EU energy system transformation

Cost of Non-Europe

STUDY

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The European Union's energy system is on a path of transformation that should allow it to achieve a net-zero emissions target by 2050. However, there are many challenges ahead and achieving this target requires making profound structural changes. In this context, the present report, drafted at the request of the European Parliament's Committee on Industry, Research and Energy (ITRE), looks at what would be the consequences if the EU does not take further ambitious and united action in the transformation of its energy system. The **cost of non-Europe in this area is estimated at up to 5.6 % of EU GDP in 2050**, and avoiding this will require EU budgetary, regulatory and coordination action. The benefits would be many, including averted environmental costs and damage, and more sustainable and prosperous societies emerging as a result of a just and fair transition. The report recommends several EU actions to ensure a successful transformation: ambitious EU financing levels in addition to Member States' resources to support innovation in clean energy technologies; making sure that any financial burden of energy transformation is shared fairly and in a transparent way; ensuring a well-functioning, non-distorted and integrated internal energy market; as well as ensuring more strategic, united and credible energy security policy, coupled with global EU leadership in multilateral cooperation in energy transformation.

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Executive summary

The move towards more harmonised European Union (EU) energy policies has always been at the heart of the European project, as large savings from collective action could be expected in this area. As a result, a more integrated EU internal energy market has gradually emerged as a reality, although much more needs to be done to arrive at a more efficient organisation and to ensure further beneficial convergence. Facing and understanding the ongoing climate crisis, the EU has also been at the forefront of combining energy and climate policies to reduce greenhouse gas (GHG) emissions following its international commitments under the Kyoto Protocol. After over a decade of pursuing ambitious climate and energy policies, the EU has already achieved some progress such as producing 20 % of energy from renewable energy sources, improving its energy efficiency and effectively reducing GHG emissions from sectors under the EU emission trading system. In 2021, the EU stepped up its ambition with proposals for a new set of actions across all sectors to set the right trajectory for the EU economy to efficiently achieve climate neutrality by 2050. Most importantly, this objective is underpinned by a landmark, legally binding European Climate Law that makes **the EU one of few main global emitters to have made such a strong binding commitment to achieving climate neutrality by mid-century**.

There are many challenges ahead on the road to a zero net-emitting EU energy system by 2050 (see Chapter 2). **How successful the EU is in decarbonising its energy industries, that are still responsible for 80 % of EU GHG emissions, will be key for the overall success of the European green transformation** and the climate neutrality of the EU economy in a broader sense. Action taken on decarbonising the EU energy system in the coming years will determine not only the potential net monetary impacts and successes of achieving the final environmental target of net zero emissions in 2050 but also whether the transformation is just and fair to all and contributing to achieving a sustainable and prosperous society boasting a modern, resource-efficient and competitive economy.[1]

More specifically, the present report, drafted at the request of the European Parliament's Committee on Industry, Research and Energy (ITRE), looks at the EU objective of achieving the decarbonisation of its energy system by 2050 from a perspective of **what would happen without ambitious and united EU action in this area**. It aims to establish what the cost of non-Europe would be if the EU does not step up its efforts towards achieving energy transformation. It estimates the potential environmental, social and macro-economic consequences in a decade (2030), and three decades (2050), from now. At the same time, the report presents quantifications of the potential beneficial role that the EU could play if common budgetary, coordination and regulatory actions are stepped up until 2050. The report also reviews progress made over recent years as well as analysing future opportunities for boosting the energy industries' effective actions in the context of the EU economic recovery, and the investments necessary to achieve net-zero emissions for the energy system in 2050.

The underpinning study in Annex II as well as the complementary quantitative estimations and analysis done in this report (see Chapter 3) indicate that many of the **key challenges associated with the transformation of the EU energy systemcould be difficult to overcome efficiently and effectively if no further common and determined EU action is taken**. Ensuring rapid development and deployment of the green technologies needed for decarbonising energy use in

1 As envisaged in the European Green Deal. European Commission, The European Green Deal, COM(2019) 640 final.

sectors that are difficult to decarbonise, while also reinforcing EU global competitiveness and leadership in some of these technologies, would also be achieved more rapidly and efficiently if done in a concerted way. Moreover, some society- and policy-related challenges, such as ensuring an appropriate non-distortive EU carbon price signal is sent to the internal market, are more effectively addressed at the EU level. At the same time, the distributional effects of this pricing could be addressed at the EU level so that the transformation ensures continued convergence and strengthens EU social and economic cohesion, while being fair and inclusive. Finally, given the constraints placed on public finances as a result of the coronavirus pandemic, the appropriate levels of financing dedicated to energy transformation could also be allocated at EU level, thus reinforcing the Member States' national budgetary spending.

The **cost of non-Europe in EU energy-system transformation is estimated to be worth up to 5.6 % of EU GDP in 2050** stemming from EU budgetary, regulatory and coordination actions, and including averted environmental costs and benefits from a fair transformation. Actions in that field will have boosted the EU economy by around 3.3 % of EU GDP or €464 billion in 2030 and by up to 5.6 % or more than €1 trillion in 2050 (see Table 1). An analysis of the quantitative results done both in this report and in Annex II therefore confirms that the EU climate and energy policy is an area where an ambitious and united EU approach could be key to boosting EU GDP, competitiveness and sustainability. However, failure to arrive at common approaches in this area, in particular through collectively addressing volatile energy prices and systemic risks emerging from the dependency of the EU from external suppliers would result in the non-materialisation of some or of the entirety of the potential benefits reported in Table 1. In that respect, in a context of increasing uncertainty, systematically stress-testing ongoing initiatives and moving away from feel-good agendas and towards a more strategic vision would be essential, as preparedness and foresight prove beneficial in increasing resilience and robustness in times of crisis.

Table 1 – Computation of the CoNE, summary: Ambitious and united EU action in 2030 and 2050 vs baseline (€billion per year)

Year	2021	2030	2050
Averted costs of climate change-related damages	34	125	203
Benefits from climate-related NGEU investments	24	31	37
Benefits from climate-related MFF investment and cohesion funds	22	33	66
Benefits from climate-related MFF RD&I spending	0	14	55
Benefits from EU ETS	14	14	96
Benefits from further energy sector integration	4	53	53
Benefits from the development of renewable energy	7	61	94
Benefits from increasing energy efficiency	11	88	126
Benefits from the Taxonomy Regulation	0	12	39
Benefits from a fair transformation	12	33	261
CoNE	**129**	**464**	**1 029**

Source: Authors' own calculations.

More specifically, the analysis (see Chapter 3.1) reveals that keeping the global temperature rise at 1.5 degrees Celsius would avert damages worth **€203 billion per year**. With regard to the impact of climate-related EU budgetary actions (see Chapter 3.2), the report finds that climate-related NGEU investment could bring long-term benefits of **€37 billion per year**, while benefits from climate-related EU investment and cohesion funds, and benefits from climate-related EU RD&I spending, could reach respectively **€66 and €55 billion per year**. The **EU emissions trading system (EU ETS)** has the potential to provide benefits worth **€96 billion per year** (see Chapter 3.3) through the efficiency gains that it ensures compared to non-economic approaches and through the double dividend generated by revenue recycling.

With regard to the **integration of the energy market** (see Chapter 3.3), its full integration could bring potential gains to the European economy of at least **€53 billion per year**. This includes a gain of €25 billion per year related to the further integration of the electricity market and €28 billion per year related to the further integration of the gas market. Further development of renewable energy and respect for the EU targets in this area would bring **€94 billion per year**. This includes €27 billion from reduced EU dependency on fossil fuel imports. Achieving increased energy efficiency in the range of the EU target of 40 % by 2030 would bring economic benefits worth **€126 billion per year**. This includes €36 billion from reduced EU dependency on fossil fuel imports. The EU Taxonomy Regulation, by improving clarity on what responsible energy investment means and by encouraging environmental and social governance, would help increase EU GDP by **€39 billion per year.**

Finally, by ensuring a fair transformation where no one feels left behind, the EU could ensure that there would be an additional benefit of **€261 billion per year** (see Chapter 3.4). Here, there is a risk that a lack of common EU strategic action to address volatile and increasing energy prices could substantially reduce this positive expected impact, notably through the effect on energy affordability and energy poverty. The results thus indicate that shaping a fair continent-wide energy policy that ensures affordable energy prices would provide higher resilience in times of unexpected and distortive events.

Based on the quantifications related to the potential costs and benefits of further ambitious and united EU action on energy transformation towards climate neutrality, this report proposes taking some key actions (see Chapter 4). First, the EU should **ensure ambitious and long-term adequate financing of the energy transformation with a particular renewed and increased focus on innovation**. This would be necessary to help develop and deliver key carbon-neutral technologies to the market and allow the EU to reinforce its global competitive advantage. Second, the EU should **ensure a fair transformation so that no one feels lefts behind**. This would need targeted action, in particular catering to the needs of poor and vulnerable households, to reduce energy poverty and in general to make sure that the financial burden of energy transformation is shared fairly and in a transparent way between energy exporters, energy providers, consumers and taxpayers. Third, ambitious and united EU action could help **ensure a well-functioning and integrated internal energy market**. A harmonised energy market can only be achieved if EU Member States avoid distortive subsidies, further develop common standardisation and infrastructure for green technologies as well as strengthen EU security of supply and reduce dependencies through increased diversification of supply and possibly through collective purchasing of energy. Fourth, the EU could act on **ensuring a more strategic, united and credible energy security policy as well as global multilateral cooperation in energy transformation**. This would require, among other things, a more united approach towards third-country energy suppliers, broader use of the euro in energy-related international agreements and non-binding instruments, and developing a WTO-compliant carbon mechanism on the EU's external border to ensure that EU industries remain competitive throughout the energy transformation process.

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1. Introduction

1.1. A cost of non-Europe report on EU energy transformation

This report, prepared at the request of the European Parliament's Committee on Industry, Research and Energy (ITRE), is meant to provide support to the Members of the European Parliament (MEPs) in their work on the EU objective of achieving climate neutrality[2] by 2050, of which a successful and deep energy transformation is an essential aspect.

Cost of non-Europe (CoNE) reports prepared by the European Added Value Unit of the European Parliamentary Research Service are designed to study the **possibilities for gains and/or the realisation of a public common good through action at EU[3] level**. These reports attempt to identify areas where deeper EU integration can bring benefits and for which the European added value (EAV) is potentially significant. CoNE reports aim to contribute to evidence-based policy-making and to the extent possible try to provide quantitative estimates of the consequences of non-action at EU level.

In this context, the present CoNE report seeks to provide a reliable estimate of the potentially measurable gains to the EU economy from the various climate- and energy-related EU policy initiatives. It does not claim to make exact predictions, but rather to illustrate the share of the possible efficiency gains that could be realised from ambitious and united action. More specifically, this CoNE report aims to inform its readers about:

- the global outlook regarding the energy transformation, whether it is still possible to achieve climate neutrality by 2050 and what the EU role in this process is (Chapter 1)
- existing challenges related to transforming the EU energy system to achieve carbon neutrality by 2050 (Chapter 2)
- different potential environmental, macroeconomic and social impacts if there is no further ambitious EU-level action related to the transformation of the energy system ? (Chapter 3)
- priority actions that could be taken at EU level to address the identified challenges (Chapter 4)

This report largely builds on the results of the study described in Annex II. However, as the study does not evaluate all EU actions in detail and, in order to avoid basing the EAV computation on results from a single model, the analysis presented in the report was broadened and enriched. In particular, the report points to the savings that can be made by averting potential environmental costs that would otherwise arise if ambitious energy transformation at EU level is not pursued further. The report also presents a broader context to challenges, impacts and priority EU-level actions that relate to energy transformation. Furthermore, it systematically recalls and uses the results obtained by other publically available macro-economic analyses. Therefore, the EAV results presented in the report cover the environmental, economic and social effects associated with reaching carbon neutrality in 2050.

2 Climate neutrality is understood here as net-zero emissions meaning that still some greenhouse gas emissions might occur but they are neutralised either through carbon dioxide removal and sequestration or through carbon removals by protecting and restoring carbon sinks (e.g. forests).

3 EU-27, unless specified otherwise.

The baseline scenario in this report does not foresee carbon neutrality in 2050. It corresponds to the EU reference (REF) scenario of July 2021,[4] which updates the previous version published in 2016.[5] This report compares the results[6] with a scenario of more ambitious and united EU action leading to reaching 55 % less GHG emissions by 2030 and net-zero emissions by 2050 (MIX55);[7] this scenario was selected as a baseline for the study in Annex II.[8] Regarding the environmental cost of inaction, this report also simulates additional counterfactual scenarios to illustrate the large impact of no-EU action in the area of energy transformation.

Regarding the sectors covered in this report and in line with the study in Annex II, the report focuses on domestic energy-related CO_2 emissions and on the main sectors of the EU economy responsible for these emissions: energy industries, buildings, industry and transport. It lays out different scenarios, which analyse these sectors' potential future greenhouse gas (GHG) emissions reductions,[9] estimate the related EU budgetary appropriations needed for limiting these emissions and the associated macroeconomic effects (e.g. on GDP and on employment). Along with the focus on these economic sectors, the report assesses the key challenges related to the energy system, society, policy and finance. These are taken from the study in Annex II[10] as well as from publicly available literature listed in the references. The report also evaluates the impacts of further non-action at EU level in terms of lost environmental and macroeconomic benefits that would otherwise accrue through EU budgetary and regulatory action. Prices used in the quantitative analysis (Chapter 3) are relative to the baseline GDP expenditure measure at market prices (the year 2010, €) in the EU-27 in the baseline scenario of the study in Annex II.

Regarding some of the limitations of this report, it has to be noted that there are potential large benefits from the reduction of other types of pollution in the net-zero scenario.[11] The report does not directly investigate these limitations. Similarly, the adoption of some new GHG-reducing technologies might also have adverse environmental effects and lead to additional emissions or other environmental externalities. Again, these matters are not directly examined in this report. Also, considering the selection of sectors, the data presented in this report do not include GHG emissions produced by agriculture, land use, land-use change and forestry, and waste management.

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4 European Commission, EU reference scenario 2020 – Energy, transport and GHG emissions: trends to 2050, July 2021. The Reference Scenario is a projection on the future developments of the EU energy system, transport system and greenhouse gas GHG emissions that acts as a benchmark for new policy initiatives. It reflects policies and market trends used by policymakers as baseline for the design of policies that can bridge the gap between where EU energy and climate policy stands today and where it aims to be in the medium- and long-term, notably in 2030 and 2050.

5 The study in Annex II uses REF2016 as a reference scenario because its manuscript was completed before the publication of REF2020 and before the publication by the European Commission of the 'Fit for 55' package of proposals on 14 July 2021.

6 The reference scenario builds on EU and Member State policies. This scenario is based on the EU energy, transport, and climate acquis as of the end of 2019. National policies accounted for in the reference scenario include the main ones laid out in the national energy and climate plans (NECPs) and in other national plans put forward as of the end of 2019.

7 This correspond to the MIX55 scenario in the study in Annex II. MIX55 is an extension of the MIX scenario in the European Commission Impact assessment. It combines regulatory and carbon pricing instruments, which realise 50-55 % GHG emissions reductions by 2030 and net-zero emissions by 2050.

8 For more details, see Chapter 3 below.

9 GHG emissions refers to CO_2 domestic energy-related CO_2 equivalent emissions (in $MtCO_2eq$).

10 For the methodology employed in selecting the key challenges involved in accomplishing the EU energy transformation from an energy supply and demand perspective, see O. Hoogland et al., 2021, Chapter 2.

11 The net-zero scenario in the study in Annex II that achieves net zero GHG emissions in 2050 does not include other emissions than greenhous gases.

1.2. The need for an effective, fair and inclusive global energy transformation

Energy systems play a pivotal role in our economies and societies. They ensure security of supply, allow economies to grow as well as ultimately contribute to wellbeing. At the same time, energy systems have a heavy impact on the environment, as the majority of global energy supply comes from GHG-emitting fossil fuels.[12] On a global scale, the latest available data show that despite an economic downturn in 2020[13] due to the coronavirus pandemic and the ensuing record-low global energy demand,[14] in 2021 there will be a rebound effect in both trends.[15] Consequently, in 2021 the GHG emissions from energy systems will increase again compared to the pre-pandemic levels of 2019, after a historic drop in 2020.[16] Data analysis and projections of 2021 energy supply and demand show that the Covid-19 crisis will not significantly change the current decarbonisation trends in the global energy system (Enerdata, 2021; IEA, 2021a) and the two indicators – energy intensity and the carbon factor[17] – should both revert to their trends from before the pandemic.

Climate science has shown that **reinforced international cooperation towards an energy transformation from carbon intensive fossil fuel-**based energy systems is urgent and necessary for limiting the worst effects of climate change and keeping the atmospheric temperature rise well below 2°C compared to pre-industrial levels (1850-1900) as agreed in the Paris Agreement of 2015.[18] Emissions coming from energy systems constitute the main source of human-caused climate change and account for over three quarters of all global GHG emissions (Climate Watch Historical GHG Emissions, 2021). Meanwhile, at the global level, there has been insufficient progress in curtailing global warming and GHG emissions have gone up 50 % since 1990 (Climate Watch Historical GHG Emissions, 2021). The energy transformation is taking place too slowly and unevenly (WEF, 2021). Emissions have been constantly rising, particularly in countries that have decided to follow a path of economic development still underpinned by vast increases in unabated fossil fuels like coal in their energy mix. Moreover, long-term projections show that global energy demand will be growing together with global population growth. This forcefully suggests that to be successful, the energy transformation should be addressed in a multilateral framework and involve more international cooperation.

Furthermore, recent *gilets jaunes* protests in France have recalled that the energy transformation should be fair. It should not only ensure **clean and sustainable energy** but should at the same time create energy systems that are **inclusive**, **affordable** and **secure** (SDSN – IDDRI, 2015). There are numerous challenges associated with meeting these goals. It has been recently

12 Energy emissions coming from: energy production and use in buildings, electricity/heat, fugitive emissions, manufacturing/construction, other fuel combustion and transportation.

13 World GDP decreased by 3.5 % in 2020 compared to pre-pandemic 2019 levels.

14 Decrease by 4 % in 2020 compared to 2019.

15 GDP: +6 % and energy demand: +4.6 % compared to 2019. https://iea.blob.core.windows.net/assets/d0031107-401d-4a2f-a48b-9eed19457335/GlobalEnergyReview2021.pdf

16 Projected increase of 4.8 % in 2021 after a drop of 5.8 % in 2020 compared to 2019. https://iea.blob.core.windows.net/assets/d0031107-401d-4a2f-a48b-9eed19457335/GlobalEnergyReview2021.pdf

17 Energy intensity signifies the energy consumption per GDP, while the carbon factor is a ratio of CO_2 emissions per tonne of oil equivalent (toe) of energy consumed.

18 The Paris Agreement is the first universal binding agreement signed by governments to limit global warming to well below 2°C and ideally keep it at maximum 1.5°C above pre-industrial levels.

estimated that unless efforts are scaled up and inequalities addressed, the goal of clean and affordable energy by 2030 risks to not be met (IEA, IRENA, UNSD, World Bank, WHO, 2021). Energy access [19] is still uneven; in the European Union, almost 7 % of those surveyed said they would not afford to heat their homes sufficiently.[20] These trends could get worse, especially in the most economically vulnerable regions, due to the recession provoked by the coronavirus pandemic. Moreover, the recent surge in gas prices [21] poses a risk of stark increases in gas and electricity prices for households this winter, further exacerbating energy poverty. This places even stronger emphasis on the need for more preparedness, more political will and more strategic action in this area at EU level. As shown by some recent crises, a policy of fragmented response lacking a strategic long-term and visionary approach could prove to be extremely costly.

Finally, the energy transformation needs to be **accepted and understood at an individual level**. This means that the **transparency** of the process should be ensured, that all actors should be **consulted** and all citizens **involved**. In the EU, the European Parliament (EP) has a key role to play to make sure that EU citizens and their representatives are fully involved at all levels in the decision-making process of the energy transformation. The EP has been vocal in its resolutions[22] on the need for inclusiveness during the transformation to climate neutrality and the importance of active participation by all of society 'based on genuine dialogue and transparent and participatory processes'. It has also emphasised at several occasions that climate action has to be **socially fair, equitable** and **science-based**. Moreover, it has advocated for access to justice in environmental matters throughout the climate transformation process, in accordance with existing legislation and relevant case law.

1.3. Global net-zero GHG emissions by 2050 still possible with renewed ambition and visionary leadership

The latest research on energy transformation, which factors in some of the impact of the coronavirus pandemic, confirms that the current **decarbonisation trajectory does not place the world on track to achieve global net-zero emissions by mid-century** (IEA, 2021; UNEP, 2020). Current policies, if continued without more ambitious action, could result in an average temperature rise of 2.7°C[23] – 2.9°C by 2100 (Climate Action Tracker, 2021). According to the latest assessments, even if fully implemented, governments' current net-zero target pledges and national determined contributions (NDCs), which cover over 70 % of global CO_2 emissions, do not allow us to reach the Paris Agreement target of a 1.5°C temperature rise (Climate Action Tracker, 2021; IEA, 2021). Instead, a global average surface temperature rise in 2100 could be at 2-2.1°C (Climate Action Tracker,

[19] Meaning access to electricity and clean cooking facilities.

[20] See Eurostat (2021), Can you afford to heat your home? Accessed at: https://ec.europa.eu/eurostat/en/web/products-eurostat-news/-/ddn-20210106-1?redirect=/eurostat/en/news/whats-new

[21] See, for example: https://www.reuters.com/business/energy/global-markets-gas-2021-09-20/ and https://www.euronews.com/2021/09/23/why-europe-s-energy-prices-are-soaring-and-could-get-much-worse.

[22] European Parliament resolution of 28 November 2019 on the climate and environment emergency (2019/2930(RSP)); European Parliament resolution of 15 January 2020 on the European Green Deal (2019/2956(RSP)); European Parliament legislative resolution of 24 June 2021 on the proposal for a regulation of the European Parliament and of the Council establishing the framework for achieving climate neutrality and amending Regulation (EU) 2018/1999 (European Climate Law) (COM(2020)0080 – COM(2020)0563 – C9-0077/2020 – 2020/0036(COD)).

[23] See the STEPS scenario results in: IEA (2021), Net Zero by 2050, IEA, Paris.

2021).[24] Nevertheless, these pledges are a step in the right direction and need to be complemented further with NDCs target updates this year in advance of the UN Conference of the Parties (COP26) in Glasgow.

