors, housing and transport, are often substantially governed by city mayors. As long-term emissions pathways will be implemented, governments will need more awareness of how many decision are made at the local level. Today, 55% of the world’s

[491] Peter-Paul Pichler, Timm Zwickel, Abel Chavez, Tino Kretschmer, Jessica Seddon, Helga Weisz (2017): Reducing Urban Greenhouse Gas Footprints. *Scientific Reports* http://www.nature.com/articles/s41598-017-15303-x

population lives in urban areas, a proportion that is expected to increase to 68% by 2050.[492] Cities will thus play an increasingly crucial role.

[Need a change of attitude – any numbers on what is needed from IPCC Citations? Cumulative numbers on the impact on cities – under Gcom – here or in a specific box? xxx]

The EU encourages local actors to engage in long-term planning exercises, and globally local actors have started these processes: A C40 study has shown that of 228 cities 25% have set 2050 targets, among them Berlin, Stockholm and Antwerp, but also Yokohama and Seoul[493]. Local governments have a unique role to play and by encouraging them to come up with their own 2050 plans, they also create ownership that a long-term transition may be difficult, but possible.

Through various activities the EU is supporting local climate action, notably through the Covenant of Mayors. The Commission is working with the UNFCCC to increase the visibility of such initiatives, encourage the scaling up of existing initiatives and the creation of new ones. EU institutions, such as the European Economic and Social Committee and the Committee of the Regions can play a crucial role in improving understanding of their challenges and barriers for taking climate action by regions and how to create an enabling environment.

Local and regional authorities play a pivotal role in achieving the Energy Union objectives. The Governance of the Energy union Regulation under the Clean Energy for all Europeans package underlines the involvement of all governance levels and proposes multi-stakeholders consultation process around the national climate and energy plans.

While ultimately, member states are responsible for the achievement of the EU climate and energy targets within their borders, regional and local authorities have a key role to play in delivering on the Energy Union goals. Under the multilevel governance model, regional and local authorities can accelerate and complement national government measures thereby helping (the European Commission) to mainstream EU Energy and climate policy, ensure its long-term coherence and provide certainty to investors. Many local and regional authorities have been already taking ambitious actions by putting in place and implementing climate and energy plans at their levels. Encouraging vertical integration and local level involvement in energy and climate planning is important to be able to both recognise and capitalise on these efforts. Through inclusive and transparent planning processes and target setting vertical integration can facilitate the effective implementation of national targets, and priorities by "localizing" them. At the same time, linking local priorities with higher-level objectives can provide important opportunities for "bundled approaches" and "co-benefits" – enhancing local authorities' role in

[492] *2018 Revision of World Urbanization Prospects*, UN Department of Economic and Social Affairs (UN DESA)

[493] https://c40-production-images.s3.amazonaws.com/researches/images/24_Working_Together_Global_Aggregation.original.pdf?1411483385

aggregating smaller projects into sizable packages and in mobilising the significant amount of investment needed for clean energy transition.

Focussing on decentralisation, citizens' involvement and communities' ownership in the governance legislation enhances local and regional authorities' role and provides them with new tools. Opening investments in infrastructure to local communities and the facilitation of (local) and renewable energy communities can offer new opportunities to local and regional authorities to engage in projects, help ensure public support, raise awareness and facilitate citizens' involvement in the energy transition. Furthermore, non-legislative (bottom-up) initiatives such as Covenant of Mayors or Clean Energy for EU Islands initiative should continue playing their role in scaling up local action and facilitating exchange of good practice in designing and implementing local energy and climate strategies and measures. As climate and energy policies in cities are closely linked to a wider urban context and related specific aspects such as urban planning or public procurement, scaling up and disseminating methods and solutions in these areas, for example through Urban Agenda Partnerships is important for strengthening action at the local level.

The proposal for the next multiannual financial framework (MFF) makes an ambitious commitment for climate mainstreaming across all programmes, with a target of 25%, which will help spending a significant part of the proposed budget of the regional and cohesion policy on climate objectives. In this context, facilitate information and access to the EU funding for local level and creation of regional investment advisory hubs can further increase cities' capacity to mobilise investments for clean energy transition.