Since the signing of the 2015 Paris Agreement, the world has seen a steep increase in climate neutrality pledges and tangible effects of some implemented policies. [25] However, as of 21 April 2021, **only 10 % of global emissions were covered by legally binding net-zero commitments** adopted by governments (IEA, 2021). For the EU, this percentage has increased since that date, as a result of the adoption of the European Climate Law.[26] Also, at the Leader's Summit on Climate, which took place on 22-23 April 2021 at the initiative of the United States President, Joe Biden, the US, Japan and Canada announced their new 2030 NDCs.[27] After years of relative inaction and lack of leadership on this issue, the US is currently legislating a clean future act that proposes to set a national goal of net-zero emissions by 2050 and an interim goal of reducing GHG emissions by at least 50 % by 2030 (compared to 2005 levels). China, which announced in 2020 that its emissions could peak by 2030 and that it could reach carbon neutrality by 2060, pledged at the summit to strictly control coal consumption between 2021 and 2025 and to start phasing out coal between 2026 and 2030 (Climate Action Tracker, 2021). Moreover, the net-zero targets need to be backed by real-world action and interim 2030 emission reduction goals. While these pledges cannot be downplayed, what will however be more important is their effective implementation with concrete actions and measured reduction of emissions. So far, despite more than 21 years of commitments since the Kyoto Protocol, tangible results have remained elusive at global level. Achieving **climate neutrality at a global scale is therefore still possible** but only if mitigation efforts are stepped up. In practice, this means that more countries need to develop and implement long-term decarbonisation strategies consistent with the Paris Agreement, and NDCs[28] need to become consistent with the net-zero emissions goals (UNEP, 2020).

There is therefore an urgent need for an **upgrade in the model of global economic development**. In practice, this means that welfare cannot only be based on the continuous increase of the quantity of consumption, or on endlessly falling prices, but that the qualitative aspects need to be considered too as an integral part of any economic development model. Countries need to find the right balance between undertaking energy system transformation and developing their economies while at the same time avoiding harming the climate and the environment, but also ensuring social justice and guaranteeing fundamental rights. In times of increasing uncertainty and interdependences compounded by the impacts of the coronavirus pandemic, this will undoubtedly necessitate more ambitious and common action at EU level. Choosing the right decarbonisation policies and ensuring they deliver results on time will also be extremely challenging due to the **societal, environmental, economic and technological complexity** of energy transformation. Policy choices have to be made now and implemented in the coming decades otherwise the energy transformation will

[24] See also the results for the Announced Pledges Case (APC) scenario in Net Zero by 2050, A Roadmap for the Global Energy Sector, IEA 2021, Paris.

[25] The latest Climate Action Tracker estimates that the temperature effect of policies implemented as a result of the Paris Agreement is a 0.7°C decrease by the end of the century.

[26] Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 (European Climate Law) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32021R1119.

[27] https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/23/leaders-summit-on-climate-summary-of-proceedings/.

[28] https://www.wri.org/ndcs.

become far more costly[29] and there will be very little chance of avoiding the worst effects of climate change (IPCC, 2021). Climate policy is driven by facts and figures and both are largely available to enable decision-makers to take the right action.

Moreover, in **climate neutrality pathways**, **renewables would become the main source of global energy supply in 2050**, increasing from the current level of 15 % to levels of up to 60 % (IEA, 2021) or even 65% (IRENA, 2018). At the same time, installed renewable capacity would serve to produce 85 % of electricity in 2050 (IRENA, 2018), enabling the electrification of sectors such as buildings and transport. This is accompanied by and results in continuous energy efficiency gains despite a growing world population and economy by mid-century. Fossil fuel use would fall from 80 % of total energy supply in 2020 to 20 % in 2050 (IEA, 2021).[30] Shifting energy systems to **renewable energy and increasing energy efficiency** is thus believed to be the key to reducing global GHG emissions by up to 90 % by mid-century (IRENA, 2018). Similarly, a recent IEA report assesses that the bulk of emissions reductions (around 40 % at global scale) needed to achieve net zero emissions in 2050 would depend on the adoption of low-carbon technologies and over a half would depend (55 %) on these technologies together with the involvement or engagement of citizens and consumers, e.g. through actions such as installing a solar water heater or buying an electric vehicle. The remaining 8 % would depend on **behavioural change** and materials efficiency gains that reduce energy demand (IEA, 2021). Because 'almost half of the emissions savings needed in 2050 to reach net-zero emissions rely on technologies that are not yet commercially available', a net zero reality is achievable in 2050 only thanks to 'an **unprecedented clean technology push to 2030**' (IEA, 2021). Each country has its specificity but in general the three end-use sectors – industry, transport and buildings – remain the most challenging to decarbonise worldwide due to their highest fossil fuel dependence (IRENA 2018). Oil consumption in both the residential and the road transport sectors has been growing for decades now (IEA, 2020a). As a result, space heating and passenger cars exhibit the lowest energy efficiency savings among residential appliances and other road transport modes (IEA, 2020a).

Furthermore, an appropriate level of available **climate finance** will be crucial to succeed in shifting from a fossil-based energy system to a clean and sustainable one. Although the investment necessary for energy transformation seems very high in the short term, the long-term return on investment – potentially big – could bring about a substantial increase in in well-being and in productivity. The required **investment in energy transformation would as a result entirely pay for itself** (IRENA, 2018).[31]

As governments are currently spending and mobilising money at an unprecedented scale for fiscal rescue and recovery packages in response to the coronavirus pandemic, analysts stress that investments accelerating the low-carbon transformation would be of key importance in getting closer to achieving the Paris Agreement targets. Many G20 governments, including the EU as a bloc, have agreed that, with a view to preserving the wellbeing of future generations, the **economic**

[29] According to IRENA estimations, if climate mitigation action is delayed by one decade, the number of stranded assets will double (IRENA, 2018).

[30] In different modelling scenarios – see also O. Hoogland et al., 2021 – fossil fuel supply does not fall to zero, as important amounts would continue to be used for non-energy goods with the application of carbon capture use and storage (CCUS) as well as in sectors where emissions are particularly difficult to reduce (heavy-industry and long-distance transport).

[31] In the IEA net-zero pathway, annual average energy investment between 2021 and 2050 would increase by 1 % of GDP compared to investments that took place globally over the past five years (IEA, 2021).

recovery would need to be green, i.e. climate- and environment-friendly. Nevertheless, for the time being the analysis of the G20 stimulus packages paints a mixed picture, as plans are still being adopted and executed. The business-as-usual approach is still present by some G20 countries in this context instead of a new **transformational approach to investing that is needed to protect the climate and the environment and ensure sustainable growth** (OECD, 2021).

Finally, all economies will need to increase their GHG emissions reductions ambitions while ensuring more international solidarity, as climate neutrality is only possible as a result of a concerted and increased global effort.[32] In particular, the global commitment of reaching around €80 billion[33] for climate finance directed to developing countries from 2020 onwards has not been met, according to latest data. Public climate finance contributions by developed countries have increased and private financing has stabilised (OECD, 2021). The European Commission President, Ursula von der Leyen, has recently stressed that the EU is delivering on its commitment (by contributing US$25 billion per year) and is ready to do more (an additional €4 billion until 2027), while also expecting the US and partners to step up their climate financing too.[34]

In view of all these challenges ahead, people around the world seem to understand the urgency to act and generally support climate action. In the context of economic recovery from the coronavirus pandemic, **65 % of respondents surveyed in 29 countries** (including all of the G20) **supported a green recovery** and considered it important that government actions prioritize climate change (WEF, 2020).

1.4. The EU as a global leader in the energy transformation – and why it matters

The EU has the ambition of becoming the first carbon-neutral continent. It is responsible for 12 % of the world's energy consumption and 8 % of global GHG emissions (IEA, 2020). It is the only world economy that has successfully pursued legally binding decarbonisation measures on a continental scale for over a decade. Since 1990, the EU has to a significant extent decoupled its domestic GHG emissions (-26 %) from economic growth (+64 %) and has overachieved its 2020 GHG emission reduction target of 20 %.[35] In comparison, the other major developed economies have only stabilised their emissions since 1990 (Climate Watch Historical GHG Emissions 2021). Since that year, the US has slightly increased its emissions by around 0.6 % and Japan has recorded a nearly 2 % growth. Meanwhile, China has increased its emissions over three times and India nearly three times compared to 1990.[36] Moreover, it has to be noted that given the rapid transformation of the global production landscape in the past 30 years, some of the most heavily polluting activities have been shifted to economies outside of the EU and the EU displays a large CO_2 content in its imports.

32 See IEA (2021), Net Zero by 2050, IEA, Paris; Chapter 2: A global pathway to net-zero CO_2 emissions in 2050.

33 The international commitment was to deliver US$100 billion.

34 https://ec.europa.eu/info/sites/default/files/soteu_2021_address_en_0.pdf.

35 Although it should also be underlined that a part of the abatement effort was also possible due to the restructuring of the European economy and industry. Some of the most polluting factories and plants were closed (e.g. in central and eastern Europe) as economies turned more to services and some plants delocalised to countries beyond the EU.

36 Latest available data at Climate Watch is from 2018.

To see these results from a different perspective, it is worth noting that since 2000, the EU has been a net importer of CO_2 emissions.[37] A study analysing the period from 1995 to 2009 estimated that EU total **carbon emissions had increased 11 % under a consumption-based** approach. This accounts for emissions that are embedded in imports of products with a high carbon footprint (Becqué et al., 2017).[38] Since 2002, there has been a sharp rise in consumption-based emissions a result of increased trade flows between China and other countries after China joined the WTO in 2001. In addition, the EU Member States are among the main contributors to the stock of GHGs accumulated in the atmosphere since the Industrial Revolution.[39] In accordance with a well-established UNFCCC principle (common but differentiated responsibilities), the EU has not only a responsibility but also a duty towards the rest of the world in leading the global efforts for mitigating climate change.

EU energy policy has undergone substantial changes in the past decade, driven by internal energy market reforms (the third energy package), the development of new technologies, EU policy on the security of energy supply and, most importantly, the **EU's commitments to fighting climate change**, which were translated into the 2020 and 2030 climate and energy goals.[40] This unprecedented coordination of energy and climate policies stems from the EU Member States' long track record of jointly addressing environmental concerns, the EU's international commitments made under the Kyoto Protocol and the realisation that pursuing a fragmented approach in this area entails a large cost.

The EU is **set to reach its 2020 target of producing 20 % of energy from renewable sources**[41] (compared to only 9 % in 2005[42]). Consequently, the EU has the lowest and still declining carbon intensity of power generation compared to other large economies.[43] Due to a reduction in energy demand in 2020 provoked by the coronavirus-related lockdowns of economies**, the EU should also reach its 2020 energy efficiency target**.[44] However, before the pandemic, it was not on track to reach it. A rebound effect is expected in 2021 and more efforts to practically apply the energy-efficiency-first principle will be needed. In particular, emissions from the transport and the buildings sectors should be abated more effectively. The EU is well short of achieving its 10 % renewable fuels target by 2020 in transport.

The current EU climate and energy agenda focuses on the implementation of the **European Green Deal** presented by the Commission in December 2019 and endorsed by all EU Member States and institutions. This strategy aims to pave the way for the EU to achieve carbon neutrality by mid-century and to **reduce its GHG emissions by at least 55 % by 2030** (compared to 1990 levels). This

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[37] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Trends_in_consumption-based_CO2_emissions_of_imports_and_exports_for_the_EU_based_on_MRIO_estimates,_2000-2018_(tonnes_per_capita).png

[38] This accounting differs from production-based emissions, which are internationally reported and relate to emissions in the place of production.

[39] https://www.statista.com/statistics/1177911/cumulative-co2-emissions-worldwide-by-region/

[40] European Commission, Climate strategies & targets, https://ec.europa.eu/clima/policies/strategies_en.

[41] Latest data show 19.4 % in 2019. https://www.eea.europa.eu/publications/trends-and-projections-in-europe-2020.

[42] IRENA, EU RES.

[43] This is also due to nuclear power generation in some EU Member States. Carbon intensity of power generation in 2018: EU – 270 gCO_2/kWh, US – over 400 gCO_2/kWh, Japan – over 500 gCO_2/kWh, China – around 600 gCO_2/kWh, India and Australia – over 700 gCO_2/kWh. In 2019, the EU decreased its power generation intensity to 235 gCO_2/kWh. IEA 2020, European Union 2020 – Energy Policy Review.

[44] The 2020 target envisages a final energy consumption reduced by 9 % from 2005 levels.

latter commitment raises the EU's ambition from the previously agreed 40 % target, because it has been estimated that without a steeper emission reduction by 2030, the EU could have great difficulties in reaching net-zero emissions by 2050. Both objectives (for 2050 and revised for 2030) were made a part of the European Climate Law,[45] one of the world's few legally binding commitments for achieving net-zero emissions by 2050. As a consequence, the EU also updated its NDC in December 2020 in preparation for the next climate summit – COP26 – in November 2021 in Glasgow.[46]

With all this track record in energy and climate policies, the EU has a lot of lessons to share with other countries both in respect of its successes and failures. The bloc has been 'learning by doing' over the years and, as illustrated by the case of the EU ETS, finding an **EU-level solution has been more efficient** than if Member States were to seek it separately.[47] Another lesson, as pointed out by the authors of the 2016 paper, is that there is **'no "silver bullet"**, meaning that a complex issue such as reducing GHG emissions cannot be addressed by a single policy instrument. EU climate and energy regulatory experience so far also shows that a **facts-based, transparent and inclusive approach** towards all stakeholders is of 'utmost importance' as pointed out in the same 2016 paper. This aspect will remain one of the key challenges as EU transformation to carbon neutrality will have to accelerate in the coming decade but at the same time – as the European Parliament advocates – 'this action must be science-based and must involve citizens and all sectors of society and the economy ... in a socially balanced and sustainable way...'.[48] Moreover, delivering climate transformation through a democratic process seems what EU citizens value and where they see a potential for European Parliament action.[49]

45 Regulation 2021/1119 of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 (European Climate Law).

46 https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/European%20Union%20First/EU_NDC_Submission_December%202020.pdf.

47 As pointed out in a 2016 paper by Delbeke, and Vis, 2016.

48 European Parliament resolution of 15 January 2020 on the European Green Deal (2019/2956(RSP)).

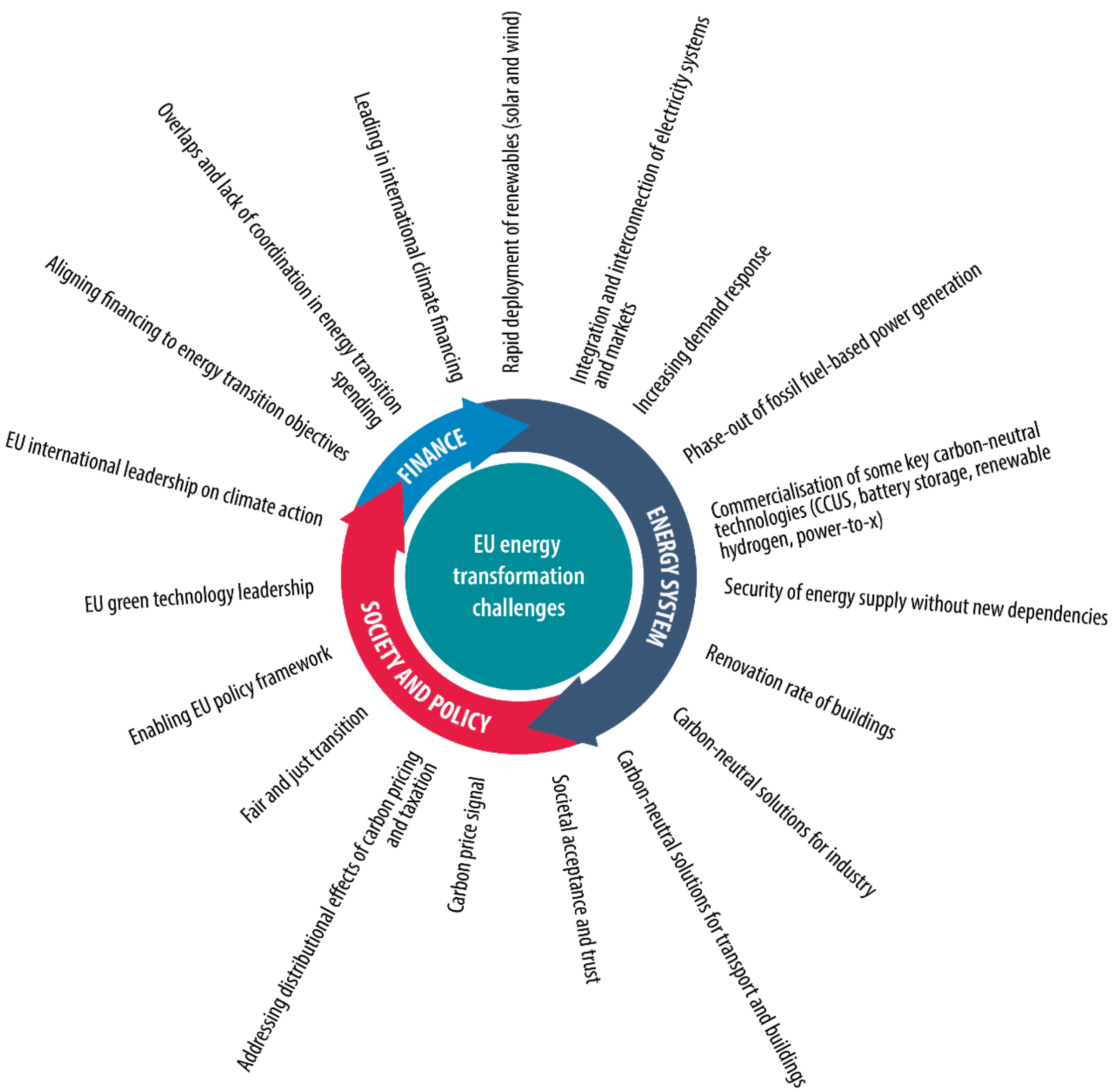
49 There is a general upward trend in EU citizens' support for the European Parliament to play a more important role, including with regard to 'measures to protect our environment and biodiversity' (32 %) and 'measures to develop renewable energy and reach carbon neutrality' (23 %). Kantar (2021), Parlemeter 2020: A Glimpse of Certainty in Uncertain Times. Eurobarometer Survey 94.2 of the European Parliament – A Public Opinion Monitoring Study. Directorate-General for Communication, Public Opinion Monitoring Unit, PE 689.219.

2. Key challenges and trade-offs of energy transformation

This chapter presents the challenges that are most relevant to cooperation and action at EU level. The selection is based on the findings of the study in Annex II, supplemented by a literature review.

Although the EU is at the forefront of the global energy transformation, many challenges and associated risks still lay ahead of it. EU GHG emissions coming from the energy system still constitute 80 % of all EU GHG emissions (similar to the levels in the rest of the world), EU energy production negatively affects the environment (e.g. water, air and land pollution), the EU is still the economic block that is the most strongly dependent on energy imports and has the highest energy prices in the world (Delbeke and Vis, 2016). Action will be needed to help resolve issues related to solidarity, security of energy supply, the internal energy market, competitiveness and innovation.

Figure 1 – Key challenges to EU energy transformation



Source: Prepared by the authors.

Key challenges can be identified within three dimensions of the energy transformation (Figure 1.):

- energy systems,
- society and policy,
- finance.

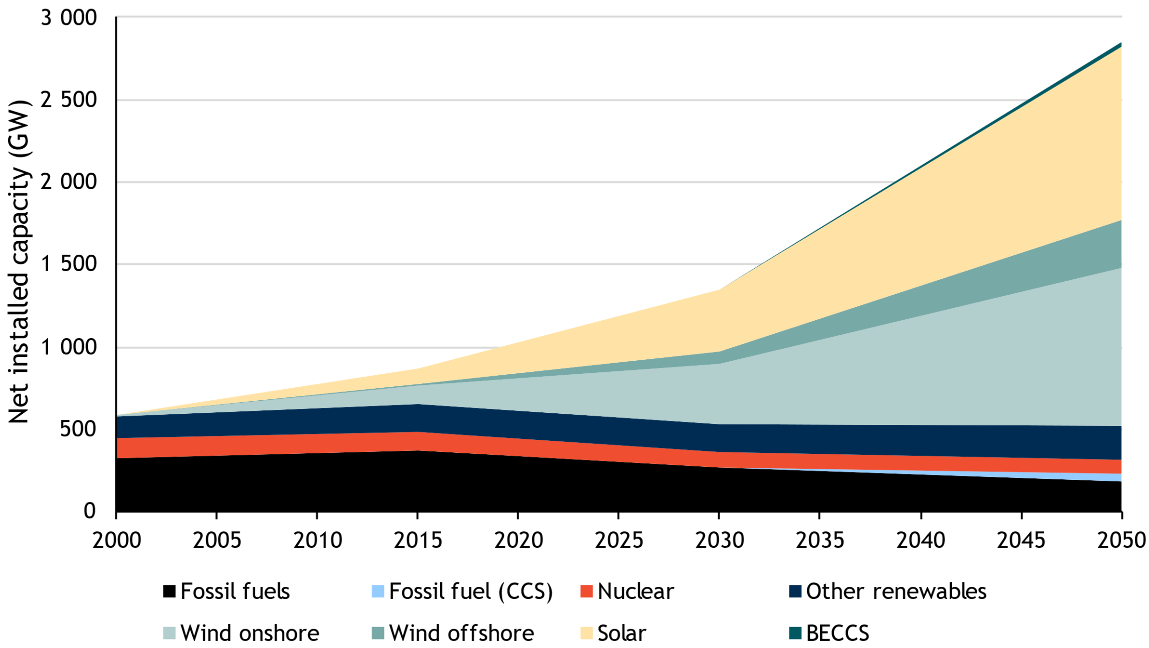
These key challenges are of an economic, societal, environmental and regulatory nature. At the same time, all three dimensions have enabling components that should be made use of, as these dimensions are interconnected and interdependent. If well designed, these enabling components could mutually reinforce each other and create a highly resilient framework ensuring a shock- and crisis-proof energy transformation.

2.1. Rapidly transforming the energy system to one that is carbon-free, smart, integrated and efficient

The main challenge before the EU energy system in the context of its deep transformation is to keep reducing GHG emissions and at the same time ensuring a **secure, reliable, integrated, affordable and sustainable energy supply**.

An EU decarbonisation pathway modelled in the annexed study foresees that by 2050, nearly 90 % of net installed electricity production capacity will come from renewables with over 87 % of it coming from wind (34 % onshore and 10 % offshore) and solar power (37 %) (Hoogland et al., 2021, Figures 2-6). This would double the share of renewables in power production capacity compared to actual shares in 2015 (see Figure 2.).

Figure 2 – Historical and projected EU27 net installed electricity production capacity by source (MIX55 scenario)



Data source: Hoogland et al., 2021, based on European Commission data.

The **massive deployment and integration of renewables to electricity is a regulatory and investment challenge in itself** (see Chapter 2.2 and 2.3 below), but it also impacts the reliability and security of the power system due to the variability of wind and solar energy supply. This can be balanced out to some extent by an increased power system flexibility and storage through use of interconnectors and grids, demand response and energy storage. All these solutions are expected to play an important role in decarbonising the electricity system and addressing problems such as the current losses occurring when renewable energy is in oversupply in comparison to the electricity grid's capacity. However, deployment of the necessary technology and infrastructure is slower than that of renewables (IEA, 2020). For example, electricity storage through batteries still requires support at the level of market formation and scaling-up.[50] It faces problems related to profitability, high technology costs and double application of grid tariffs and energy consumption taxes.[51]

Improving the cross-border integration of electricity systems and markets needs further action as the **10 % interconnection target by 2020 has still not been reached by eight Member States**.[52] As variable renewables (such as solar and wind) have relatively low capacity factors compared to conventional power plants, a substantial increase in transmission capacity will be needed to address the fluctuations in electricity supply.[53] Moreover, the limited capacity of the electricity grid can also be a barrier in the deployment of renewables, including the offshore grid that is necessary to accommodate offshore power generation. Another element that is expected to increase reliability, flexibility, integration and cost-effectiveness of a decarbonised energy system is demand response.[54] Nevertheless, **only 10-20 % of the achievable potential of demand response in the EU is currently realised**. Its development is hindered by insufficient financial incentives, in particular inadequate carbon pricing, system and market design barriers, and sometimes lack of consumer awareness.[55] A related challenge is to ensure at the same time 'a competitive market for **digital energy services** and **digital energy infrastructure** that are cyber-secure, efficient and sustainable'.[56]

In parallel with the shift to renewables, the EU will face a challenge of **phasing-out fossil fuel-based power generation**. Fourteen Member States have so far announced they will phase out coal-based generation,[57] but none has announced the phasing out of gas-based generation. This shift, together with some planned nuclear power phase-outs, is projected to increase gas-fired power generation in the EU.[58] The challenge of a clean energy transformation will be to progressively eliminate GHGs emitted from burning fossil fuels in order to achieve a net-zero carbon energy system by mid-century. Meanwhile, a rapid phase-out of fossil-fuelled power generation is still difficult, as running such power plants is economically viable, given that fossil fuels are relatively cheap (carbon prices have remained low for a long time and environmental damages have not been fully reflected in the prices, as pointed out by to Hoogland et al., 2021).

Strengthening carbon price signals across the whole economy, as well as **addressing its impact** on EU businesses, consumers and the competitiveness of the EU economy, will be some of the key

[50] The EU is already supporting the EU batteries sector through the European Battery Alliance. For a a detailed description of the challenges before energy transformation in energy supply and demand, see the study in Annex II, Hoogland et al., 2021, Chapter 2.

[51] For details, see Hoogland et al., 2021, Chapter 3.1.4.

[52] COM(2020) 950 final.

[53] See details in Annex II, Hoogland et al., 2021, Chapter 2.2.

[54] Demand response can be defined as 'the intentional modification of normal consumption patterns by end-use customers in response to incentives from grid operators.' Hoogland et al., 2021 following European Commission.

[55] For details see Hoogland et al., 2021, Chapter 3.1.7

[56] European Commission, Digitalising the energy sector – EU action plan.

[57] See Table 2 in Hoogland et al., 2021.

[58] IEA, EU 2020.

challenges. Moreover, some key carbon-neutral energy carriers (e.g. biogas, biomethane, advanced biofuels, renewable hydrogen) as well as other **enabling technologies** needed in the transformation of the energy system (e.g. CCUS, renewable hydrogen) are **not yet widely available** and will need to be scaled up. Technologies, such as carbon capture and storage (CCS), also face additional challenges, among them the availability of suitable geological sites and the potential lack of public acceptance (Erbach, G., 2021). Another challenge involves ensuring their cost-competitiveness; success in overcoming it will determine the speed of uptake. Moreover, relevant cross-border markets (e.g. for low carbon/renewable hydrogen) as well as dedicated infrastructure (e.g. cross-border infrastructure for hydrogen) will need to be developed.

Mitigating the potential **environmental externalities** of some of the above-mentioned carbon-neutral carriers and technologies will also be a challenge. There are concerns that increasing renewable power supply, despite the many benefits that it provides, 'could shift environmental burdens in ways that do not always lower overall pressures' (EEA, 2021). Moreover, there is still room for improvement in ensuring the sustainability of certain types of biomass used for bioenergy. As biogas and advanced biofuels are foreseen to substantially increase by 2050 in order for carbon neutrality to be reached, the availability of **sustainable biomass** will constitute a challenge and trade-offs specific for different type of biomass will have to be evaluated (Hoogland et al., 2021). Ensuring **sustainability** (that goes beyond a strict carbon-neutrality) in the whole supply chain of products, such as **batteries**, will also be challenging, because raw materials used for their production are often sourced without ensuring environmental and social protection (Erbach, G., 2021a; Szczepanski, M., 2020) and sometimes in countries with unstable governments or with little respect for fundamental rights.

In terms of security of supply, the EU, being the world's biggest energy importer, is highly exposed to energy price volatility and security risks related to producing and transit countries (Tagliapietra, S. and Zachmann, G., 2021). In the longer-term, the EU's very high import dependence on fossil fuels should be progressively decreasing with the decarbonisation of the energy system, yet **new supply dependencies** on third countries risk emerging (e.g. for lithium-ion batteries produced in China) unless more effort is put into diversifying supply and building independent value chains (Erbach, G., 2021a). This would be a challenge for the EU in the long run, as it aims to become a respected global player with some level of strategic autonomy, while at the same time avoiding the pitfalls of protectionist industrial policies.[59]

From the standpoint of energy end-use, the **uptake of low-carbon energy carriers and fuels** remains a challenge in most energy-consuming and GHG-emitting sectors such as industry, buildings and transport.[60] There is a wide consensus among experts and academics that energy efficiency measures and electrification will help decarbonise the buildings and the transport sectors. Improving **energy system integration** (sector coupling) also remains a challenge. Energy system integration involves creating an integrated network based on a renewable electricity grid that provides electricity to different sectors (industry, buildings, and passenger and urban transport).[61] It

[59] For more details on strategic autonomy and related energy issues, see: Anghel, S. et al., On the path to 'strategic autonomy'. The EU in an evolving geopolitical environment, Study, European Parliamentary Research Service, PE 652.096, September 2020.

[60] See details on challenges for energy demand identified for EU energy transformation in the study in Annex II, Hoogland et al., 2021.

[61] For details, see Erbach, G., Energy storage and sector coupling, Briefing, European Parliamentary Research Service, PE 637.962, June 2019.

is still underdeveloped, due to lack of interconnection capacity and sub-optimal use of the capacity available.[62]

One of the key challenges in the **buildings sector** is a **low rate of the renovations** needed for reducing energy consumption and for switching to low or carbon-neutral fuels and to solar-water heating and electricity generation (rooftop solar). The main obstructions to doubling the current 1 % annual rate of buildings renovations in the EU are high upfront costs, long payback methods and split incentives.[63] Another challenge for the sector is the **electrification** of buildings end-uses. Uptake of electric heat pumps – a key technology allowing the substitution of fossil fuel-burning heating systems with climate-neutral ones[64] – is still too slow. In many EU countries, it is still cheaper to heat buildings with fossil fuels than with this technology.

While a lot of progress on energy efficiency has been made (Erbach G., 2021), the acceleration of application of carbon-neutral technology remains a key challenge (Hoogland, O., et al., 2021). This has slowed down due to a **low clean technology readiness**, and **lack of competitiveness** compared to manufacturing technologies based on fossil-fuels,[65] lack of markets for 'green' products, lack of infrastructure e.g. to store and transport hydrogen and CO_2, difficulty of changing integrated industrial operations, and a risk of carbon leakage. Support for circularity in industrial production processes will be essential to reduce energy consumption and environmental impacts. Moreover, zero-emission technologies for heavy industry, which would make it possible to achieve the 2050 goal, are still under development and need an important push to become commercialised (IEA, 2021).

In the **transport** sector, **electrification** is the key challenge for passenger- and light-duty vehicles. One of the main problems of importance from an EU point of view is the lack of relevant **charging infrastructure** and the **lack of interoperability** of systems and equipment across the EU.[66] Heavy-duty road transport, navigation and aviation are transport modes that could be electrified only to a certain extent (for short distance travel). Decarbonisation pathways considered for these means of transport include hydrogen and synthetic fuels.[67] However, these **technologies are not yet market-ready** and there is a lack of regulatory pressure amplified by **tax exemptions** for some fossil fuels (e.g. kerosene for aviation).

The European Parliament has been advocating for addressing the different challenges that decarbonisation poses to the EU's energy market, energy security as well as addressing specific sectorial decarbonisation problems.[68]

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[62] See details in Chapter 3.1.6 of the study in Annex II, Hoogland et al., 2021.

[63] Other barriers to investments in energy efficiency at a socially optimal level include market failures triggered by imperfect information, positive externalities, and some 'behavioural' mistakes. See more in Erbach G., et al. (2021), EU climate action policy. Responding to the global emergency, Study, EPRS, March 2021.

[64] Assuming the electricity is 100 % GHG-free.

[65] For details on carbon-neutral industrial processes, see Hoogland et al., 2021, Chapter 3.1.11.

[66] For details on the electrification of passenger and light-duty vehicles, see Hoogland et al., 2021, Chapter 3.1.12.

[67] For details on carbon-neutral options for heavy-duty road transport, navigation and aviation, see Hoogland et al., 2021, Chapter, 3.1.13.

[68] European Parliament resolution of 15 January 2020 on the European Green Deal (2019/2956(RSP)).

2.2. Becoming a global leader of a sustainable, socially just and coherent energy transformation

The on-going energy system transformation, apart from confronting the challenges discussed above, has to be environmentally **sustainable, equitable and implemented in such a way as to not leave anyone behind**. Moreover, the European Green Deal sets an ambition of creating a more prosperous society with a modern, resource-efficient and competitive economy. These are considered the biggest challenges of the 21st century.

Societal acceptance as well as trust will be crucial enablers in this transformation and, if not present, can become a structural hurdle that would be difficult to overcome, creating deep societal divides and making the full realisation of climate transformation impossible. The IEA assesses that globally, over half of cumulative emissions reductions in the net-zero pathway 'are linked to consumer choices' (IEA, 2021). This means that the transformation cannot happen if there is no uptake of electric vehicles or if there are no investments in the retrofitting of houses with energy-efficient technologies or in the installation of heat pumps. While convergence in recent years has been a key achievement of EU integration, there are some worrying signs of a socio-economic divide in the EU.[69] To prevent further inequalities from appearing during the decarbonisation of the economy, several trade-offs will need to be addressed. According to different studies of impact, if the right policies are not put in place and discussed in an inclusive way, affordability problems will arise as carbon pricing, carbon taxation and heavy regulatory approaches will provoke an increase in the prices of fossil fuels that will have important social and distributional effects.[70]

It is expected that this will affect in particular the vulnerable groups of society, as proportionally they are the ones with the highest share of their income directed to basic housing, food and energy expenses. Although the share of the energy costs both in household spending and in production costs has been decreasing in recent years, the poorest European households still spend over 8 % of their total expenditure on energy, with this figure reaching up to 15-22 % in some central and eastern European countries.[71] Moreover, some EU countries are at the starting point of addressing **energy poverty** (or even recognising it), and there is a risk that without an ambitious and united push from the EU, a challenge of such a magnitude might not be solved through isolated actions by the Member States' national governments.[72] One of the most cost-efficient solutions to this problem could be to increase the very low rate of buildings renovation. Nevertheless, although some relevant regulatory and financial instruments have recently been adopted to ensure an increase in the energy efficiency of buildings (the Clean Energy Package,[73] the Renovation Wave[74] and the EU

69 Understanding the socio-economic divide in Europe. Background report, OECD Publishing, 2017.

70 For details, see: European Commission, Commission Staff Working Document Impact Assessment Report Accompanying the document Directive of the European Parliament and of the Council amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union, Decision (EU) 2015/1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading scheme and Regulation (EU) 2015/757, SWD/2021/601 final.

71 European Commission, Energy prices and costs in Europe, accessed at: https://ec.europa.eu/energy/data-analysis/energy-prices-and-costs_en.

72 https://caneurope.org/content/uploads/2021/01/Energy-poverty-report-_FInal_December-2020.pdf

73 https://www.europarl.europa.eu/news/en/headlines/society/20180216STO98004/six-new-rights-for-eu-electricity-consumers; https://www.europarl.europa.eu/news/da/press-room/20181217IPR21949/eu-deal-on-electricity-market-rules-to-benefit-both-consumers-and-environment

74 Communication from the Commission on a Renovation Wave for Europe – greening our buildings, creating jobs, improving lives, COM/2020/662 final, October 2020.

stimulus package[75]), the Member States' latest long-term renovation strategies seem not to be aligned with the EU objective of reaching net-zero GHG emissions by 2050. Therefore, the necessary acceleration of the annual building renovation rate from the current 1 % to 3 % of deep renovations by 2030 is unlikely to be achieved (Staniszek, D., 2021).

In view of phasing out fossil fuels from the EU energy system, **another socio-economic challenge is to ensure a just transformation** and to support communities whose livelihoods depend on fossil fuels and carbon-intensive industries. Affected regions will need to face unprecedented changes, as jobs will be lost and local economic activities will need to be rendered sustainable. Such changes take decades and the EU has an important role in supporting a just transformation through the cohesion funds. The EP recognised the need for EU-level action in this field already in 2018, when it put forward the idea of setting up a Just Transformation Fund, now a reality.[76] In the process of legislating on the Just Transformation Fund, the EP has also advocated for more ambitious measures, some of which have been adopted (Widuto, A., 2021). Nevertheless, the socio-economic transformation is a long-term challenge for the communities most vulnerable to its impacts and will need to be closely monitored and supported in the in the coming decades, well beyond the next EU budgetary period.

Behavioural change[77] will also be needed in the EU to shift energy consumption patterns and achieve the net-zero goal. Even though on a global scale changing behaviours would contribute to less than 10 % of GHG emission reductions overall,[78] it will be a very challenging endeavour as it requires public support and acceptance of changes to some established habits. Fossil fuel use in the transport sector is responsible for the largest share of GHG emissions, with housing emissions coming second (Oxfam and SEI, 2020). This confirms that transport mode-switching will be a key challenge for Europeans in the decarbonisation process. The EU has a global role and duty to act, as various analyses show that in relative terms, it is the richest[79] who consume the most energy among all income groups and consequently cause much more emissions (ETI, 2021; Oxfam and SEI, 2020). A risk exists that, if no action is taken, the spread of these **unsustainable consumption patterns** could, by 2030, 'eat up' the remaining carbon budget for a 1.5ºC global temperature rise.[80]

The current EU regulatory framework is not yet fit to deliver the 2050 net-zero target (and for this reason more ambitious legislative proposals were proposed by the Commission in July 2021). Apart from energy market gaps and barriers that still exist (mentioned in Chapter 2.1 above), an enabling regulatory environment should also be ensured for other activities. For example, in research and innovation (R&I) the **regulatory burden** should be lightened. According to the IEA, large corporate players remain reluctant to become involved in Horizon 2020 projects, due to the long timetables, bureaucracy and need to partner with organisations from at least two other Member States (IEA, 2020). Moreover, the EU also **lacks coherence in some of its climate and energy policies** (i.e.

75 https://ec.europa.eu/info/business-economy-euro/recovery-coronavirus/recovery-and-resilience-facility_en#example-of-component-of-reforms-and-investments.

76 European Parliament resolution of 14 November 2018 on the Multiannual Financial Framework 2021-2027 – Parliament's position with a view to an agreement (COM(2018)0322 – C8-0000/2018 – 2018/0166R(APP)).

77 'Behavioural change refers to changes in ongoing or repeated behaviour on the part of consumers which impact energy service demand or the energy intensity of an energy-related activity', IEA (2021).

78 IEA (2021) estimates in its net-zero in 2050 pathway (NZE) that 'a final 8% of emissions reductions stem from behavioural changes and materials efficiency gains that reduce energy demand, e.g. flying less for business purposes'.

79 People with a net income of over US$38,000, Oxfam and SEI (2021).

80 For more details on behavioural change and green transformation, see Meeting the Green Deal objectives by alignment of technology and behaviour, Study, European Parliamentary Research Service, Scientific Foresight Unit (STOA), PE 656.337 – July 2021.

between some EU policies and between EU and national policies).[81] This incoherence is one of the reasons why some sectors – such as transport, where the polluter pays principle is not fully applied – are underperforming in their decarbonisation efforts. As the current energy and climate regulatory framework is set to be revised towards more ambitious targets, its coherence will need to be ensured.

The EP has been calling for a transformation that ensures a prosperous, fair, sustainable and competitive economy.[82] It has been stressing that fighting energy poverty should continue to be a priority addressed with targeted measures. In its resolutions, it has also underlined the importance of policy coherence. Moreover, EU citizens seem to want the EP to play a more important role in relation to measures aimed at reducing poverty and social inequality.[83]

2.3. Aligning financing with energy transformation objectives

While providing an adequate level of financing to ensure a successful EU energy transformation is definitely a significant challenge, this challenge should be looked at in the context of long-term benefits that outweigh the short-term costs (IEA 2021; IRENA, 2018). The role of public finance is deemed to be key if the EU wants to ensure long-term sustainability and competitiveness (EIB, 2021). However, a challenging task for policymakers will be to ensure that the spending will be done in an effective and efficient manner so as to avoid the duplication of projects at Member State level and to avoid 'white elephant' projects. In particular there is a need to ensure that spending related to NGEU and the next MFF addresses the green transformation investment gap.[84] The challenge in particular for the EU will be to monitor and ensure that spending on reforms and investments by the Member States has a positive environmental impact as provided for in the Recovery and Resilience Facility Regulation.[85] Moreover, in the previous budgetary term, there were some inefficiencies and lack of coherence related to climate spending among the different EU instruments. This lack of coordination among the financial instruments at different levels – EU-national and EU-EU – should be avoided so as to ensure an optimal policy impact (Pellerin-Carlin et al., 2017).

Most importantly, financing along the whole innovation chain will be key in achieving EU energy transformation and maintaining EU green technology leadership as well as gaining it in new technologies and market shares. This is necessary because, as estimated by the IEA, nearly 50 % of emissions reductions needed to achieve net zero by 2050 depend on technologies that are **not yet commercialised** (IEA, 2021). Meanwhile, there is a **growing gap in EU investment in R&D**, which is critical for climate mitigation. The level of EU investment until now has been insufficient to achieve the current 2030 emissions reduction target as well as the more ambitious goal of 55 % GHGs reduction by 2030 (EIB, 2021; European Commission, 2020b). While being ranked among the top

81 For more details on policy coherence and EU climate action, see Erbach, G., et al. (2021), Chapter 3.

82 European Parliament resolution of 15 January 2020 on the European Green Deal (2019/2956(RSP)).

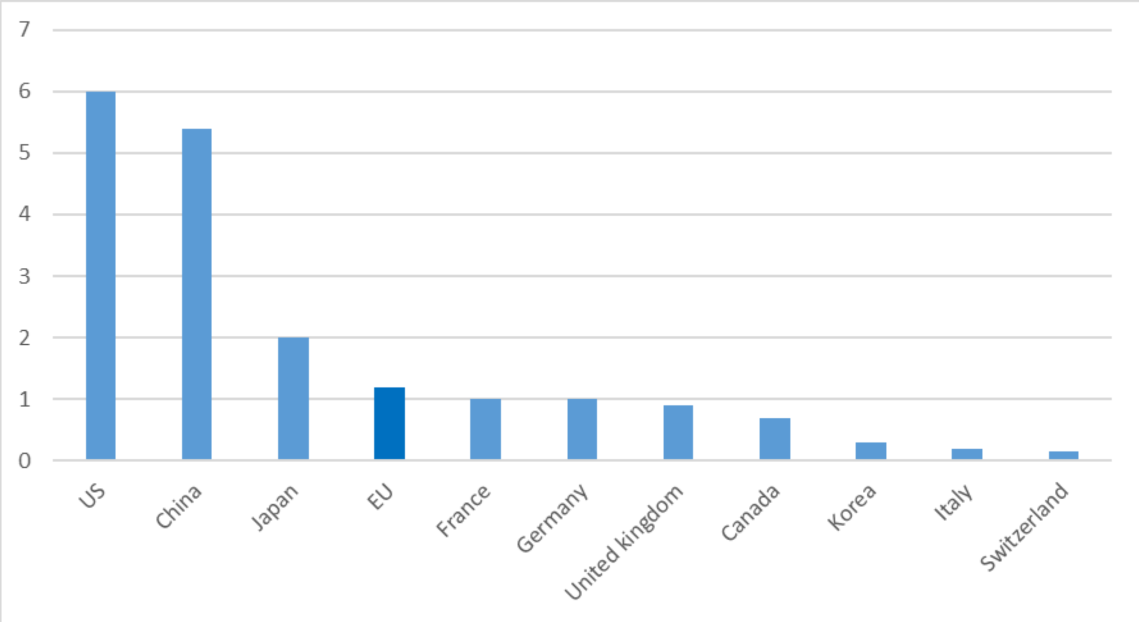
83 48 % of consulted EU citizens think this should be the main priority of the European Parliament, according to Parlemeter 2020: A Glimpse of Certainty in Uncertain Times.

84 Regarding the European Commission estimates on the green transformation investment gaps up to 2030, see Commission Staff Working Document, Identifying Europe's recovery needs, Accompanying the document Communication on Europe's moment: Repair and Prepare for the Next Generation – COM(2020) 456 final, SWD(2020) 98 final, 27.05.2020.

85 Spending should not lead to 'significant harm to environmental objectives', as provided for by Article 17 of the Taxonomy Regulation (EU) 2020/852.

global spenders in energy R&D (see Figure 3), the EU did not achieve its overall R&D spending objective[86] (a 3 % GDP EU target and 2 % of GDP for business) by 2020.

Figure 3 – Energy-related R&D spending (€ billion)



Source: IEA, 2019.

Moreover, despite the fact that EU R&D funding (EU Horizon Europe framework programme) for 2021-2027 is higher than in the previous programme (Horizon 2020), it is lower by a third compared to what the European Parliament as well as academia advocated for as necessary to meet the EU objectives (Pari, M., 2021; EUA, 2020). Additionally, the EU is at a different stage of the process of decarbonising its economy than it was a decade ago and current investments will no longer target the 'low hanging fruit' but the '**harder-to-reduce-emissions**' (EIB, 2021).