The EU governance regulation has created of permanent Multilevel Climate and Energy Dialogue: European cities and regions have proven to be important delivery agents for the European transition towards a more decentralised, energy-efficient, and decarbonised energy system. A permanent and regular dialogue on climate and energy among all levels of governance and relevant stakeholders would deliver various benefits: continuous political support, ownership of process, feedback loops, shared responsibility as well as a better implementation of the actions necessary.

Going forward there are several areas that will require further attention:

- In terms of governance, cities in countries (Denmark, France, Slovakia and the UK) where local climate plans are compulsory are about twice more likely to have a mitigation plan and about 5 times more likely to have an adaptation plan than cities in other countries, reaching respectively 64% and 56% of the analysis' sample.[494]. To foster, therefore, the adoption and monitoring of local climate mitigation and adaptation strategies and action, it would be important that the European Commission (1) encourages Member States to consider frameworks to enhance

[494] D. Reckien et al., How are cities planning to respond to climate change? Assessment of local climate plans from 885 cities in the EU-28, Journal of Cleaner Production, 26 March 2018, https://www.sciencedirect.com/science/article/pii/S0959652618308977?via%3Dihub

local action and (2) increases awareness-raising and technical and financial assistance to local authorities.

- Need to address data limitations and fill gaps on local climate mitigation and reporting. This will also facilitate local modelling exercises – which would also closely link to adaptation planning.
- Engage in big capacity building initiative to highlight areas of local climate governance. Local governments could take decisions, eg. public procurement, based on criteria of sustainability and low greenhouse gas emissions. Another area is the building stock – very often it is at the local level and in city-planning that emphasis can be set, an example is the decision to encourage data centers in the city to feed into district heating in Stockholm[495] under the city's plan to be fossil fuel free by 2040[496].

To support local authorities in making the most of the opportunities and challenges of the transition, the role of national/EU constituencies should:

- be more ambitious and bold when it comes to climate and energy (e.g. end to fossil-fuel energy)
- set more ambitious targets and mirror what some cities are committing to, much earlier than 2050
- Build local authorities' capacities to develop long-term strategies
- Build local authorities' capacities to engage citizens and change the governance at local level
- Facilitate access to finance to invest in low-carbon and resilient economy
- Ensure that fiscal and economic mechanisms include environmental externalities.

7.3 Role of business and civil society

Some businesses have started taking action in identifying their own pathways to reach emissions reductions of 80%, 95% or full carbon neutrality. Going forward what is needed is a much larger proportion of 2050 (and beyond) plans from businesses and different sectors, containing core components. These should clearly identify the opportunities and provide sectoral knowledge – need to put in their information, eg. what disruptive technologies they expect to become economically viable and within what timeframes. This will help governments and fill data limitations and gaps, open possibilities for measuring and reporting the impact of voluntary climate action, while also helping direct sustainable finance and ensuring targeted investments in innovation and competitiveness.

[495] http://www.datacenterdynamics.com/content-tracks/power-cooling/digiplex-plugs-into-district-heating-in-stockholm/99886.fullarticle
[496] https://international.stockholm.se/globalassets/rapporter/strategy-for-a-fossil-fuel-free-stockholm-by-2040.pdf

Analysis in the UNEP gap report 2018 shows that most global initiatives are taking place in Europe, with a focus on the core sectors of transport, energy efficiency and agriculture[497], which are core for the deep decarbonisation envisaged by the EU's long-term strategy. [to be updated with the analytical data on emissions reductions from different initiatives in September 2018] While assessments vary, for instance CDP and We Mean Business assessed individual businesses to have a systemic global impact of 3,200-4,200 MtCO2e per year in 2030, reaching even 5,000-11,000 MtCO2e for international cooperative initiatives[498]. One of the EU's long-term strategy's key purposes is to guide investment decisions, create the policy environment, identify ways to support business activities and create reporting and awarding options.