At the same time, the EU's competitors are still leading the race for high-quality universities, registration of patents and research outcomes, including sometimes in areas key for energy transformation such as batteries, digital hardware and software. The EU has recently launched a series of initiatives[87] in these areas and has already taken the lead in some competitive technological areas, such as wind power and the transport industry. Nevertheless, a risk exists that the EU will be left behind on green energy patenting. According to a World Intellectual Property Organization analysis, while green innovation is emerging all over the world, only a few countries account for the vast majority of applications (see Figure 4.). Of the top 10 countries, all except China, the Republic of Korea and Denmark experienced a decline in the number of patent applications between 2013 and 2019.[88] The growth of Chinese Patent Cooperation Treaty (PCT) filings in the field has been

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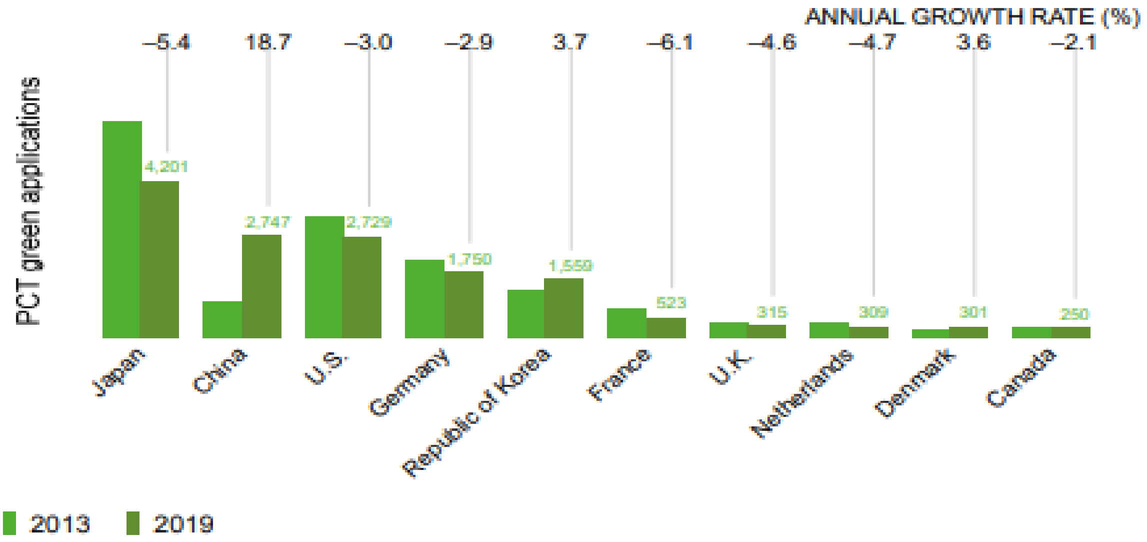
[86] In March 2000, the European Union set itself an ambitious goal to become, by 2010, 'the most competitive and dynamic knowledge-based economy in the world', what later became known as the Lisbon strategy. Leveraging investment in R&D became a key element of this strategy following the March 2002 Barcelona European Council's objective to raise overall R&D investment to 3 % of GDP by 2010. https://www.consilium.europa.eu/ueDocs/cms_Data/docs/pressData/en/ec/00100-r1.en0.htm.

[87] European Commission communication on Criteria for the analysis of the compatibility with the internal market of State aid to promote the execution of important projects of common European interest, OJ C 188, 20.6.2014, pp. 4-12.

[88] https://www.wipo.int/pressroom/en/articles/2020/article_0007.html and Annex 1: https://www.wipo.int/export/sites/www/pressroom/en/documents/pr_2020_851_annex.pdf.

extraordinary in most green energy technologies. Notably, China has become a world leader in the patenting of green transportation technologies in recent years, which should be a source of renewed commitment for the EU to invest in this area given the importance of this sector for the EU economy.

Figure 4 – Green patenting applications, annual growth rate



Source: WIPO IP Statistics Database applying the WIPO International Patent Classification (IPC) Green Inventory.

The European Parliament supports an ambitious level of financing that would help to close the EU investment gap, help finance the transformation to a carbon-neutral economy and ensure a just transformation across all EU regions.[89] It has advocated for more ambitious spending on climate from **the EU budget (at a level of 30 %)** and for a 'green' recovery from the coronavirus pandemic. It has furthermore backed the European Commission plan to mainstream climate (and environmental) concerns in recovery initiatives[90] and emphasised that EU expenditure to realise the objectives of the European Green Deal has to be increased and generate European added value.

[89] European Parliament resolution of 15 January 2020 on the European Green Deal (2019/2956(RSP)).

[90] Resolution of 15 May 2020 on the new multiannual financial framework, own resources and the recovery plan, European Parliament; Resolution of 23 July 2020 on the conclusions of the extraordinary European Council meeting of 17-21 July 2020, European Parliament.

3. Evaluating the cost of non-Europe: Benefits of united and ambitious EU action

The Green Deal for Europe embodies the EU's ambition to contribute to keeping our planet healthy and to become the first carbon-neutral continent in the world by 2050. Europe's citizens continue to call for stronger climate action and effective results, in line with the Paris Agreement goal of keeping global temperature increase well below 2°C and pursuing efforts to limit the increase to 1.5°C. Given the large environmental, economic and social impacts of the choices that have to be made, it is crucial to have a scope of analysis as broad and extensive as possible and not to rely on the result of one single model. Therefore, the information presented in this chapter complements the results of the study in Annex II with a series of analyses looking at estimates provided by other prominent macroeconomics models. The estimates derived from these results are then used to compute the CONE.

3.1. Climate neutrality is not achievable with a fragmented approach

Building on the climate target plan[91] adopted in September 2020, the study in Annex II provides a complete and detailed analysis of the potential impacts of different decarbonisation paths for the EU energy system up to 2050. Chapter 3.1 analyses these results, focusing more specifically on the environmental impacts of various scenarios and on energy-related emissions. The baseline scenario used corresponds to the EU reference (REF.) scenario of July 2021,[92] which updates the previous version published in 2016.[93] The results are then compared[94] with a scenario of more ambitious and united EU action leading to a 55 % cut of GHG emissions by 2030 and net-zero emissions by 2050 (MIX55).[95] Two fictional scenarios are also included to illustrate the potential benefits and the global leading role of the EU in this area.

3.1.1. The environmental benefit of an ambitious and united EU approach toward reaching net zero

The results of the study in Annex II (see Figure 5 below) clearly show that the **target of net zero by 2050 will not be achieved without an ambitious and united EU approach**.

[91] European Commission, report on Stepping up Europe's 2030 climate ambition. Investing in a climate-neutral future for the benefit of our people, COM/2020/562 final, September 2020.

[92] European Commission, EU reference scenario 2020 – Energy, transport and GHG emissions: trends to 2050, July 2021. The reference scenario (REF.) is a projection based on the future developments of the EU energy system, transport system and greenhouse gas GHG emissions. This scenario acts as a benchmark for new policy initiatives. It reflects policies and market trends used by policymakers as a baseline for the design of policies that can bridge the gap between where EU energy and climate policy stands today and where it aims to be in the medium- and long-term, notably in 2030 and 2050.

[93] The study in Annex II uses REF2016 as a reference scenario because its manuscript was completed before the publication of REF2020 and before the publication by the European Commission of the 'Fit for 55' package of proposals on 14 July 2021.

[94] The reference scenario builds on EU and Member State policies. The scenario concerns the EU energy, transport, and climate acquis as of the end of 2019. National policies accounted for in the reference scenario include the main ones laid out in the national energy and climate plans (NECPs) and in other national plans put forward as of end-2019.

[95] This corresponds to the MIX55 scenario in the study in Annex II. MIX55 is an extension of the MIX scenario in the European Commission impact assessment. It combines regulatory and carbon pricing instruments that realise 50-55 % GHG emissions reductions by 2030 and net-zero emissions by 2050.

Furthermore, complacency coupled with a fragmented approach would always be the most costly from an environmental point of view as the target of limiting global temperature rise to +1.5°C would be out of reach without more ambitious EU action. The IPCC in its latest report[96] analyses a set of new scenarios at global level to explore the climate response to a broader range of GHGs (see Figure 5 below). It shows that it is only under the very low GHG emissions scenario,[97] which for the EU would means achieving net zero by 2050, that the +1.5° target would be 'more likely than not to be reached'. In a worst-case scenario, where the response of the EU and the international community would remain fragmented, the IPCC even concludes that the temperature could increase by between 3.3 to 5.7° in the long run.[98]

According to the calculations made in this report, without ambitious EU action and using the reference EU action scenario as a baseline,[99] a reduction of around 47 % of GHG energy-related emissions would be achieved at best in 2050 compared to 2020 (i.e. 1 193 million tonnes versus 2 255[100] million tonnes of GHG emissions). As this scenario encompasses all the measures already implemented at EU and Member State level from 1990 to 2019, one could conclude that the results from a fragmented approach at Member State level would be even more dismal. To illustrate this point, this report recomputes **two additional fictional counterfactual scenarios**.

The first scenario – NO COOP – corresponds to a situation of non-cooperation at EU and international level. Here, EU emissions from 1990 are recomputed as if they had evolved at the same pace as the emissions for the OECD as a whole.[101] From 2020 onwards, the authors of the report simply compute a prolongation of the past trend up to 2050. The second scenario – FRAG – corresponds to insufficient EU action, where the fight against climate change would mostly occur in a fragmented and loosely coordinated way at Member State level. For that purpose, the authors of the report simply assume that from 2021 onwards the EU's energy-related emissions grow in the same way as the OECD's, based upon the prolongation of the past trend until 2050. Emissions between 1990 and 2020 are assumed to be at the same level as past EU emissions.

The results obtained for the two scenarios suggest that a non-cooperative approach (NO COOP scenario) would have resulted in 59 % more emissions in 2020 than what was observed (3 590 million tonnes versus 2 255 million tonnes of GHG emissions). These results also suggest that insufficient EU action coupled with a mostly fragmented approach (FRAG scenario) would achieve a reduction in energy-related emissions of around 2 % in 2050 compared to 2020 (2 045 million tonnes versus 2 255 million tonnes of GHG emissions).

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96 IPCC, Sixth assessment report, 2021.

97 Called SSP1-1.9.

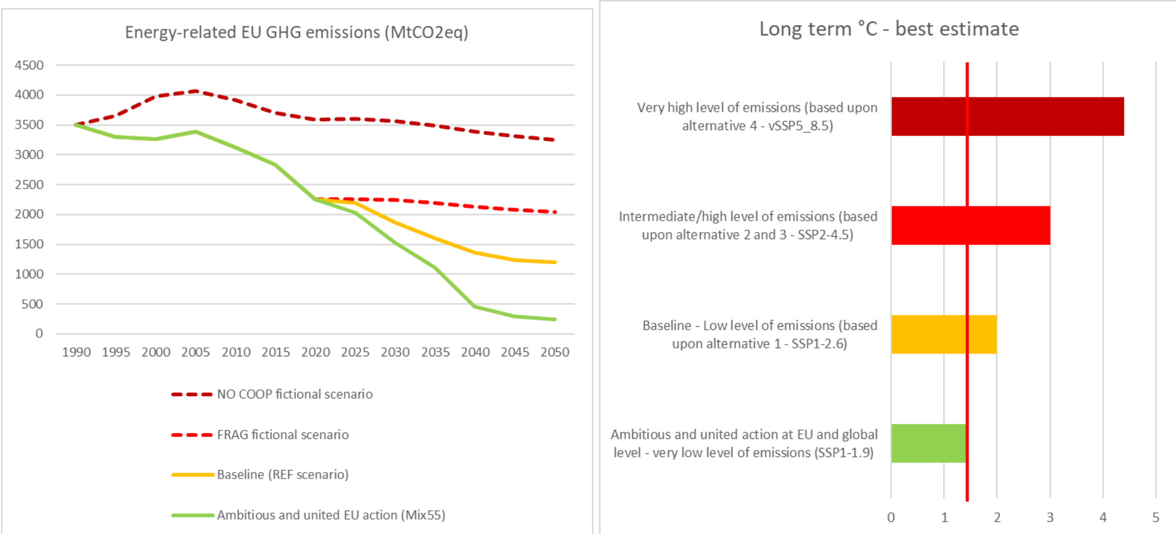
98 Potential impact at the 2081-2100 horizon.

99 The data corresponding to the July 2021 update of the REF scenario can be found here.

100 See European Commission, EU reference scenario 2020 – Energy, transport and GHG emissions: trends to 2050, July 2021.

101 In total, OECD members increased their emissions by 2 % from 1990 to 2019, while the EU reduced its emissions by more than 30 % during the same period. The data for the evolution of GHG emissions for the OECD are taken from the IEA.

Figure 5 – Potential adverse environmental impact of complacency and fragmentation



Data source: Authors' own calculations based on data from Hoogland et al., 2021, IEA, 2021a and IPCC, 2021.

Compared with other scenarios, ambitious and united EU action (MIX55 scenario) therefore constitutes the best path towards achieving the climate goal of net zero by 2050 (see Table 1). In five years (from 2021 to 2025), it would have already yielded a reduction of 168 million tonnes (Mt) of GHG emissions compared to the baseline REF scenario and 237 MT of GHG emissions compared to the FRAG scenario. In 2050, the difference is even more substantial: at **944 MT of GHG emissions reduction compared to the baseline REF scenario** and 1 795 MT of GHG emissions compared to the FRAG scenario. The modelling results of the study in Annex II showed that the extension of carbon pricing through the EU ETS to other sectors that are not currently covered by the EU ETS plays a substantial role. Without an extended EU ETS, a substantial gap in reaching net zero GHG emissions, of around 50 million tonnes of GHG emissions by 2050, would be observed. Similarly, additional MFF and NGEU funding will also have a significant impact, contributing to a reduction of roughly 50 million tonnes of GHG emissions by 2050.

Table 1 – Environmental benefit of ambitious and united EU action (MIX55 scenario), MT CO_2eq reduced per year compared to the baseline (2020)

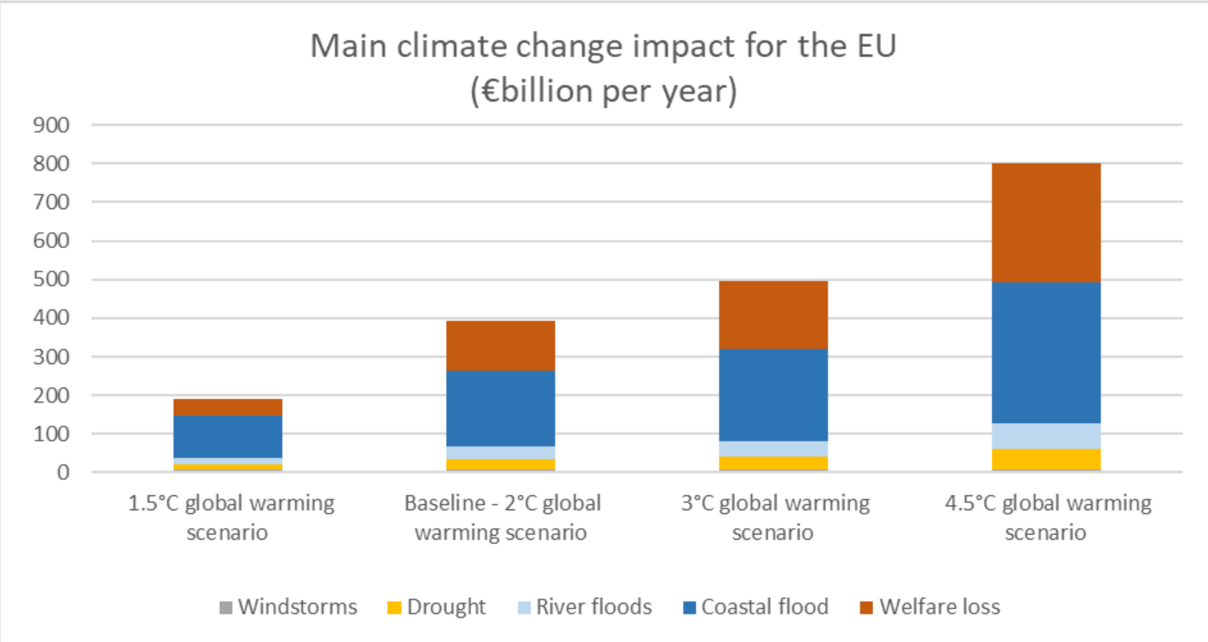
Year	2021	2022	2023	2024	2025	2030	2040	2050
difference with NO-COOP scenario	-1 384	-1 432	-1 480	-1 528	-1 576	-2 041	-2 940	-3 006
difference with FRAG scenario	-47	-95	-142	-190	-237	-716	-1 678	-1 795
difference with REF scenario (baseline)	**-34**	**-67**	**-101**	**-134**	**-168**	**-348**	**-908**	**-944**

Source: Authors' own calculations based on data from Hoogland et al., 2021, IEA, 2021a and IPCC, 2021.

3.1.2. An ambitious and united EU approach also increases welfare and reduces the cost of climate change-related potential damages

As stressed on numerous occasions by the IPCC, failure to rapidly engage in tackling climate change and in implementing measures to reach net zero in 2050 would lead to a disastrous environmental impact both for the EU and the rest of the world. A previous EPRS report[102] estimated that the related monetary costs of such complacency would also be substantial, at around €160 billion per year for the EU as a whole. Recently, the Joint Research Centre of the European Commission (JRC) has provided a comprehensive updated evaluation of the environmental consequences of non-Europe in this area in its projection of the economic impacts of climate change in sectors of the EU based on a bottom-up analysis (PESETA project).[103] Under this project, impacts are computed for various warming targets for the EU and they grow with the intensity of global warming.[104] Building on these results, the authors of this report estimated the losses corresponding to the best temperature estimate in the various scenarios highlighted in Figure 6 below. Exposing the economy to a global warming of 4.5°C would result in an annual welfare loss of approximatively €308 billion. Under a 2°C scenario the welfare loss would be €130 billion per year, while limiting global warming to 1.5°C would reduce welfare loss to €42 billion per year. The effective realisation of ambitious and united EU action would thus be beneficial, yielding welfare gains of potentially €89 billion per year compared to the baseline reference scenario.

Figure 6 – Environmental costs of a lack of ambitious and united EU action (2020-2100)



Data source: Authors' own calculations based on JRC PESETA data.

Interestingly, in addition to the effects on welfare, the assessment by the JRC includes the effects on a series of adverse climate-related events. Building again on these results and assuming a linear increase in costs in line with the increase of temperature, the authors of this report estimated the

[102] Teasdale, A., (editor), Europe's two trillion euro dividend: Mapping the Cost of Non-Europe, 2019-24. European Parliamentary Research Service, European Parliament, April 2019.

[103] JRC, PESETA IV, projection of economic impacts of climate change in sectors of the EU based on bottom-up analysis, 2020.

[104] PESETA integrates climate scenarios, socio economic analysis and biophysical process simulation.

corresponding impacts for various levels of temperature. The results are consolidated and summarized in Figure 6 above. Under a 1.5°C global warming scenario and compared to a 2°C global warming scenario used as a baseline, there is a significant increase in the damages related to coastal flooding (from €110 billion to €195 billion), river floods (from €16 billion to €32 billion), droughts (from €16 billion to €29 billion), while the impact of windstorms remain significant (at around €6.8 billion in both scenarios). Taking all the impacts into consideration, this analysis constitutes a **powerful justification for ambitious and united action, as the total environmental benefit, including welfare gains, would be around €203 billion per year on average for the period 2020-2100 compared to the baseline reference scenario**.

More broadly, and assuming that damages will grow in line with the total sum of emissions over the 2020-2050 period,[105] the authors of the present report computed the potential monetary benefits of a scenario of ambitious and united EU action compared to the other alternatives until 2050 (see Table 2). These results further emphasize the large potential cost of insufficient action and fragmentation, with a potential averted environmental damages cost of €305 billion per year for the FRAG scenario and even up to €610 billion in the case of the most extreme NO COOP scenario. These results are broadly in line with the consensus in the literature,[106] where the economic costs of climate change impacts have been estimated to stand in the range of 1 % to 3.3 % of global GDP by 2060, which for the EU would correspond to around between €120 billion and €420 billion.

Table 2 – Estimated monetary benefits (averted environmental damages cost (€ billion per year and % of GDP) with ambitious and united EU action, year compared to baseline (2020)

Year	2021	2022	2023	2024	2025	2030	2040	2050
difference with NO-COOP scenario	97	147	197	248	299	355	480	610
difference with FRAG scenario	41	62	83	106	129	157	227	305
difference with baseline (€ billion per year)	34	52	70	88	107	125	163	203
difference with the baseline (% GDP)	**0.3%**	**0.4%**	**0.6%**	**0.7%**	**0.8%**	**0.9%**	**1.0%**	**1.1%**

Data source: Authors' own calculations based on JRC PESETA data.

3.2. Climate-related EU budgetary action could bring substantial benefits

The budgetary impacts of the transformation to net zero have to be understood clearly, particularly as some Member States are already facing extremely challenging fiscal positions and therefore

[105] This is naturally a crude assumption, which serves to illustrate the potential negative impact associated with each path.

[106] See OECD, Innovation and Business/Market Opportunities associated with Energy Transformations and a Cleaner Global Environment, Issue Paper Prepared by the OECD as input for the 2019 G20 Ministerial Meeting on Energy Transformations and Global Environment for Sustainable Growth, February 2019.

would be unable to sustain additional investment and spending in the medium term.[107] Therefore, the section below examines how the sustainable Europe investment plan (the financial arm of the European Green Deal) will address these challenges. It also assesses how EU budgetary action could prove fruitful in this regard, in particular through the MFF and the recently adopted NGEU.

3.2.1. EU-led sustainable investment plan on net-zero emissions in 2050

The transformation towards net zero will require a large structural transformation of the EU economy in a relatively short period of time considering the size of the challenge and the fact that since 1997, when the Kyoto Protocol was adopted, only the easiest and least costly part of the transformation has been achieved.[108] Regarding investment needs, estimation varies greatly depending on the type of model used, on the climate objective taken as a reference and the time horizon selected for the estimation. In a recent review of existing results the IMF[109] concluded that the additional cumulative investment needs for the next two decades could amount to a cumulative €9 trillion to €14 trillion globally, with around 30 percent of the required investment coming from public sources and 70 percent from private sources. A comprehensive study[110] reviewing the results of the six main global modelling frameworks showed that pursuing the 1.5°C target demands a marked up-scaling in low-carbon capital beyond that of a 2°C consistent future. On average for Europe, the study concluded that between €114 billion and €354 billion per year would be needed for the transformation until 2050. This represents an average potential cumulative investment need of almost €7 trillion over the period. The European Commission[111] assessed the financing needs related to the current climate mitigation and energy 2030 targets at €340 billion per year, representing €3.4 trillion in the next 10 years. According to the IMF, these estimates may however be conservative, as other results[112] suggest that, on average, additional investment of about €1.1 trillion a year could be required over the next 30 years to decarbonize the world economy, of which €0;9 trillion would be needed in the power sector. Another study[113] estimated that annual investment in the energy sector alone will need to rise from about €1.2 trillion today to somewhere between €2.2 trillion and 4€ trillion on average over the next three decades.

As highlighted by the IEA in its report on the EU,[114] the economic consequences of such a deep structural transformation are going to be profound and should certainly not be underestimated. At the same time, large opportunities are already emerging and will continue to emerge. It is therefore key to ensure that EU businesses continue to be at the forefront in this area and to avoid the fragmented and costly approach pursued, for instance, in some areas related to the digital

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107 Unless the EU fiscal framework under the Stability and Growth Pact is substantially revised, which at present does not seem to be favoured by some Member States.

108 Enerdata, global energy trends, 2021 edition.

109 IMF, Investment needs fostering the transition to a green economy, Chapter 3, Global Financial Stability Report, October 2021

110 McCollum, David L., Wenji Zhou, Christoph Bertram, Harmen-Sytze de Boer, Valentina Bosetti, Sebastian Busch, Jacques Després, et al. 2018. "Energy Investment Needs for Fulfilling the Paris Agreement and Achieving the Sustainable Development Goals." Nature Energy 3 (7): 589–99.

111 European Commission, Commission Staff Working Document, Identifying Europe's recovery needs, Accompanying the document Communication on Europe's moment: Repair and Prepare for the Next Generation – COM(2020) 456 final, SWD(2020) 98 final, 27.05.2020

112 See for instance Energy Transitions Commission, "Making Mission Possible—Delivering a Net-Zero Economy." September 2020.

113 BloombergNEF."'New Energy Outlook 2021', July 2021.

114 IEA report on the EU, 2021.

transformation.[115] The potential economic gains for the leaders and the innovators in the area of green technologies are going to be sizeable, with a demand at global level. For the EU, this means that the current first-mover advantage that it has secured itself in some sectors should continue to be reinforced, and research in the areas linked to the green transformation should be boosted.

To reply to these concerns and as part of a recovery strategy following the coronavirus pandemic, the newly adopted **NGEU and the 2021-2027 MFF** provide a strong response to the shortage of public funding and public investment in some Member States. Climate mainstreaming in the MFF will ensure the bulk of resources, while the data show that NGEU is expected to play a major role in boosting climate-relevant expenditure (D'Alfonso A., 2021). In this respect, the final agreement on 2021-2027 EU finances raised the overall objective of climate mainstreaming from 20 % in the previous programming period to at least 30 % and the target applies to both the MFF and NGEU. In absolute figures and considering only the amounts corresponding to the scope of this report (see Figure 7), the EU mobilised more than €590 billion [116] of budgetary resources for the coming period. This amount is composed of i) a temporary contribution of €268 billion from NGEU and ii) of what could be considered as a more permanent contribution[117] of €326 billion from the MFF, or around €47 billion per year up to 2050.

Within the 2021-2027 MFF, various items could be regrouped under headings that will then be useful in assessing these items' macroeconomic impact. The first heading regroups the main investment-related items, namely the Connecting Europe Facility (CEF), the LIFE programme (Programme for environment and climate action) and the Invest EU Fund, with a total of €130 billion [118] or around €18 billion per year. The second heading regroups the cohesion items, namely the Cohesion Fund, the European Regional Development Fund (ERDF), the Recovery Assistance for Cohesion and the Territories of Europe package (REACT EU) and the Just Transformation Fund, with a total of €156 billion or around €22 billion per year. The third heading regroups funding directly related to supporting R&D, namely Horizon Europe and ITER, with a total of €39 billion or around €5.6 billion per year.

Finally, considering the scope of this report, which primarily focuses on energy systems, the two remaining headings – on common agricultural policy and fisheries, and cooperation and assistance – are not included in the calculations. Although this separation is not always clear-cut and some programmes might also have investment, R&D and cohesion impacts, a detailed evaluation of each programme is beyond the scope of this report.

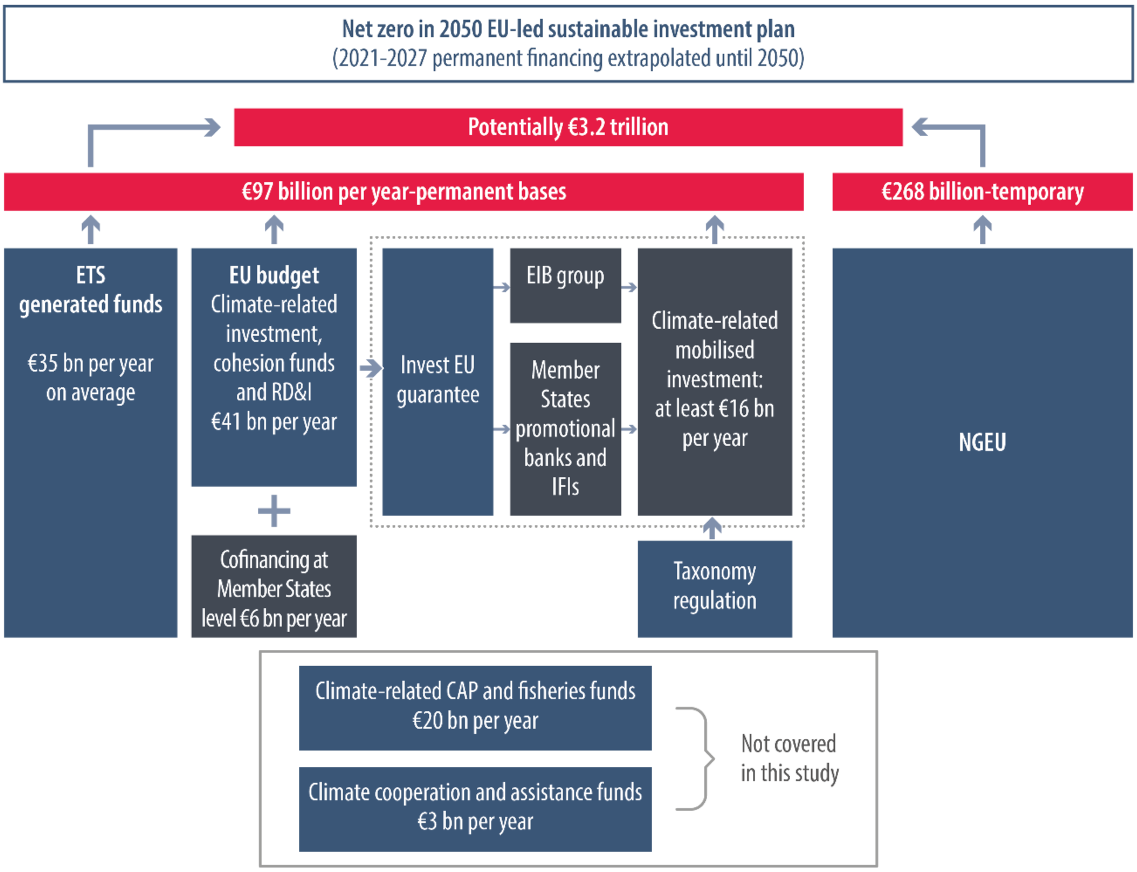
[115] The cost of non-Europe in the digital area could be estimated at around €118 billion per year. See Teasdale, A., (editor), 2019, op. cit.

[116] This does not take into account the amount generated through the ETS, MFF spending on the CAP and fisheries and on international cooperation and assistance.

[117] It is indeed likely that the MFF will be renewed in the future, although the amount might vary and the composition could naturally be altered, in particular if new programmes are added. The purpose here is to evaluate the impact of the current proposal, as by definition the content of future MFF agreements is not known in advance.

[118] Amounts taken from D'Alfonso A. (2021).

Figure 7 – EU-led sustainable investment plan



Source: EPRS.

3.2.2. Evaluating the impact of climate-related EU budgetary action

A series of macro-modelling exercises have already been conducted to assess the potential impacts of EU budgetary action. In this section, we start by reviewing the literature and by computing the results for the NGEU headings related to spending on climate; for climate-related investment in the MFF; and for climate-related R&D spending in the MFF. One key difference between NGEU and the MFF is that NGEU is supposed to be temporary. It should therefore be treated as a temporary shock in the various models. A recent paper by the ECB[119] provides a detailed analysis of the macroeconomic impact of NGEU and compares the results of simulations done by two different models, – EAGLE[120] and ECB-base[121] – and with the basic model elasticities (BMEs) of the forecasting models in use in the national central banks of the Eurosystem. Another simulation exercise was carried out by the European Commission using the QUEST model.[122] As described in Figure 7 above,

[119] Bańkowski K., Ferdinandusse M., Hauptmeier S., Jacquinot P., Valenta V., 2021. The macroeconomic impact of the Next Generation EU instrument on the euro area, Occasional Paper Series 255, European Central Bank.

[120] EAGLE is an ECB large dynamic stochastic general equilibrium (DSGE) model of the euro area and global economy that has been adapted to reflect the modalities of the NGEU instrument.

[121] ECB-BASE is an ECB semi-structural model.

[122] QUEST is a dynamic stochastic general equilibrium (DGSE) model developed by the European Commission. See European Commission, European Economic Forecast, institutional paper 136, November 2020 and European Commission, Identifying Europe's recovery needs, SWD(2020) 98 final, May 2020.

only a certain proportion of NGEU will be directed towards spending related to the green transformation. The authors of the present report have therefore recalibrated the results so that they correspond to the climate part of the funds (representing €268 billion) within NGEU. Finally, they recall the results obtained with E3ME[123] in the Annex II study. The results are presented in Table 3.

Table 3 – Macroeconomic impact (% GDP difference with the baseline) of climate-related spending in NGEU (temporary spending of €268 billion), year compared to baseline

Year	2021	2022	2023	2024	2025	2030	2040	2050
E3ME	0.1	0.1	0.2	0.2	0.3	0.0	0.0	0.0
BMEs	0.1	0.3	0.5	0.6	0.5	0.0	0.0	0.0
ECB base	0.1	0.3	0.4	0.5	0.6	0.2	0.2	0.2
Eagle	0.2	0.2	0.3	0.4	0.6	0.5	0.4	0.4
Quest	0.5	0.7	0.8	0.8	0.5	0.4	0.4	0.4
Average	**0.2%**	**0.3%**	**0.4%**	**0.5%**	**0.5%**	**0.2%**	**0.2%**	**0.2%**

Data source: Authors' own calculations based on ECB, European Commission and E3ME data from Hoogland et al., 2021.

All models confirm a positive and significant impact on GDP for the NGEU horizon. The direct effect of NGEU climate-related spending will be particularly important in the 2021-2025 period. In the long run, on average, climate-related spending in NGEU is expected to boost EU potential GDP by around +0.2 % and the effect is the strongest under EAGLE and QUEST (+0.4 %). The main differences arise from the differences in the modelling assumptions and from the specific characteristics of each model.[124]

Regarding **investment and cohesion funds in the MFF,** a number of modelling exercises have also already studied the potential macroeconomic impact in detail. An earlier study by the European Commission[125] using the QUEST model analysed the effects of various government budgetary interventions. It simulated the impact of a tax-financed[126] permanent increase in government investment. The ECB,[127] using the EAGLE model, conducted a series of similar simulations. The EIB, using the Rhomolo model,[128] also conducted an evaluation of the long-term impact of its investment activities[129] and more specifically of the funds invested under the European Fund for Strategic

[123] E3ME is a macroeconomic model that integrates a range of social and environmental processes. See Cambridge Econometrics, E3ME Technical Manual v6.1, 2019.

[124] For more detailed explanations on the assumptions, characteristics and specificities of each ECB model for this exercise, see Bańkowski et al, 2021, op. cit. For QUEST, see European Commission, 2020, op. cit. For E3ME, see Cambridge Econometrics, E3ME Technical Manual, Vol. 6.1, 2019.

[125] Roeger W., and In't Veld J., Fiscal policy with credit constrained households, European Commission, January 2009.

[126] The impact might vary depending on which type of funding is used to finance the investment, with a higher long-term impact for debt- and government consumption-financed investment. Our results could therefore be considered a prudent estimate.

[127] De Jong J., Ferdinandusse M., Funda J., Vetlov I., The effect of public investment in Europe: a model-based assessment, ECB Working Paper Series, 2017.

[128] RHOMOLO is the spatial computable general equilibrium model of the European Commission focusing on EU regions. See Lecca, P., Barbero Jimenez, J., Christensen, M., Conte, A., Di Comite, F., Diaz Lanchas, J., Diukanova, O., Mandras, G., Persyn, D. and Sakkas, S., RHOMOLO V3: A Spatial Modelling Framework, 2018.

[129] EIB, Assessing the macroeconomic impact of the EIB group. Economics – Impact Studies. European Investment Bank, June 2018.

Investment (EFSI).[130] The present report uses these results to derive an average estimate of the potential impact of climate-related investments. Its authors assume that investment and cohesion funds will have a permanent character. They furthermore also assume a unique multiplier and always refer to the central modelling scenario. Moreover, as described in Figure 7 above, only a certain percentage of MFF investment and cohesion funds will be directed towards the green transformation. The authors of the present report therefore recalibrate the existing results so that they correspond to the climate part of investment in the MFF (representing €130 billion per financial period or around €41 billion per year on average). The results are presented in Table 4.

Table 4 – Macroeconomic impact (% GDP difference with the baseline) of climate-related investments and cohesion funds in the MFF (permanent investment of €41 billion per year on average), year compared to the baseline (2020)

Year	2021	2022	2023	2024	2025	2030	2040	2050
E3ME	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.2
Rhomolo	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.4
Eagle	0.4	0.3	0.2	0.3	0.3	0.4	0.4	0.4
Quest	0.2	0.1	0.1	0.1	0.1	0.2	0.4	0.4
Average	**0.2%**	**0.2%**	**0.1%**	**0.1%**	**0.2%**	**0.2%**	**0.4%**	**0.4%**

Data source: Authors' own calculations using ECB, European Commission and E3ME data.

All models again confirm a positive and significant impact on GDP. In the long run, on average, climate-related investment in the MFF is expected to boost EU potential GDP by around 0.4 %. All three models – that of the European Commission, the ECB and the EIB – provide relatively similar results for the long-term impact (around +0.4 %), but differ in their short-term and medium-term estimates. E3ME displays a lower impact. This is again explained by differences in the modelling assumptions and by the specific characteristics of each model.[131] In particular, long-run output effects are the strongest according to EAGLE and QUEST, which are both more advanced macroeconomic DGSE models and are more adapted to measuring the expected long-term structural effects of policies. The results obtained by the authors of this report are in line with other empirical analyses in the literature. The IMF, for instance, conducted a comprehensive review of such empirical evidence about the macroeconomic effects of public investment.[132] The results confirm that in the current economic circumstances, increased public investment raises output, both in the short term and in the long term, crowds-in private investment, and reduces unemployment.

Regarding the impact of climate-related **research, development and innovation (RD&I) spending in the MFF**, the study in Annex II does not include a specific modelling scenario analysing the potential benefits of EU action. As innovation is the main source of economic growth and given the crucial importance of RD&I for the green transformation, this reinforces the necessity to always rely on more than just one type of model when gathering evidence. Thus, an ad-hoc calculation was conducted establishing that R&D spending in the MFF could generate up to €113 billion over 25 years from 2021 to 2036 or around 0.03 % of GDP per year on average. A series of more relevant

[130] EIB, 2018 EIB Group Financing and Investment Operations under EFSI. European Investment Bank, 2018.

[131] For more detailed explanations on the assumptions, characteristics and specificities of each ECB model for this exercise, see Bańkowski et al, 2021, op. cit. For QUEST, see European Economic Forecast, 2020, op. cit. For E3ME, see the study in Annex II of this report.

[132] Abiad A., Furceri D., Topalova P., The macroeconomic effects of public investment: evidence from advanced economies, IMF, 2015.

simulations[133] using three different models (Nemesis,[134] QUEST and Rhomolo) have been used to evaluate the macroeconomic impact of EU RD&I as part of an EU impact assessment of the Horizon Europe programme. All three models analyse the impact of funding of the Horizon Europe programme (at €77 billion in total for the previous MFF period). However, as described in Figure 7 above, only a certain percentage of MFF RD&I will be directed towards the green transformation. The authors of the present report therefore recalibrated the existing results to make them correspond to the climate part of investment in the MFF, in which they also included the funds directed towards ITER (€39 billion per financial period or around €6 billion per year on average). They used these results to derive an average estimate of the potential impact of climate-related RD&I spending, assuming that they will have a permanent character. The results are presented in Table 5.

Table 5 – Macroeconomic impact (% GDP difference with the baseline) of climate-related RD&I spending in the MFF (permanent spending of €6 billion per year on average), year compared to the baseline (2020)

Year	2021	2022	2023	2024	2025	2030	2040	2050
Rhomolo	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2
Quest	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3
Nemesis	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.4
Average	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.1%**	**0.2%**	**0.3%**

Data source: Authors' own calculations using European Commission data.

Overall, Nemesis, QUEST and Rhomolo present consistent results in terms of the sign and temporal pattern of the GDP gains. In the long run, on average, climate-related RD&I spending in the MFF is expected to boost EU potential GDP by around 0.3 %. The size of the GDP gains is the highest when based on the Nemesis results. This can be explained by the fact that the three models use different sets of innovation channels and elasticities. Furthermore, Nemesis is assuming a higher leverage and expected performance of EU funding for RD&I. The results also confirm that having an excessively fragmented EU research, occasionally coupled with duplication of research activities among the Member States, is a very inefficient and ineffective approach to developing green technologies.

3.3. Substantial economic and competitiveness benefits could also accrue

In addition to budgetary action, the EU has a key role to play through its regulatory instruments, such as the EU ETS and the Taxonomy Regulation, through standard settings and through its coordinating role of actions at Member State level. Here it is worth recalling that the reference scenario (REF), which serves as a baseline, already includes the EU energy, transport, and climate acquis as of the end of 2019. It covers energy policies updated with the Clean Energy for All Europeans package and its eight legislative acts setting the EU energy targets for 2030 and paving

133 European Commission, Impact Assessment accompanying the document Proposals for a regulation of the European Parliament and the Council establishing Horizon Europe – the Framework Programme for Research and Innovation, laying down its rules for participation and dissemination, SWD(2018) 307 final, June 2018.

134 The NEMESIS model (New Econometric Model of Evaluation by Sectoral Interdependency and Supply) is a sectoral detailed macroeconomic model for the European Union. See Boitier et al., NEMESIS Model: Full description. Tech. rep., SEURECO. 2018.

the way for their achievement.[135] Furthermore, it includes revised EU policies like the EU ETS, the CO_2 standards for vehicles, the Regulation on F-gas, the legislation on waste, the Directive on Alternative Fuels Infrastructure (AFID), the TEN-T Regulation, the fourth railway package, the Clean Vehicles Directive.[136] Further potential challenges and actions in each sector of the economy that correspond to the MIX55 scenario are described in detail in the study in Annex II.[137] Non-budgetary policy options mainly concern carbon pricing through the EU ETS (notably EU-wide carbon pricing for buildings and road transport), the setting of more stringent standards and minimum requirements (40 % of energy from renewable sources by 2030, and in buildings fossil fuels consumptions reduced by 58 % in 2030). They also include bans on specific energy vectors/technologies/applications (coal phase-out, phase-out of other fossil fuels in power plants by 2050 unless connected to CCS, all Member States ban new fossil fuelled cars from 2030, ban of fossil fuel boilers). Finaly, they include better market design and market regulation, strategy development, infrastructure planning and target setting (increases in renewable-based electricity production in industry, fuel switches (e.g. to electricity and clean gases) and new technologies (e.g. CCUS technologies, low-emission steel production), increase of communication and training. This is therefore in line with the measures announced recently by the European Commission.[138] In the following section, the report analyses these issues, focusing on the economic benefit that could stem from an ambitious and united EU approach.

3.3.1. Impact of the EU ETS and the Taxonomy Regulation

Regarding the impact of the **EU Emission Trading Scheme**,[139] it is first worth recalling the pioneering and visionary role of the EU in establishing what is the largest GHG emissions trading system in the world.[140] This allows for maximal thickness of the market, minimal administrative costs and an overall higher efficiency compared to systems based on local/regional/national markets for emissions. The EU ETS is also a far less costly instrument compared to more traditional command and control regulatory tools used by the EU. Moreover, the EU ETS is a source of public resources, as auctioning generates revenues to governments that can be used to fund other policies. According to the latest report on the functioning of the European carbon market,[141] revenues from the auctioning of EU allowances already increased from €5.5 billion in 2017 to more than €14 billion in 2019, reflecting the increase in the allowance price. Over the course of 2019, a total of 77 % of these revenues were directed towards spending on climate and energy-related purposes. Recently, an ex-post evaluation of the three initial phases of the EU ETS[142] investigated the impact of the EU ETS on

[135] The recast Renewable Energy Directive (RED II) and amending Directive on the Energy Efficiency and the Energy Performance of Buildings Directive, as well as the new Electricity Regulation and the amending Electricity Directive are the central pillars of the package.

[136] See European Commission, EU reference scenario 2020 – Energy, transport and GHG emissions: trends to 2050, July 2021 for a detailed account of all EU policies considered.

[137] See the study in Annex II, Chapters 2 and 3.

[138] European Commission, Communication on 'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality, COM(2021) 550 final, July 2021.

[139] Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a system for greenhouse gas emission allowance trading within the Union and amending Council Directive 96/61/EC

[140] The current ETS covers around 40 % of the EU's GHG emissions and around 800 million allocations were auctioned in 2019 according to the EEA.

[141] European Commission, Report on the functioning of the European carbon market Brussels, COM(2020) 740 final, November 2020.

[142] Saulnier J., Improving the quality of public spending in Europe – Budgetary 'waste rates' in EU Member States, EPRS, October 2020.

performance and profitability during its three past phases.[143] It concluded that businesses profitability and competitiveness were not adversely impacted by the EU ETS, including during the tightening of the EU ETS regulation between phases 2 and 3, and that this might be linked to positive productivity and innovation developments in the sectors concerned. Looking forward, it suggested that given the increasing efforts of EU action against climate change, prices of carbon emissions allowances are expected to rise in the future, suggesting potential revenues above €50 billion/year in the medium to long term.

The European Commission recently presented a series of legislative proposals[144] explaining how it intends to achieve the intermediate target of at least 55 % net reduction in GHG emissions by 2030. The package aims to support the reduction in GHG emissions over the next decade, notably by increasing the ambition of the existing EU ETS.[145] Regarding the impact of the EU ETS deepening and extension to achieve the net-zero objective in 2050, few up-to-date quantitative results are available. Earlier results provided some detailed analysis of the potential impact of the EU ETS up to 2030. The impact assessment by the European Commission[146] summarized these results obtained through modelling exercises using QUEST, E3ME and GEM-E3.[147] QUEST and E3ME both found a positive impact of respectively 0.13 and 0.50 % of GDP compared to the baseline in 2030. GEM-E3 assumes free allocation in EU ETS industries outside of the power sector, which does not appear as being relevant any more. The model thus fails to account for revenue redistribution effects and display a negative impact of around -0.27 % of GDP compared to the baseline in 2030. The studies also concluded that the impact of climate and energy policy to achieve 55 % GHG reductions on real GDP will depend greatly on how the revenues collected through the EU ETS are used by governments.

The simulation carried in the study in Annex II complements and improves these initial assessments by providing updated insights into the potential economic implications arising from the expected extension of EU ETS to transport and buildings and the increase of the prices of carbon emissions allowances up to 2050. The main results are reported in Table 6 below. As explained in the study in Annex II, achieving net zero will require an extended EU ETS and a substantially higher EU ETS allowance price. From a macroeconomic point of view, this has direct implications for the generation of government revenues (estimated at around €42 billion per year in the long term – Table 6). This also has a direct impact on potential growth through the innovation channel as the higher price of allowance will accelerate the shift towards decarbonised technologies and thus trigger renewed research and innovation in this area. As innovation is the main source of modern economic growth, this implies that the green transformation is completely compatible with long-term economic growth and it also opens up a vast range of economic opportunities for the most entrepreneurial

143 Phase one corresponds to the period 2005-2007, phase two to the period 2008-2012 and phase three to the period 2023-2020.

144 European Commission, July 2021 op. cit.

145 This notably concerns making necessary adjustments to the Market Stability Reserve, extending the EU ETS to the maritime sector and implementing the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), establishing a new ETS to cover emissions from fuels used in buildings and road transport, and increasing Member States' emissions reduction targets in a fair and cost-effective way. A detailed evaluation of the impact of each measure is beyond the scope of this study, which takes a more macroeconomic approach.

146 European Commission, Impact Assessment accompanying the document Proposals for a regulation of the European Parliament and the Council, the Economic and Social Committee and the Committee Of the Regions, Stepping up Europe's 2030 climate ambition Investing in a climate-neutral future for the benefit of our people, SWD(2020) 176 final, September 2020.