This long-term strategy provides a process in which stakeholders and EU citizens can be more actively involved in decisions of crucial importance to the EU's low-carbon future. One of the ways to already do this is to include interested stakeholders in the preparation of the analysis underpinning the long-term strategy – through public and expert stakeholder consultations. The vision document published in November 2018 furthermore serves as the basis for ongoing engagement and discussion with citizens, civil society and sectors of the European economy. Civil society will need to continue and increase its role of creating awareness among citizens about long-term decarbonisation and in particular about behavioural and lifestyle changes that each citizen can take. On implementing climate policy civil society has a unique role to play by on the one hand providing best practices and on the other hold accountable businesses and other non-state actors on their commitments. Civil society organisations have already come forward to support countries, local governments and businesses to come up with and understand long-term plans, even beyond 2050, examples for this are handbooks published by the 2050 Pathways initiative and the World Resources Institute, and others adding long-term planning to their project and outreach activities.

As voluntary initiatives have gained importance in particular around COP21 in Paris, civil society will be increasingly important to either link up with business and local actors, but also to act as control to avoid greenwashing.

Overcoming obstacles for non-state climate action and long-term planning

In order to encourage climate action from non-state actors, States can help them to overcome the most common challenges they face, in particular when they are volunteering to do more. The key obstacles identified globally, but also applicable to Europe, include:

1. Obstacle: Lack of access to funding
2. Obstacle: Lack of recognition
3. Obstacle: Lack of organizational capacity
4. Obstacle: Lack of knowledge

(UNFCCC Yearbook of Global Climate Action 2017, p. 28)

[497] UNEP Gap 2018, Chapter 7, to be published September 2018; based on UNEP DTU Climate Initiatives Platform
[498] Roelfsema et al. (2018) and Graichen et al. (2018)

Governments' most important function is to set the enabling environments and long-term plans and visions that provide certainty and allow non-state actors to make ambitious decisions. Governments should also examine where international cooperation is required to address barriers to non-state actor ambition, for example, on trade and product standards, land tenure and commodity and natural resource resilience planning – each of which may affect cross-border supply chains. Or for example, in reforming international financial flows to increase access to funding for climate friendly activities and increasing support to infrastructure project preparation, in order to close the existing gap between

Targeted programs or platforms for different sectors are good practice for enabling and creating the right kind of knowledge and organisational capacity to make climate action work on the ground. Strengthening these platforms, promoting the cooperation between stakeholders and the sharing of experiences is crucial to accelerate and scale up climate action. Government support schemes, as well as integration of different levels of decision-making in particular for local governments, can help overcome capacity shortcomings.

The need for non-state action to be recognised and promoted can be addressed, by reporting schemes that may also provide access to further funding, but also through individual award schemes, highlighting the successes of frontrunners and distinguishing from potential greenwashing initiatives.

Climate action starts with transparency, and it is crucial that businesses, cities, states and regions transparently report carbon emissions and progress toward meeting verifiable emissions reduction goals. National governments should actively encourage non state actors to use transparent reporting, as a tool beneficial to them and especially to the private sector. It fosters trust, reduces surprises, the volatility of asset prices and lowers the cost of capital. The more accurately risk is calculated, the more sophisticated any mitigation response can be. That means better insurance, flood defences and drought resistant crops. Investors win, as do those most vulnerable to climate change. Transparency on key parameters and analytical choices will help to support the comparability of results between the different scenarios used by an organization and between organizations. This will, in turn, support analysts and investors 'assessment of the soundness of the organizations' strategies in a series of plausible impacts, thus supporting a better allocation of risk and capital.

How to overcome obstacles for voluntary action? Some examples

Obstacle of recognition: showcasing flagship initiatives

At the One Planet Summit in Paris on 12 December 2017 the Global Covenant of Mayors issued a *Call for Vertical Integration of Local Authorities in national climate investment plans,* building on the need to show the importance of cities as economic actors contributing to the climate finance opportunities latent in the Paris Agreement.