147 For a detailed description of GEM-E3, see Capros P., Van Regemorter D., Paroussos L., Karkatsoulis P., Fragkiadakis C., Tsani S., Charalampidis I., Revesz T., GEM-E3 Model Documentation, 2013.

businesses. All in all, the modelling results with E3ME suggest a long term impact of around 0.5 % extra GDP compared to the baseline (Table 6).

Table 6 – Macroeconomic impact of the EU ETS (% GDP difference with the baseline), year compared to the baseline (2020)

Year	2021	2022	2023	2024	2025	2030	2040	2050
Estimated auctioned allocations[148] ($MtCO_2eq$) A	723	693	662	632	601	449	296	144
Emissions Allowance Price (€/tCO_2) B	35	38	42	45	49	74	146	289
Estimated generated budgetary resources (€)billion) (A*B)/1000	25	26	28	29	29	33	43	42
Macroeconomic impact (% GDP difference with the baseline – E3ME)	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.1%**	**0.3%**	**0.5%**

Data source: Authors' own calculations based on European Commission and Hoogland et al., 2021 data.

The recently adopted **Taxonomy Regulation**[149] it is another important building block that will contribute to providing the clarity needed on what constitutes a sustainable economic activity. It will also seek to address the need of redirecting private financing towards clean and sustainable energy projects and activities. The impact assessment that accompanies the delegated act[150] does not provide a quantification of the potential impact of the taxonomy. Another study[151] provides a more detailed assessment of potential economic implications. It first reviews the scope of the taxonomy[152] and the various evaluations of financing needs to achieve various GHG reduction target

148 Estimations up to 2030 are based on the latest EEA report – See Trends and projections in the EU ETS in 2019 – The EU Emissions Trading System in numbers, Eionet Report – ETC/CME 3/2019, December 2019. It builds upon the Öko-Institut's MSR model projections up to 2030. The estimations for 2030 assume a prolongation of the past 2020-2030 trend.

149 A first delegated act on sustainable activities for climate change adaptation and mitigation objectives was adopted in July 2021. A second delegated act for the remaining objectives will be adopted in 2022. The publication of the first delegated act was accompanied by the adoption of a Commission Communication on 'EU taxonomy, corporate sustainability reporting, sustainability preferences and fiduciary duties: Directing finance towards the European green deal'

150 European Commission, Impact assessment report accompanying the document Commission Delegated Regulation (EU) supplementing Regulation (EU) 2020/852 of the European Parliament and of the Council by establishing the technical screening criteria for determining the conditions under which an economic activity qualifies as contributing substantially to climate change mitigation or climate change adaptation and for determining whether that economic activity causes no significant harm to any of the other environmental objectives, SWD(2021) 152 final, June 2021.

151 European technical expert group on sustainable finance, Taxonomy technical report, 2019.

152 The taxonomy identifies economic activities substantially contributing to climate change objectives within selected sectors representing 93.2 % of GHG emissions.

in 2030. It then investigates where EU capital markets stand today in terms of funding environmentally sustainable economic activities. It concludes that the EU taxonomy would bring benefits to financial markets participants by increasing transparency, facilitating the identification of sustainable assets and consequently the integration of sustainability factors in their investment decisions. Regulators could then leverage the taxonomy to implement new green investment frameworks at a lower cost. The main costs derived from the implementation of the taxonomy relate to the collection and management of data needed to assess the compliance with the defined screening criteria. The study concludes that it would help redirecting financial resources towards sustainable economic activities and contribute to fill the investment gap in the relevant sectors but do not foresee major challenges for the financial sector.

In the previous chapter, we already indirectly considered the potential impact of the taxonomy by assuming that private investment is leveraged without friction (€112 billion during the next MFF period) in relation with EIB financing. As the taxonomy would mostly induce a transfer of funds from carbon-related investments to non-carbon-related investments, one might argue that the net benefit will be small. However, this could substantially reduce the cost of capital in the non-carbon-related sector, thus potentially leading to substantial growth in this sector, in sustainable finance and more generally in the economy as a whole. The study in Annex II provides us with an investment trajectory until 2050 for the MIX55 scenario compared to the baseline. Using these results we first compute the amount of interests to be paid assuming a long term interest rate back at its long-term average (at 3.19 % for the period 2001-2020[153]) in 2050, assuming a linear increase from a long-term interest rate of 0.31 % in 2020. The amount of interest on the investments made each year is computed assuming a 30-year reimbursement schedule. The authors of this report then compute the amount of interest to be paid, assuming a path towards a lower long-term interest. The authors then assume a difference of 50 basis points, which is a reasonable assumption given the already low level of interest rates and the indications given by the impact assessment of a potential limited impact. The difference gives an approximation of an amount of interest payment savings that could be expected each year from the taxonomy in relation to climate-related investments up to 2050.[154] The results (presented in Table 7) show a positive long-term macroeconomic impact of 0.2 % of GDP representing around €39 billion per year.

Table 7 – Macroeconomic impact of the Taxonomy Regulation (interest savings in € billion and % GDP – difference with the baseline), year compared to the baseline (2020)

Year	2021	2022	2023	2024	2025	2030	2040	2050
Macroeconomic impact (€ billion)	0	1	2	3	4	12	26	39
Macroeconomic impact (% GDP)	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.1%**	**0.2%**	**0.2%**

Data source: Authors' own calculations based on Eurostat data.

153 See Eurostat, EMU convergence criterion series – annual data, long term interest rates, August 2021.

154 This however does not take into account the broader positive potential impact of the development of ESG related activities that the taxonomy could induce.

3.3.2. Moving towards a more integrated energy market with greater energy efficiency

Substantial benefits could also be expected from a **more integrated EU energy market and an increased energy efficiency** resulting from regulatory action coordinated at EU level. In particular, while the EU energy system is transforming towards carbon neutrality and as the share of renewable is increasing, smart energy use and energy storage will play a key role in ensuring the matching between energy production and energy consumption. Moreover, the switch to electricity and renewable sources such as hydrogen and renewable fuels would require added flexibility in the system and would be achieved at lower cost through sector coupling and integration.[155] The EU has already made some progress towards integrating its gas and electricity markets. It has also started to facilitate the participation in storage, to support joint initiatives for batteries and hydrogen, notably through Important Projects of Common European Interest (IPCEI)[156] schemes while encouraging the use of renewable gases, notably through the proposed revision of the Renewable Energy Directive and the Energy Taxation Directive.[157]

However, as recently stressed by the European Parliament,[158] more could be done to improve the transnational connection for the purpose of balancing energy systems, to improve energy efficiency, to optimize and decarbonize the energy systems and to accelerate effective progress towards reaping the benefits of a more integrated EU energy market. As diversification of energy supply develops, the IEA also stressed[159] that an integrated approach will be essential for a sustainable energy future as success not only depends on technologies and type of fuels but also on how the overall energy system functions. As put by the IEA: 'the most important challenge for energy policy makers will be to move away from a siloes, supply-driven perspective towards one that enables systems integration' (IEA, 2017). In particular, interconnections, integration and market coupling could lead to higher security of supply on the one hand, and to lower overall system costs on the other hand, as power generation capacity is used more efficiently and balancing and reserve capacity including demand response resources can be shared amongst Member States, which reduces the marginal cost and the overall capacity needs. The study in Annex II does not provide any quantitative modelling estimate of further progress in this area. Through a review of the literature, it estimated that additional benefits ranging between €16 billion and €43 billion per year could be achieved by 2030, which is taken from an earlier report[160] that aggregates the existing

155 See Erbach G., Energy storage and sector coupling: Towards an integrated, decarbonised energy system, EPRS, June 2019.

156 For more on IPCEI see European Commission website available at: https://ec.europa.eu/competition-policy/state-aid/legislation/modernisation/ipcei_en

157 For a review of ongoing initiative see European legislative train schedule https://www.europarl.europa.eu/legislative-train/theme-a-european-green-deal/file-strategy-for-smart-sector-integration.

158 European Parliament resolution of 19 May 2021 on a European strategy for energy system integration; (2020/2241(INI)).

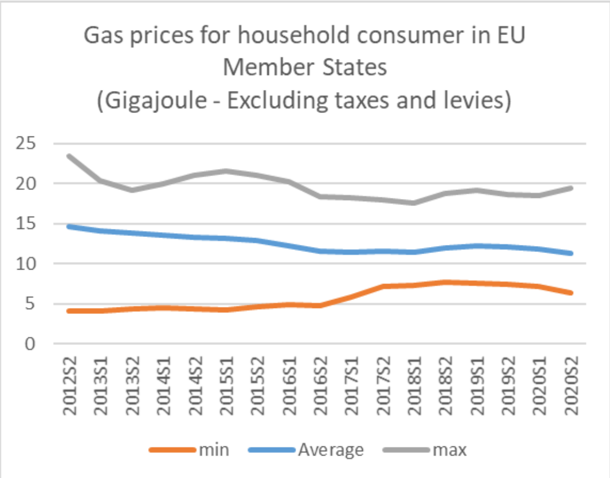
159 IEA, 2021, op cit.

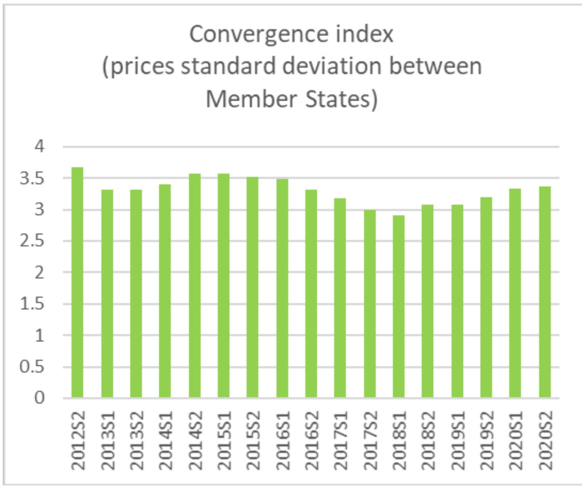
160 Baker P., Hogan M., Kolokathis C., Realising the benefits of European market integration, May 2018.

relevant results from a previous evaluation coming from the European Commission impact assessment[161] and from an earlier comprehensive study (Hoogland et al., 2021, Chapter 4.2.1).[162]

In the gas sector, the annexed study estimated that greater integration of the gas market will likely produce important economic benefits from price effects and from increased security of supply, estimating a maximum benefit from price effects (price of gas, and price of flexibility) of up to €30 billion per year over the 2015-2030 period. Looking at changes in the integration of the EU gas sector since 2015 by using the dispersion of gas prices between Member States as a proxy indicator, one can deduce that only a small progress has been made (see Figure 8). Therefore, it is assumed that the total amount of €30 billion to be realised progressively until 2030 could be discounted by half the amount corresponding to the linear evolution from 2015 to 2020, representing €5 billion. Furthermore, it is concluded that around €25 billion of benefits per year could still be progressively achieved in this area. As no estimation is available beyond 2030, it is assumed that this amount also corresponds to the long term benefit (see Table 8).

Figure 8 – Evolution of prices and convergence in the gas sector (2012-2020)





Data source: Authors' own calculations based on Eurostat structural indicators data.

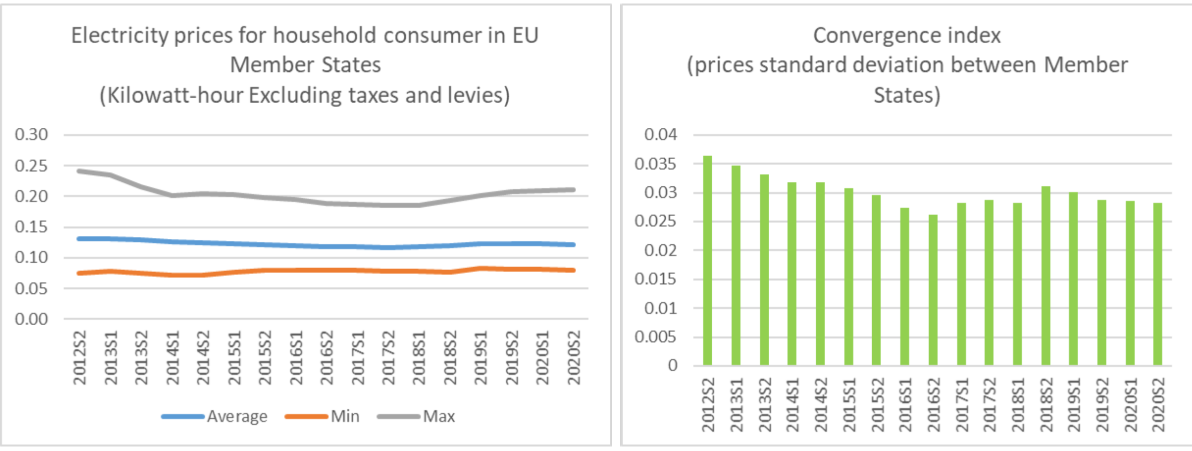
In the electricity sector, the study estimated that ambitious action to integrate the market could deliver benefits of up to €40 billion per year by 2030. This could be reduced by up to €7.5 billion if the increment in transmission capacity is only half of what is optimal. A reduction in benefit of €5 billion would apply if cooperation is not optimal and if some Member States seek to achieve more security of supply at a national level. Some increase in benefits in the order of up to €0.5 billion could come from sharing balancing reserves and gains of up to €5 billion could come from using smart grids to facilitate demand side response. Taking all these elements into account, a reasonable amount of €33 billion per year by 2030 could still be expected as a result of further integration in this sector. Looking at changes in the integration of the EU electricity sector since 2015 using the dispersion of electricity prices between Member States as a proxy indicator, one could see that after the progress made from 2012 to 2015, progress since then has been modest (see Figure 9). It is therefore assumed that the total amount of €33 billion to be realised progressively until 2030 could

[161] European Commission, Impact assessment Accompanying the document Proposal for a Directive of the European Parliament and of the Council on common rules for the internal market in electricity (recast) Proposal for a Regulation of the European Parliament and of the Council on the electricity market (recast) Proposal for a Regulation of the European Parliament and of the Council establishing a European Union Agency for the Cooperation of Energy Regulators (recast) Proposal for a Regulation of the European Parliament and of the Council on risk preparedness in the electricity sector, SWD(2016) 410 final, November 2016.

[162] Benefits of an integrated European energy market, Booz and co, July 2013.

be discounted by half the amount corresponding to the linear evolution from 2015 to 2020, representing €5.5 billion. Consequently, it is concluded that around €27.5 billion of benefits per year could still be progressively achieved in this area. As no estimation is available beyond 2030, it is assumed that this amount also corresponds to the long term benefit (see Table 8 above).

Figure 9 – Evolution of prices and convergence in the electricity sector (2012-2020)



Data source: Authors' own calculations based on Eurostat structural indicators data.

Furthermore, as stated in the 2030 Climate Target Plan (CTP), the development of **renewable energy** will play a fundamental role in achieving net-zero GHG emissions by 2050, as the energy sector contributes over 75 % of total GHG emissions in the EU. According to the CTP, achieving at least 55 % GHG emissions reductions would result in an accelerated clean energy transformation and a greener energy mix, with renewable energy seeing its share reaching 38 % to 40 % of gross final energy consumption by 2030. Currently, the revised energy directive adopted in 2018 (REDII) is the main EU instrument dealing with the promotion of energy from renewable sources. The Commission's proposal for a revised REDII[163] would increase the binding EU minimum share of RES in final energy consumption to 40 % by 2030, in effect doubling the share of RES in the energy mix over the next decade. It was estimated in an earlier study[164] that large gains of up to €30billion per year by 2030 would be available if there is a common market for renewable energy with effective coordination of renewable energy supply investment. Given the new EU ambitions in this area, this could be considered as a lower estimate. The European Commission in its impact assessment on its recent proposal for a revision of REDII,[165] estimated using E3ME that measures in this area in the MIX55 scenario could generate up to 1.1 % GDP increase in 2030 compared to the baseline. This is however mostly driven by the impact of investments that we already addressed in previous chapters. Correcting for these, we arrive at an estimate of around 0.4 % of GDP in 2030. As reductions in fuel imports are one of the main drivers of the results, we expect the impact to further grow in line with the reduction of fuel imports from 2030 as estimated in the study in Annex II. This gives a final impact in 2050 of 0.5 % of GDP, or €94 billion in the long term (see Table 8). Assuming a proportional repartition of the savings linked to the reduction of fossil fuel import estimated by the

163 See European Parliament legislative train schedule for the state of play on the revision of the Renewable Energy Directive.

164 Booz and co, 2013, op cit.

165 European Commission, Impact assessment Accompanying the Proposal for a Directive of the European Parliament and the Council amending Directive (EU) 2018/2001 of the European Parliament and of the Council, Regulation (EU) 2018/1999 of the European Parliament and of the Council and Directive 98/70/EC of the European Parliament and of the Council as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652 Brussels, SWD(2021) 621 final, July 2021.

study in Annex II, this could be decomposed into €67 billion (in the long-term in 2050) coming from benefits derived from a common market for renewable energy and €27 billion (in the long term in 2050) from fossil fuel imports savings due to increased renewable energy.

Finally, to meet the new EU 2030 climate target, progress in improving **energy efficiency** will also be crucial. The European Commission put forward, in July 2021, a proposal for a new directive on energy efficiency (EED).[166] The proposal promotes 'energy efficiency first' as an overall principle of EU energy policy. The proposal raises the level of ambition of the EU energy efficiency target and makes it binding. It proposes EU countries to collectively ensure an additional reduction of energy consumption of 9 % by 2030 which corresponds to the 39 % energy efficiency targets for primary energy consumption in the CTP. The proposal also nearly doubles the annual energy savings obligation, which is one of the key policy instruments of the Energy Efficiency Directive to meet the headline target. EU countries must achieve new savings each year of 1.5 % of final energy consumption from 2024 to 2030, up from the current level of 0.8 %. The impact assessment[167] based upon results by E3ME indicates that in the MIX 55 scenario compared to reference projections, GDP is 0.5 % higher in 2030. Another more comprehensive study carried out by the Commission,[168] always using E3ME, evaluates the impact of achieving a 40 % energy efficiency target in 2030 at around 2.2 % of GDP. This however includes investment impacts and environmental impact that we already addressed in previous chapters. Correcting for these, we arrive at an estimate of around 0.64 % of GDP in 2030, close to the value in the impact assessment. As explained in the study reductions in fuel imports are one of the main drivers of the positive GDP results, we expect the impact to grow in line with the reduction of fuel imports from 2030 as estimated in the study in Annex II. This gives a final impact in 2050 of 0.80 % of GDP, or €126 billion (see Table 8). Assuming a proportional repartition of the savings linked to the reduction of fossil fuel import estimated by the study in Annex II, this could be decomposed into €90 billion saving for households and businesses linked to the sectoral impact of energy efficiency measures and €36 billion linked to fossil fuel import saving for the EU economy.

166 European Commission, Proposal for a Directive of the European parliament and of the Council on energy efficiency (recast), Brussels, COM(2021) 558 final, July 2021.

167 European Commission, Impact assessment Accompanying the Proposal for a Directive of the European Parliament and of the Council on energy efficiency, SWD(2021) 623 final, July 2021.

168 European Commission, Report on The macro-level and sectoral impacts of Energy Efficiency policies, June 2017.

Table 8 – Macroeconomic impact of more integrated EU energy market and increased energy efficiency and renewable energy (€billion and % GDP difference with the baseline), year compared to the baseline (2020)

Year	2021	2022	2023	2024	2025	2030	2040	2050
Integration of gas and electricity (A)	**4**	**8**	**13**	**17**	**21**	**53**	**53**	**53**
further effective integration of the gas sector	2	4	6	8	10	25	25	25
further effective integration of the electricity sector	2	4	7	9	11	28	28	28
Development of renewable energy (B)	**7**	**13**	**18**	**23**	**33**	**61**	**81**	**94**
common market for renewable energy	5	10	13	17	24	44	58	67
savings on fossil fuel imports from EU renewable and energy efficiency policies	2	3	5	6	9	17	23	27
Enforce Energy efficiency first principle (C)	**11**	**21**	**29**	**36**	**51**	**88**	**111**	**126**
sectoral impact of energy efficiency measures	8	16	21	27	37	64	79	90
savings on fossil fuel imports from energy efficiency policies	3	5	7	9	13	24	32	36
Total (A+B+C) macroeconomic impact (€billion)	**22**	**43**	**59**	**76**	**104**	**202**	**245**	**272**
Total (A+B+C) macroeconomic impact (% GDP)	**0.2%**	**0.3%**	**0.5%**	**0.6%**	**0.8%**	**1.5%**	**1.5%**	**1.5%**

Data source: Authors' own calculations based on European Commission data.

3.4. The key role of the EU to ensure a fair transformation that continues to contribute to a healthy convergence

The EU's commitment to transforming its economy towards net-zero emissions is a very laudable pledge, but it also needs to ensure that this transformation is fair, that it contributes to convergence between the Member States and that it does not lead to fragmentation in the single market. If the

EU is serious about achieving a net-zero economy, some profound structural changes will have to be implemented and the related trade-offs have to be addressed in a transparent way.

3.4.1. The EU as a convergence ecosystem

First, regarding the **employment impact** of decarbonisation, the study in Annex II provides an overview of previous modelling estimates[169] that show a positive impact on employment of between 0.02 % to 0.60 % depending on the model and on the target for emission reduction (Hoogland et al., 2021). The results of the study in Annex II also finds a positive employment impact in the MIX55 scenario compared to the baseline (see Table 9) According to the study, employment in the long term could be 2.1 million higher or 1.1 % higher compared to the baseline. Employment in the construction sector increases because of the required additional investment in this sector. There is also a large increase in employment in the utilities sector mostly due to the higher labour intensity of low-carbon generation technologies. This contributes positively to raising household income and consumption.

Table 9 – Employment impact of moving towards net zero (interest savings in € billion and % – difference with the baseline)

Year	2021	2022	2023	2024	2025	2030	2040	2050
Employment impact (thousands)	318	444	755	1 019	1 513	1 912	2 449	2 135
Employment impact (%)	0.2%	0.2%	0.4%	0.5%	0.7%	0.9%	1.2%	1.1%

Data source: Authors' own calculations using Hoogland et al., 2021.

In addition to environmental, economic growth and employment effects, the green transformation of the EU economy will also have some important structural social impacts. The success of EU policies should naturally not be judged exclusively on the basis of its effects on economic growth as the objective is to foster real convergence in the EU. As explained by the World Bank, the EU growth model, notably through the transfers linked to the cohesion funds and through the MFF but also through the beneficial impacts of the single market and the EMU, has contributed to large trade, capital and talent flows (Gill I., Raiser M., 2014). The economic development that resulted from this unique **EU convergence ecosystem** helped boosting prosperity in a way that is both sustainable and socially inclusive and that brought the continent together.[170] The policies of the European Green Deal and the budgetary amounts made available through NGEU and the MFF should without doubt further reinforce this solidarity pillar of the European construction as funds will again be largely directed towards ensuring that no Member States feels left behind.[171] Looking at the progress made in the last 25 years (see Figure 10.) one could see that the relative standard of living for the Member States at the bottom of the distribution curve has converged significantly towards the EU average. At the same time, the gap with the Member States at the top of the distribution curve has not increased, resulting in to a substantial reduction of the dispersion of standard of living during the period (measured by the interquintile difference in terms of GDP per capita in purchasing power

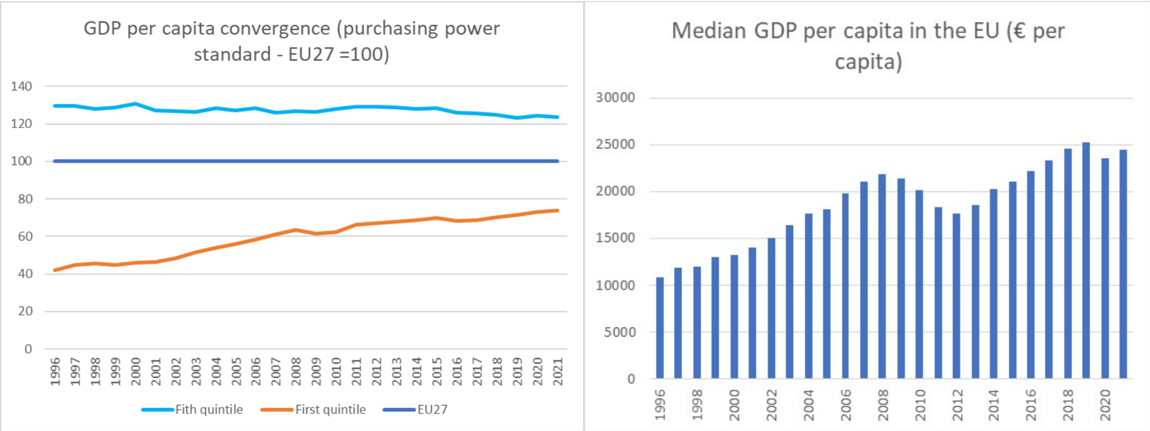
[169] European Commission, 2020 op. cit. with JRC-GEM-E3; European Commission, 2020 op. cit. with E3ME, European Commission, 2020 op. cit. with E-QUEST.

[170] For a recent review of potential economic impacts of EU integration see Evas, T. et al, Coronavirus and the cost of non-Europe: An analysis of the economic benefits of common European action, EPRS, 2019.

[171] See European Commission, Recovery and Resilience Facility – Grants allocation per Member State, 2021 and D'Alfonso A., Next Generation EU. A European instrument to counter the impact of the coronavirus pandemic, EPRS, July 2020.

parities between the first and the fifth quintile). In absolute terms (see Figure 10b), one could also see that during the same period and despite unprecedented economic turbulences, the median GDP per capita[172] in the EU has risen in the last 25 years by around €15 000 to reach nearly €25 000 in 2021.

Figure 10 – The EU as a convergence ecosystem: a) GDP per capita convergence 1995-2021; and b) median GDP per capital in the EU



Data source: Authors' own calculations based on Ameco data.

More elaborated macroeconomic modelling results all confirm this positive convergence impact of EU cohesion policies. Earlier results using different models[173] all concluded that EU cohesion policy had a significantly positive effect, with absolute GDP and employment being higher in Member States at the bottom of the distribution curve than in the absence of EU action. The results also showed that the majority of the increase in GDP is attributable to increases in physical and human capital and RD&I, which serve to push up productivity and competitiveness over the long-term. More recently, comprehensive modelling analysis at regional level by the JRC[174] using the Rhomolo model concluded that the long-run impact of EU action on the GDP growth could reach up to 0.7% above the baseline scenario. The study also stressed that all EU regions benefit from increase in their standard of leaving triggered by EU funds. If the EU implements an ambitious and united agenda to move its economy towards net zero in 2050, further positive convergence could therefore be expected, although given the different relative starting position and different economic and industrial structure, not all region will make similar progress. This is confirmed by the results of the study in Annex II which also find a positive **convergence impact** in the MIX55 scenario compared to the baseline (see Table 10). The convergence index (which is measured by the interquartile difference in terms of real income between the first and the fifth quintile and converted into a base 100 in 2021 index) shows a continuation of the past convergence trend until 2050 in the MIX55 scenario, with a further reduction of the interquintile difference by 33 percentage points. This is a relative positive development, which confirms that EU leadership and ambitious action in this area would continue to be beneficial for EU citizens. A fragmented approach on the opposite, in addition

172 GDP per capita is the measure that determines eligibility for cohesions support, and it therefore appears as one of the potential logical measure to use in an economic assessment.

173 The European Commission in 2007 using three models (HERMIN, QUEST and Ecomod) for an ex-ante assessment of potential effects of cohesion expenditure over the 2007-2013 programming years. All three models showed positive output effects from cohesion expenditure.

174 Di Comite, F., Lecca, P., Monfort, P., Persyn, D., Piculescu V., The impact of Cohesion Policy 2007-2015 in EU regions: Simulations with the RHOMOLO Interregional Dynamic General Equilibrium Model. JRC Working Papers on Territorial Modelling and Analysis No. 03/2018, European Commission, Seville, JRC114044.

to its negative environmental costs, would induce less convergence as Member States would not benefit from the budgetary support of the EU and would have smaller national markets at their disposal to sell their green technologies.

Table 10 – Potential convergence gains from an ambitious and united EU approach towards net zero

Year	2021	2022	2023	2024	2025	2030	2040	2050
Convergence index	100	99	99	99	99	95	86	77

Data source: Authors' own calculations based on data from Hoogland et al., 2021.

Taking into consideration the potential positive developments in terms of increased employment and convergence, one would expect that on the demand side, further gains would also materialize from a fair transformation, in particular in terms of increased **purchasing and consumption power for EU consumers**. The study in Annex II gives an estimation of the difference in terms of additional consumption between the MIX55 scenario and the baseline until 2050. We consider that this could be a proxy for the expected monetary benefits that could result from a fair transformation. As already mentioned and as for the environmental benefits, the gains in this area are not necessary precisely quantifiable, so this assumption seems reasonable as a first approximation. Nevertheless, in this report it is decided to subtract the amount related to the savings from lower energy imports, as these have already been accounted for in the previous chapter. The results are given in Table 11. It can be observed that the gain from a fair transformation would largely materialise in the medium and long term, whereas a positive impact in the short term, when the transformation has still not yet been fully effective, is more subdued.

Table 11 – Potential monetary impact of a fair transformation towards net zero (€ billion and % – difference with the baseline)

Year	2021	2022	2023	2024	2025	2030	2040	2050
Macroeconomic impact (€ billion)	12	6	2	1	3	33	156	261
Macroeconomic impact (% GDP)	**0.1%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.2%**	**1.0%**	**1.4%**

Data source: Authors' own calculations based on data from Hoogland, O et al., 2021.

3.4.2. Cost of non-Europe in the area of energy

As described in the previous chapters, the CoNE in the area of energy is made up of various interrelated and mutually reinforcing building blocks that reflect more direct actions by the EU but also the equally important regulatory and coordination activities of the Member States. The estimation of the CoNE in the area of energy can also not be separated from the ongoing transformation toward a carbon neutral economy. Taking this more holistic perspective, the purpose of this section is to summarize and aggregate the findings of the previous chapter. The results are presented in Table 12 and Figure 11 below. All monetary calculations have been realised using the baseline reference GDP figure for the EU taken from the E3ME baseline scenario (Hoogland et al., 2021).[175] Analysing the results it confirms that the EU energy policy is an area where **an**

[175] Prices are therefore relative to the baseline GDP expenditure measure at market prices (2010 euro) in the EU-27 in the baseline scenario.

ambitious and united EU approach could be key to boosting EU GDP significantly. Further actions in that field could boost the EU economy by around 3.3 % of EU GDP or €464 billion in 10 years and by up to 5.6 % or **more than €1 trillion in the long term (2050)**. This is comparable to some other estimates in the literature[176] for the broad impact of ambitious reforms in this area.

Table 12 – Computation of the CoNE – summary table (€ billion per year) – Ambitious and united EU action vs the baseline

Year	2021	2022	2023	2024	2025	2030	2040	2050
Averted costs of climate change-related damages	34	52	70	88	107	125	163	203
Benefits from climate-related NGEU investments	24	39	56	65	64	31	32	37
Benefits from climate-related MFF investment and cohesion funds	22	19	16	19	23	33	56	66
Benefits from climate-related MFF RD&I spending	0	0	0	1	2	14	34	55
Benefits from EU ETS	14	15	16	16	15	14	55	96
Benefits from further energy sector integration	4	8	13	17	21	53	53	53
Benefits from the development of renewable energy	7	13	18	23	33	61	81	94
Benefits from increasing energy efficiency	11	21	29	36	51	88	111	126
Benefits from the Taxonomy Regulation	0	1	2	3	4	12	26	39
Benefits from a fair transformation	12	6	2	1	3	33	156	261
Cost of non-Europe (CoNE)	**129**	**174**	**221**	**268**	**322**	**464**	**767**	**1029**

Source: Authors' own calculations.

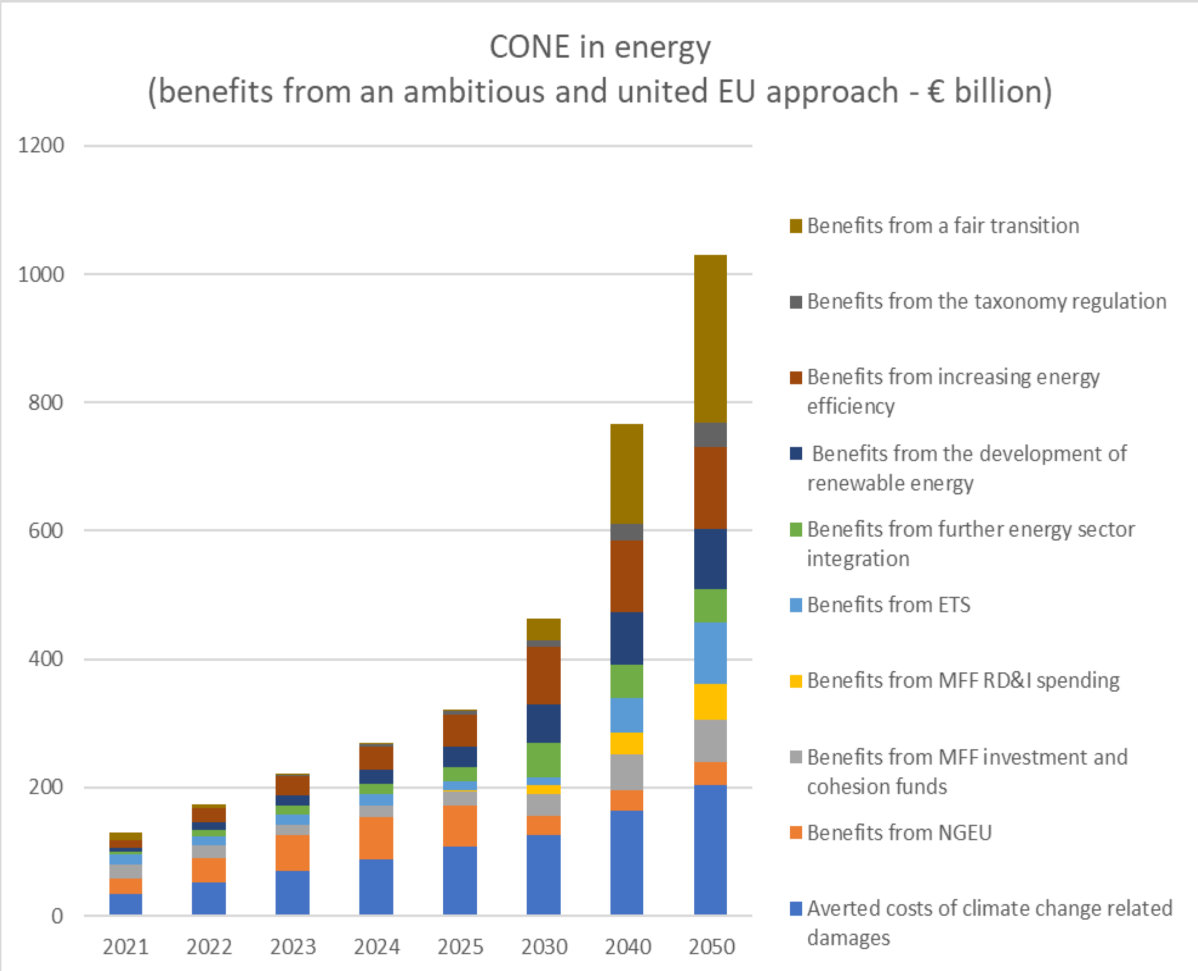
More specifically, the CoNE incorporates the gains expected from EU action in 10 policy fields. It thus complements previous analyses and broadens their scope. The first result, based on looking at selected climate impacts, reveals that by leading and doing its share to keeping the global temperature rise at 1.5 C, the EU could avert damages worth **€203 billion per year**. With regard to

[176] See notably OECD, Investing in Climate, Investing in Growth, 2019.

the impact of climate-related EU budgetary actions, this report found that climate-related NGEU investments would bring long-term benefits of **€37 billion per year;** while benefits from climate-related MFF investment and cohesion funds and benefits from climate-related MFF RD&I spending would reach respectively **€66 and €55 billion per year. The EU ETS**, through the efficiency gains that it ensures compared to non-economic approaches and through the double dividend generated by revenues recycling, would **contribute with €96 billion per year.**

With regard to the **integration of energy markets**, a full integration could result in potential gains for the European economy of at least **€53 billion per year**. This includes a benefit of €25 billion per year related to further integration of the electricity market and €28 billion per year related to further integration of the gas market. Further development of renewable energy and the respect of EU targets in that area would bring **€94 billion per year.** This includes €27 billion from related reduced EU dependency on fossil fuel imports. Achieving increased energy efficiency in the range of the EU target of 40 % by 2030, would bring **€126 billion per year** in economic benefits. This includes €36 billion from reduced EU dependency on fossil fuel imports. The EU Taxonomy Regulation by improving clarity on what responsible energy investment means and by encouraging environmental and social governance would increase GDP by **€39 billion per year.** Finally, by ensuring a fair transformation where no one feels left behind, the EU could ensure that an additional benefit of **€261 billion per year** materialises.

Figure 11 – CoNE in energy: Ambitious and united EU action vs the baseline (€ billion per year)



Source: Authors' own calculations.

As usual in this kind of exercise, the results are subject to a number of well-known caveats. First, non-market damages are captured only partially. For instance we do not include all potential co-benefits such as reduced air pollution and co-costs that could also be triggered by the transformation towards a greener EU economy. The induced effects, notably on health and productivity could therefore be affected. The results are also subject to uncertainty, in particular the results on the averted costs of climate change-related damages as by nature, extreme events and their possible systemic effects are highly uncertain and difficult to quantify. In such a long term horizon, projections are less stable as uncertainty increases with time. Results are also dependent on some assumptions made, such as when certain technologies will be available. That being said, investment made today and trajectory taken regarding the energy sector have long term impacts, so it is important to have a vision of the situation as it currently stands.

4. Priority EU policy actions for the energy transformation

Having discussed the main key policy challenges that the EU faces in its quest towards a net-zero economy and energy system in 2050 and having looked at the potential environmental, economic and social impacts of this transformation, this chapter presents the **priority actions** that could enable an effective energy transformation. The selection is done based on the results of the study in Annex II and the available literature (listed in the References Section at the end). The proposed actions are not exhaustive and do not address all of the related challenges mentioned above. They were selected based on the assumption that these EU level actions could bring the most added value and be of the highest interest, considering the remit of the EP ITRE committee that has requested this report.

Pledges and commitments that are not operationalised and effectively implemented will not be sufficient to provide guidance, make actual change and deliver on the expectations of citizens. It has also to be acknowledged that acting on the energy transformation, some sensitive trade-offs will need to be addressed. Moreover, the European Parliament, as a direct representation of the EU citizens, has a central role to play in making sure that the energy transformation happens in a fair way, to the benefit of all EU social and economic actors.

4.1. Ensuring ambitious and long-term financing and innovation

A massive and rapid deployment of renewable energy and its necessary infrastructure coupled with investment bringing energy efficiency are necessary if carbon emissions are to be sharply reduced within the energy system. As highlighted in the study in Annex II, private funding will need to be supported by public funding. Given the constrained budgets of an increasing number of Member States, only sustained **EU financing** can bring the resources to deliver on the necessary climate ambitions while ensuring solidarity (see Chapter 3).

Moreover, as shown in Chapter 2, many challenges are linked to the fact that the necessary carbon-neutral technology is not yet widely deployed and sometimes not even available and that it will require investing significant resources to RD&I to match EU ambitions. An **appropriate level of long-term EU RD&I financing** will be key for the future of EU sustainable growth and competitiveness of a decarbonising economy. It will determine if the objective of a **rapid development and deployment of carbon-neutral technologies** can be achieved. Common EU investment capacities make perfect economic sense. For example in research, they allow to benefit from large economies of scale in some programmes, but also to avoid waste of resources in duplication of existing parallel national research programmes in 27 Member States.

Moreover, the appropriate amount of financing will allow the EU not to lose in the global green technology race and ensure more EU competitiveness, strategic autonomy and less costly dependencies. This could also ensure that past mistakes such as lost competitive advantage in deployment of some green technologies (notably solar panels) are avoided by strategic financing In particular, **continent-wide research and innovation cooperation and investment** is proved to bring benefits and European added value (Teasdale, A., 2019; Beun, H., et al., 2019). EU actions and investments in research are delivering public goods that would not be done by private sector alone. Common EU Member States' action in this field is more coherent and efficient compared to individual one, and can reap the benefits of economies of scale. The success of relevant policies, instruments and actions could be reflected in an increased level of EU patenting of green technologies in the next decade.

Key EU actions in energy projects financing and innovation

- ensure appropriate long-term investment for clean energy projects;
- ensure a continuous support for energy efficiency investment and riskier energy projects (e.g. as currently done through EIB);
- ensure RD&I scale-up and deployment of green technologies;
- strengthen collaborative research and investment at EU level. For example consider new IPCEIs e.g. to scale-up: hydrogen production, power-to-X and CCUS;
- ensure efficient use of mobilised common resources, avoid budgetary waste and improve coordination between EU funds and between EU, national, regional and local spending.

Source: Prepared by the authors.

4.2. Ensuring a fair transformation so that no one feels left behind

Following a net-zero pathway is an unprecedented effort that presents many socio-economic challenges but also opportunities.[177] Such a ground-breaking and rapid transformation 'cannot be achieved without sustained support and participation from citizens' (IEA, 2021). Ensuring that it is done fairly and leaves no one behind might be the biggest societal challenge of climate transformation. Although the EU has recently taken some action to ensure that the net zero transformation is just and inclusive, it still needs to ensure that objectives are translated into tangible and sustainable over a long term results. **Acceleration of the annual renovation rate**, **reduction of energy poverty** and **successful re-orientation of economies of fossil-fuel dependant regions**, would be signs that the EU is moving in the right direction. Meanwhile, the recently adopted NGEU package constitutes an important opportunity for Member States to address socio-economic challenges of clean energy transformation in their reforms and investments. However, it remains to be seen if the available funding and investment potential will be used effectively and efficiently as well as whether it will be enough to achieve EU long-term objectives.

Critically **ensuring affordable and competitive electricity prices** could be challenging. Recent spike in gas prices that is expected to be projected into raises in both gas and electricity prices for EU households, shows how EU energy consumers are vulnerable to shocks related to energy imports. Strengthening cooperation at EU level on energy prices and security of supply could help addressing some of the arising challenges, support Member State action at national level and allow to speak with one voice at international level.

Finding the **right tools**, discussing the trade-offs in an **inclusive way** and effectively implementing the collectively found solutions will be key to ensure that those most in need are also benefiting from them.[178] EU level cooperation can support the fairness of the transformation by further enhancing territorial and country level **convergence as well as cohesion**. Moreover, involvement of the EP, civil society and representatives of all societal groups at all stages of the policy discussion should be reinforced to ensure **inclusiveness and transparency**. Without these, there is a risk that citizens and other stakeholders might feel excluded and their voice not heard. An effective and democratic energy transformation needs whole of society on board of such an unprecedented change.

[177] See Chapter 2.2 for a description of the social challenges and Chapter 3.4 for a quantification of the social impacts of EU energy transformation.

[178] European Commission, Proposal for a regulation establishing a Social Climate Fund, COM(2021)568 final.

Key EU actions in ensuring a fair transformation

- ensure that poor and vulnerable households are protected and empowered as energy consumers, thus reducing energy poverty;
- ensure affordable prices of energy and universal access to energy by making sure that any financial burden of energy transformation is shared fairly and in a transparent way between, energy exporters, energy providers, consumers and taxpayers;
- ensure that energy efficiency of buildings is boosted in the EU, is fit for the EU's climate and energy objectives and delivers not only growth and jobs but also environmental benefits;
- ensure that the necessary investment to finance the transformation does not increase the overall burden of taxation within the EU, which could have potential negative consequences in terms of competitiveness;
- ensure democratic representation, dialogue and transparency during development of the transformation's policies and actions.

Source: Prepared by the authors.

4.3. Ensuring a well-functioning and integrated internal energy market

A well-functioning internal energy market is integral to the successful realisation of carbon-neutral pathways. It will also create a level-playing field for businesses and consumers and could accelerate the EU energy transformation. Nevertheless, in the pursuit of climate and energy policies there are many trade-offs between the need for competitive markets, on the one hand, and the need for public intervention (including the allocation of public finances for low-carbon investment), on the other. One needs to make sure that public support and subsidies do not hamper competition and do not contribute to fragmentation of the energy market. **The challenge is also to avoid distortive subsidies and an excessive and heavy multi-layered administrative burden that reduces efficiency, slows entrepreneurship, reduces competition and restricts the market entry of new innovative competitors**. The EU has a key supportive role to play, by ensuring that successful EU businesses gets full access to the single market for their green products and services, without having to face the heavy multi-layered requirements placed by some national markets for the sake of artificially protecting uncompetitive local incumbents.

A key role for the EU would be to **ensure the harmonisation** of carbon neutral technologies, the development of new and the strengthening of existing **standards**, and to ensure a **well-functioning internal market**. Pursuing the transformation in a technology neutral way would help avoid market distortions, divisions and a non-respect of emission reduction objectives. A common understanding of best tools and solutions together with a concerted realisation of objectives could ensure the transformation's success. If merged, the efforts channelled towards achieving the digital and the energy transformation will be mutually reinforcing. As the IEA recommends, the EU could benefit a lot from an energy system-wide approach if it would adopt the right regulatory rules for **system integration**. This would necessitate action on removing existing barriers (related to carbon-pricing signals, regulatory aspects and infrastructure development) and **bold action** for supporting key clean fuel industries such as low-carbon hydrogen (e.g. facilitating regional clusters and enabling infrastructure and industrial alliances) (IEA, 2020).

Further integration means a more **effective EU energy union**. Increasing interconnections and energy flows between the Member States to the desired level would need to be backed by coherent political action both on the EU market but also in relations with third countries to deliver energy and ensure the EU citizens' desired level of security of supply (see more in the following chapter). A potentially effective tool that could strengthen the EU energy union would be the development of a framework for **public procurement and collective purchasing in energy** (as has been proposed by the EP in the past for gas[179]).