Spearheaded by Global Covenant of Mayors Board Member and Mayor of Quito Mauricio Rodas in collaboration with the Mayors of Buenos Aires, Medellin, Mexico City and Sevilla, the effort underlines the need to provide pathways for active participation and engagement of sub-national governments in the formulation of national climate investment plans in line with the Paris Agreement (NDC Investment Plans) and accelerated tracks for sub-sovereign financing for Latin American cities. This coalition is therefore calling for a demonstrative flagship pilot with a focus on rolling out low emissions/zero emissions measures in urban historic centers.

Opportunities for funding and investment capacity: Sustainable Finance

Businesses and other partners should be encouraged to invest in renewable energy, energy efficiency and reduced carbon emissions. The European Commission launched an Action Plan on Financing Sustainable Growth in March, followed by a set of legislative proposals on Sustainable Finance in May. It is part of the Capital Markets Union's efforts to connect finance with the specific needs of the European economy. One of the goals is to reorient private investments towards realization of the objectives of the Paris Agreement. This contributes to implementing the EU's agenda for sustainable development as well. The action plan and its accompanying legislative proposal aim to clarify for investors what types of investment are environmentally sustainable. Building on this, it should become easier, clearer and more attractive for companies to invest in economic activities that support the transition to a low-carbon, climate-resilient economy.

Governments can create the enabling environments for non-state action to prosper, by developing regulatory frameworks, by facilitating access to finance, by providing systems for reporting and tracking and by providing visibility to the climate action that are achieved. Finally, working together, learning from each other and scaling up successful approaches, are essential.

8 CONCLUSIONS AND NEXT STEPS

- To summarize the impacts across several cross-cutting indicators
  Quantitative and qualitative discussion/conclusion

8.1 Competitiveness (including labour and financial markets)

8.2 Climate ambition

8.3 Secure, competitive sustainable energy system

8.4 An EU that invests

8.5 The role of Land

8.6 Quality of life (health benefits, better living, urban planning, adaptation, resilience)

8.7 undermine public health,

8.8 Submission of EU LTS to UNFCCC in the context of global action

8.9 LTS updates

Annexes:

9 LEAD DG, DECIDE PLANNING/CWP REFERENCES

10 ORGANISATION AND TIMING

11 PUBLIC CONSULTATION

12 PUBLIC EVENTS

13 DETAILS ON METHODOLOGY AND MODELLING

14 GLOBAL CO2 BUDGET

[xxx please note this data is not yet approved and should thus be seen as confidential and not be published before approval by the IPCC early october!].

There is a near-linear relationship between the cumulative CO2 emissions in a given period and the increase of the global temperature during this period , compounded by the further impact of other greenhouse gas emissions (see also section 5.5.1)[499]. This relationship permits to infer the maximum remaining CO2 budget (also called carbon budget) that can be released into the atmosphere while keeping global temperature below 2C or 1.5C, taking into account also the expected future non-CO2 emissions.

Since the publication of the IPCC AR5, a lot of additional scientific material has been published on the carbon budgets compatible with a 1.5°C temperature goal[500].

In assessing this new literature, the IPCC Special Report on 1.5°C has concluded with high agreement that the remaining carbon budget for 1.5°C and 2°C is higher than estimated at the time of AR5. This assessment is driven in particular by studies such as Millar et al. (2017)[501], Goodwin et al. (2018)[502] and Tokarska and Gillett (2018)[503] which demonstrate how the carbon budget estimates increase once the most recent observations are taken into account.

The IPCC Special Report on 1.5°C reports CO2 budgets for the 2018-2100 period. It reports a central estimate of 1320 GtCO2, for a 66% chance of keeping the temperature increase below 2°C at the end of the century with a range from 1070 to 1570 GtCO2 depending if more stringent or less stringent non-CO2 mitigation is achieved. This is a significant increase compared to the IPCC AR5 WGIII report, which reported a budget range of 630 to 1180 GtCO2 for the period 2011-2100.

The 2018-2100 carbon budgets limiting warming to 1.5°C with 66% chance is now estimated at 570 GtCO2 and at 770 GtCO2 for a 50% chance. The IPCC Special Report on 1.5°C also reports that carbon budget estimates are subject to additional variation of at least +/- depending on the level of non-CO2 mitigation, and due to the the difficulties of quantifying several complex geophysical processes. Uncertainties mainly exist regarding the radiative forcing and response associated to non-CO2 emissions, the near-linear temperature response to CO2 cumulative emissions (transient climate response to cumulative carbon emissions – TCRE) and uncertainties around the size of historic emissions and related temperature increases. The earth system feedback is also a source of uncertainty, for instance with the risk of permafrost thawing, its timing and the magnitude of the impact. A quantitative estimate of all these uncertainties is presented in the table 2.2 of the IPCC Global Warming of 1.5°C report.

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[499] AR5

[500] Friedlingstein et al., 2014a; MacDougall et al., 2015; Peters, 2016; Rogelj et al., 2016b; Matthews et al.,2017; Millar et al., 2017; Goodwin et al., 2018b; Kriegler et al., 2018a; Lowe and Bernie, 2018; Mengis et al., 2018; Millar and Friedlingstein, 2018; Rogelj et al., 2018; Schurer et al., 2018; Séférian et al., 2018; Tokarska et al., 2018; Tokarska and Gillett, 2018

[501] Emission budgets and pathways consistent with limiting warming to 1.5 °C. *Nature Geoscience* volume 10, pages 741–747. https://doi.org/10.1038/ngeo3031

[502] Adjusting Mitigation Pathways to Stabilize Climate at 1.5°C and 2.0°C Rise in Global Temperatures to Year 2300. *Earth's Future*. Volume 6, Issue3, Pages 601-615. https://doi.org/10.1002/2017EF000732

[503] Cumulative carbon emissions budgets consistent with 1.5 °C global warming. *Nature Climate Change* volume 8, pages 296–299. https://doi.org/10.1038/s41558-018-0118-9

These estimates are assuming a 2°C or 1.5°C peaking temperature. More uncertainty is added in case of temporary exceedance of the carbon budget for a given warming threshold and resort to negative emissions afterwards to bring back CO2 cumulated emissions to within the carbon budget and warming below 2°C or 1.5°C afterwards. This is due to the knowledge gap on ocean thermal and carbon-cycle inertia in a context of decreasing CO2 atmospheric concentrations.

Updated carbon budgets and mitigation pathways

The revised carbon budget estimates of IPCC Special Report on 1.5°C are based on extremely recent literature, with the most influential papers appearing in 2017 and 2018[504]. Consequently, there has not been sufficient time for the implications of this revision to be incorporated into the more applied scientific literature that looks at the GHG emissions projections taking into account mitigation action and resulting emission pathways. As a result, most global and regional emissions reduction pathways, including those reported in table 2.4 of the IPCC Global Warming of 1.5°C report, and those produced by the JRC and Netherlands Environmental Assessment Agency in the context of this document, are based on approaches consistent with AR5 rather than the larger budgets as indicated in the IPCC Special Report on 1.5°C.

Once the revised budget estimates of the IPCC Special Report on 1.5°C are taken into account, new pathways may indicate that it is possible to remain consistent with well below 2°C or 1.5°C while reducing emissions more slowly than AR5-based pathways might indicate, or keep the pace early the same than AR5-based pathways but then require less or no net negative GHG emissions later on. Such an assessment will require additional scientific research over the years to come. Nevertheless it is clear that there are no grounds for complacency. In a scenario where all countries achieve only their NDC pledges under the Paris Agreement, even the higher new 2°C budget of the IPCC would be exceeded at around 2050 and the new 1.5°C budget (50% likelihood) of the IPCC would be exceeded well before 2040.

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[i] IRENA 2017, Renewable Cost Database and Auctions Database, http://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Jan/IRENA_2017_Power_Costs_2018.pdf
[ii] IEA 2018, World Energy Investment 2018, https://www.iea.org/wei2018/
[iii] 2017 EurObserv'ER Report , https://www.eurobserv-er.org/category/barometer-2017/

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[504] It should be noted however, that the basic science underpinning the revised estimates is not new. See for example Figure 2.3 of the IPCC Fifth Assessment Report, Synthesis Report.