Key EU actions in internal energy market

- ensure the right carbon-price signals, avoid distortive subsidies and an excessive and heavy multi-layered administrative burden;
- ensure that the EU internal market works for the green transformation: strengthen fair competition through appropriate competition and state aid rules; and build an enabling regulatory environment through standardisation and harmonisation of new carbon-neutral technologies;
- ensure that energy system integration is a key priority, that regulatory barriers are removed, and that an enabling policy and funding for development of innovation, technology and digitalisation are available;
- ensure a more integrated and secure energy market. Consider initiatives – such as public procurement and collective purchasing in energy – that strengthen EU energy policy.

Source: Prepared by the authors.

4.4. Ensuring a more strategic, united and credible energy security policy and global multilateral cooperation

A lack of EU ambition to pursue a credible and effective decarbonisation pathway would be received as a bad signal at international level, as the EU has so far spearheaded the fight against climate change. Given the accumulated amount of past GHG emissions, one can claim that the EU has a duty to prove that attaining net zero GHG emissions is achievable.

In the upcoming shifts in global fossil fuel demand and supply, the EU should strengthen its actions and be **more united towards third supplier countries**. In the short term, before higher levels of energy supply independence could be ensured thanks to renewables and carbon-neutral technologies deployment, this could avoid an excessive leakage of added value as well as some excessive prices that some Member States are facing, and help the bloc as a whole reap benefits from lower external energy dependency.

The EU is the world's biggest fossil fuel energy products importer, and this strengthens the case to be made for this immense import bill being paid entirely in euros (and not only 20 % of it as is currently the case) (European Commission, 2018; Ribakova, E. and Bruegel, 2019). The European Commission has so far issued recommendations on the issue to Member States and analyses on how to best implement them. **Wider use of the euro in international energy transactions** could bring several benefits including reducing the risk of disruption of energy supplies and counterbalancing the variation in exchange rates.[180]

[179] European Parliament resolution of 15 December 2015 on Towards a European Energy Union (2015/2113(INI)), P8_TA(2015)0444.

[180] For other potential actions to take that would increase EU resilience in the energy area, see the chapter on 'Reducing energy dependency and enhancing energy efficiency in the EU' in the EPRS, DG IPOL and DG EXPO publication: Towards a more resilient Europe post-coronavirus. Options to enhance the EU's resilience to structural risks, European Parliamentary Research Service with the Directorates-General for Internal Policies (IPOL) and External Policies (EXPO) PE 659.437, April 2021.

At the same time, in the long term, the EU should continue to ensure its security of supply by pursuing an effective energy efficiency policy, as well as **diversifying its suppliers and energy sources**. Energy markets and renewables markets can become truly integrated and interconnected across the EU if they can yield cost-savings while also maintaining security of supply.

The EU needs a long-term common vision to address the problem of carbon leakage. To mitigate the impacts of ambitious EU climate policies on the competitiveness of EU industry, a WTO-compliant carbon border adjustment mechanism advocated by the EU Parliament is a solution that is currently being considered by the European Commission (European Commission, 2020b).

Key EU actions in energy security and at international level

- aim at a united approach towards third energy supplier countries;
- ensure wider use of the euro in international agreements and non-binding instruments related to energy;
- ensure continuous diversification of supply through diversification of suppliers as well as through further integration and interconnectivity of the internal energy market;
- ensure a WTO-compliant carbon mechanism on the EU external border to ensure the competitiveness of EU industry during this unprecedented energy transformation.

Source: Prepared by the authors.

5. Conclusion

Achieving climate neutrality (net-zero GHG emissions) in 29 years from now is an unprecedented challenge at a global scale. It is about **realising a public good of paramount importance** – the protection of Earth's climate to avoid the worst climate change effects. This objective requires making profound structural changes in the whole of economy and society. **Rapidly transforming energy systems** to non-GHG emitting ones will determine whether this race against the clock can be won. However, this transformation is not only about limiting GHG emissions – it would not be successful if it is not fair and transparent. It will also not be successful if it deepens existing social and economic inequalities, if citizens around the world do not play an important part in it as energy consumers and prosumers and if the most vulnerable social groups lose instead of benefit from the changes that will be made. This transformation **should leave everyone better off**.

Although there are **many challenges ahead** and each country has a **different starting point** in decarbonising its energy system, many key objectives that need to be achieved cannot be attained by individual and uncoordinated action at national level. On the contrary, a fragmented approach would only increase costs and would not allow the targets to be achieved. This naturally does not exclude an important and necessary **action at all levels of governance**.

Looking at these issues, this report reaffirms that the decarbonisation of the European energy system is **not possible without ambitious and united EU action**. The cost of non-Europe in energy transformation means that maintaining the status quo or reverting to fragmented action for reducing GHG emissions and transforming the EU energy systems would be less efficient, less effective, but also costly and unfair. As presented in previous chapters, other socio-economic benefits of EU inaction would be forgone as well. Some of them were possible to calculate in this report, while others were out of its scope and would require more detailed research and quantification.

Action and cooperation at EU level has a potential to enable many of the necessary and rapid measures needed to be taken with regard to the internal energy market, addressing issues such as security of energy supply, pushing needed green technologies on the market, and ensuring an appropriate level of public financing by providing funds, grants and loans. Opportunities such as economies of scale and coordination gains should be seized, thereby delivering European added value (EAV) in terms of policies and financing.

Mitigating some potential socio-economic negative effects of the transformation could also be effectively and efficiently **addressed at EU level**, in order to ensure coherence and convergence within the Union. More specifically, further action at EU level should be foreseen to ensure that EU citizens have the necessary means to have access to appropriate levels of clean energy. EU energy consumer rights should also be further strengthened and a level playing field ensured for EU business.

However, failure to arrive at common approaches in this area, in particular through collectively addressing volatile energy prices and systemic risks emerging from the dependency of the EU from external suppliers would result in the non-materialisation of some or of the entirety of the potential benefits presented in this report. In a more and more uncertain world, **systematically stress testing** ongoing initiatives and moving away from feel good agendas towards a more strategic vision would be essential as preparedness and foresight prove beneficial in increasing resilience and robustness in times of crisis.[181]

Another argument in favour of further EU commitment and action on the energy system transformation is that **EU citizens seem to fully support EU level action on climate change**.[182] Moreover, EU citizens seem to be better informed than other citizens on how to reduce their individual climate change impact, although there is room for improvement.[183] The European Parliament has an important role to play as EU citizens favour seeing its role increase including in relation to green transformation.[184]

Finally, the EU cannot act alone at a global scale – there needs to be a coordinated multilateral international effort backed by concrete actions as there is no time left for promises and pledges that do not deliver. **The EU has a very important role to play** as a leader and has many experience to share after pursuing a relatively ambitious decarbonisation path for over a decade. **The EU has also a duty to act** as it has been one of the main contributors to the GHG stock accumulated in the atmosphere since the industrial revolution as well as due to some unsustainable consumption patterns.

181 For more on EPRS work on stress testing see: Fernandes, M. and Heflich A., Future proofing' EU policies-The why, what and how of stress testing, European Parliamentary Research Service, European Added Value Unit PE 694.209 – July 2021.

182 https://ec.europa.eu/clima/citizens/support_en.

183 https://www.ipsos.com/en/ipsos-perils-perception-climate-change.

184 Parlemeter 2020: A Glimpse of Certainty in Uncertain Times.

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ANNEX I

Figure 12: Climate mainstreaming in the EU MFF (2021-2027) and in NGEU

COVERED IN THIS STUDY	Financial envelope (€ billion)	Expected minimum climate target	Expected climate contribution (€ billion)	Expected climate contribution per year (€ billion)
NGEU–Recovery and Resilience Facility (Grants)	338	37%	125	
NGEU–Recovery and Resilience Facility (Loans)	386	37%	143	
TOTAL NGEU			**268**	**38**
Connecting Europe Facility (CEF)	21	60%	12	
LIFE (Programme for environment and climate action)	5	61%	3	
Invest EU Fund	10	30%	3	
Expected investment leveraged by Invest EU through the EIB	372	30%	112	
Total investment funds			**130**	**19**
Cohesion Fund	48	37%	18	
European Regional Development Fund (ERDF)	226	30%	68	
REACT EU	51	25%	13	
Just Transition Fund	19	100%	19	
Cofinancing at Member States level	114	34%	39	
Total cohesion funds			**156**	**22**
Total MFF investment and cohesion funds			**287**	**41**
Horizon Europe	96	35%	33	
ITER	6	100%	6	
Total MFF RD&I			**39**	**6**
TOTAL MFF covered in this study			**326**	**47**
TOTAL MFF + NGEU covered in this study			**593**	**85**

NOT COVERED IN THIS STUDY				
Common agricultural policy 2021-2022	*117*	*26%*	*30*	
Common agricultural policy 2023-2027	*270*	*40%*	*108*	
European Maritime Fisheries and Aquaculture Fund	*6*	*30%*	*2*	
Total MFF CAP and fisheries			***140***	***20***
Neighbourhood Development and International Cooperation Instrument (NDICI)	*81*	*25%*	*20*	
Overseas Countries and Territories (OCT)	*1*	*25%*	*0,1*	
Pre-Accession Assistance	*14*	*16%*	*2*	
Total MFF cooperation and assistance			***23***	***3***

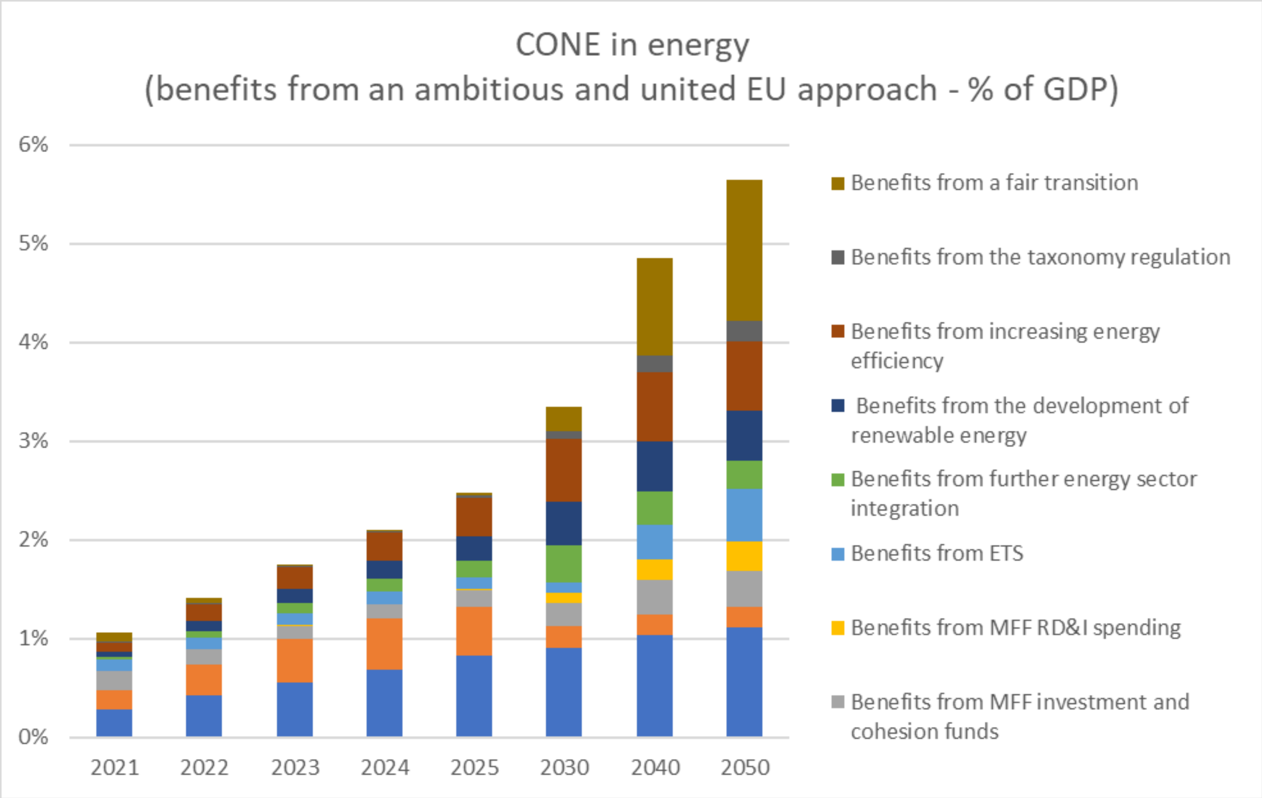
Source: EPRS, 2021.

Figure 13: Activities and sectors covered by the EU ETS in 2018

Activities	Sectors	No. of entities	Verified Emissions
20 Combustion of fuels	Combustion	7496	1.095
21 Refining of mineral oil	Refineries	139	125
22 Production of coke	Iron and steel, coke, metal ore	20	11
23 Metal ore roasting or sintering		9	3
24 Production of pig iron or steel		247	122
25 Production or processing of ferrous metals		250	13
26 Production of primary aluminium	Other metals (incl. aluminium)	33	9
27 Production of secondary aluminium		33	1
28 Production or processing of non-ferrous metals		91	8
29 Production of cement clinker	Cement and lime	261	121
30 Production of lime, or calcination of dolomite/magnesite		297	32
31 Manufacture of glass	Other non-metallic minerals	372	18
32 Manufacture of ceramics		1083	15
33 Manufacture of mineral wool		52	2
34 Production or processing of gypsum or plasterboard		40	1
35 Production of pulp	Pulp and Paper	179	6
36 Production of paper or cardboard		586	22
37 Production of carbon black	Chemicals	18	2
38 Production of nitric acid		37	4
39 Production of adipic acid		3	0
40 Production of glyoxal and glyoxylic acid		1	0
41 Production of ammonia		29	21
42 Production of bulk chemicals		364	38
43 Production of hydrogen and synthesis gas		42	8
44 Production of soda ash and sodium bicarbonate		14	3
45 Capture of greenhouse gases under Directive 2009/31/EC	Other	2	0
46 Transport of greenhouse gases under Directive 2009/31/EC		1	0
99 Other activity opted-in under Art. 24		257	1
Sum of all stationary installations	**Stationary**	**11.956**	**1.682**
10 Aviation	Aviation	511	67

Source: EEA, 2019.

Figure 14: CONE in energy (% of GDP) – Ambitious and united EU action vs baseline



Source: Authors' calculations.

Annex

Cost of non-Europe in the area of energy

Abstract

This study aims to estimate the net cost if no further action is taken at EU level to effectively decarbonise the EU energy system by 2050 (i.e. the cost of non-Europe). Thirteen key challenges to realise the energy transition are identified, and the most relevant EU and Member State policies for addressing each challenge are assessed. EU-level action is particularly important for collective strategy formation and target-setting, both through the existing governance and target-setting frameworks and through the implementation of specific projects of common interest (e.g. IPCEIs) for promoting technologies with high relevance for the energy transition (e.g. hydrogen). Furthermore, EU-level action is indispensable for implementing effective and efficient carbon pricing, through extending the EU ETS and possibly implementing a carbon border adjustment mechanism, and for ensuring sufficient investment in sustainable technologies, both through core EU funding in the Multiannual Financial Framework, and through exceptional funding under the EU recovery plan (Next Generation EU). Without such EU level policies a significant gap in the required emission reductions for reaching net zero by 2050 would occur. Additionally, GDP, jobs and import dependence would evolve less positively without such EU action. Furthermore, several other EU-level policies with significant room for further added value were identified, including additional action on market integration and research, development and innovation in the energy sector.

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Executive summary

This study aims to estimate the net cost if no further action is taken at EU level to decarbonise the EU energy system by 2050, while ensuring security of energy supply and providing competitive and affordable energy supply to EU citizens and businesses via properly integrated energy systems and markets. This net cost comprises different dimensions and includes economic, environmental, social and geopolitical cost impacts. Within this report these costs are referred to as the 'cost of non-Europe'.

We applied a three-staged approach to estimate the cost of non-Europe. In the first stage, we identified the main challenges associated with realising the energy transition efficiently. In the second stage, we identified whether and how EU policy measures can contribute to adequately addressing the main challenges. In the third stage, we estimated the impact if no further action was taken at EU level.

The identification of challenges for realising the energy transition was performed by comparing the baseline scenario of no further EU action with a trajectory[1] for reaching 55 % less greenhouse gas (GHG) emissions by 2030 and net zero emissions by 2050. Any area where a significant gap between these two scenarios was identified is considered as a 'challenge' and an opportunity for additional policy measures to fill in the gap. **This exercise allowed us to identify 13 key challenges (see Table 1), including both supply-side issues, related to energy production, infrastructure and markets, and demand-side issues, related to energy efficiency, fuel switching and demand response.**

To estimate whether and how EU policy measures can contribute to efficiently address the 13 main challenges, we first identified the underlying gaps and barriers for each of them. Secondly, we assessed which policy measures would be most appropriate for addressing those gaps and barriers. Thirdly, we identified the most appropriate level of public intervention per policy measure, categorising the considered measures into those where the EU could take the primary action, those where Member States could take the primary action, and those where a joint EU-Member State action would be most appropriate. This analysis resulted in the **identification of four policy instruments where EU primary action would be beneficial** and consequently where a lack of further EU action would obviously lead to a *cost of non-Europe*. In addition, we **identified six policy instruments where joint EU-MS action would be most appropriate** and where also a *cost of non-Europe* would occur if no further action was taken at EU level. The mapping of the most relevant policy instruments per challenge and the assessment of the most appropriate level of public intervention are summarised in Table 1.

The primary tool for quantifying the cost of non-Europe was an assessment of a selection of policy packages through the macroeconomic model E3ME. To complete the picture, a literature review was performed to assess the robustness of the results given by E3ME and to estimate the impacts of policy measures which could not be evaluated in sufficient detail through the modelling.

[1] The MIX55 scenario developed for the Climate Target Plan was selected for this purpose.

Table 1: Summary of key challenges, most relevant policy measures for addressing those and appropriate level of public intervention

Challenge	EU primary action				Joint EU-MS action and cooperation						MS primary action
	Strategies & targets	Carbon pricing	Market design & regulation	Standards & minimum requirements	Co-funding of investments	Subsidies	Loans & guarantees	RD&I funding	Tax & levy reform	Communica-tion & training	Bans on specific technologies
1. Accelerate solar and wind energy deployment											
2. Develop and scale up CCUS for power plants and industry											
3. Accelerate phase out of fossil fuel use for power generation											
4. Scale up battery storage											
5. Scale up low -carbon hydrogen production and power -to-x											
6. Promote further cross -border integration of electricity systems and markets											
7. Promote electricity demand response											
8. Increase bioenergy supply in a sustainable manner											
9. Increase renovation rates of buildings											
10. Scale up electrification of building end uses											
11. Accelerate implementation of carbon -neutral technology in industrial processes											
12. Accelerate electrification of passenger and light duty vehicles											
13. Develop & implement carbon neutral options for heavy road transport, navigation and aviation											

Source: own elaboration.

We conclude that there is considerable scope for further EU action to realise the energy transition in an efficient way. Firstly, **EU action is important for strategy development and target setting** as moving forward in a coordinated and collective manner is important for establishing ambitious and coherent national plans that also facilitate cooperation with other EU Member States, allowing to achieve an optimum outcome from an EU wide perspective. The targets and policies to reduce GHG emissions, increase renewable energy generation and enhance energy efficiency are pivotal in this regard, alongside specific EU coordination for planning and developing public energy infrastructure (e.g. Ten-Year Network Development Plans (TYNDPs) and Trans-European Networks for Energy (TEN-E)) and deploying promising key technologies (e.g. batteries, power-to-hydrogen, Carbon Capture Utilisation and Storage (CCUS), offshore renewable energy). Furthermore, EU financial support for energy infrastructure projects (as Projects of Common Interest (PCIs)) and for industry/innovation projects (as Important Projects of Common European Interest (IPCEIs) is expected to substantially contribute to addressing major challenges of the energy transition.

EU action is also crucial for effective carbon pricing, technical standardisation and energy markets' integration. Furthermore, the **EU plays an important role in co-funding energy infrastructure, providing subsidies and reducing the cost of capital for sustainable investments, funding research development and innovation (RD&I), coordinating tax reform and creating awareness**. Key instruments in this context include the EU Emissions Trading System (ETS), the Connecting Europe Facility, the EU renewable energy financing mechanism, the EU taxonomy for sustainable activities and Horizon Europe. The requirement to dedicate a minimum share of the EU budget to climate-relevant topics (30% at least) in combination with the significant size of the multiannual financial framework (MFF: >EUR 100 Bn/year) and NextGenerationEU (total budget: 750 Bn EUR) will result in a considerable amount of EU funding (EUR 50-100 Bn/year) that is directed to sustainable investments in EU Member States.

We quantified the impacts of a selection of two major EU-driven policies (extending the ETS[2] and EU funding for sustainable investments) through the macroeconomic model E3ME. The results are presented in Table 2 which summarises the impact of a set of policies that collectively reach 55% GHG emission reductions by 2030 and net zero emissions by 2050 (Net Zero), a scenario that excludes the extended/intensified ETS and a scenario that excludes the extra EU funding. The impacts are shown as a percentage-difference from the baseline scenario which represents the EU policy package agreed in 2018 that aimed to deliver GHG emission reductions of at least 40 % by 2030.

[2] This model run also excluded a reduced cost of capital assumption for sustainable investments but the impact of that was relatively minor.

Table 2: Results of modelling: summary of main impacts of major EU-driven policies

% difference from the baseline	2021	2030	2050
GDP			
Net Zero	0.7	3.2	3.0
Removing extended/intensified ETS	0.5	3.1	2.6
Removing EU extra funding	0.4	2.9	3.0
Carbon dioxide emission reduction			
Net Zero	-4.5	-43.1	-81.9
Removing extended/intensified ETS	-3.6	-41.3	-68.6
Removing EU extra funding	-1.8	-35.9	-66.4
Total employment			
Net Zero	0.2	0.9	1.1
Removing extended/intensified ETS	0.1	0.9	0.8
Removing EU extra funding	0.2	0.9	1.1

The modelling showed that the **intensification and extension[3] of carbon pricing through the EU ETS plays a substantial role in realising the climate targets** in an efficient manner. A model run without the EU-led extended ETS, showed that the absence of this instrument would result in a substantial gap in reaching net zero GHG emissions (+/- 50 million tonnes CO_2 by 2050), more unemployment (+/- 700k jobs), a higher dependence on fossil fuel imports as well as a slightly negative impact on economic growth. Additionally, to avoid carbon leakage and mitigate the impacts of ambitious EU climate policies on the competitiveness of EU industry, a WTO compliant carbon border adjustment mechanism could be considered and is currently being developed by the European Commission. The benefits and potential drawbacks of this instrument are briefly addressed in the report.

Another model run showed that the **additional EU funding channelled to sustainable investments, both through the core MFF and from NextGenerationEU, has also a significant impact**. We estimate that the climate mainstreaming commitments could amount to an additional annual investment in green technologies of €70 billion/year from 2021 to 2027, and €38 billion/year from 2028 to 2050, and that this spending has a significant impact on realising the GHG emission reduction targets (+/- 50 million tonnes CO2 by 2050) combined with positive contributions to economic growth and import dependence.

Based on a complementary literature review, we concluded that **further benefits of additional EU action in the area of electricity markets' integration would range between €16 and €43 billion per year** by 2030 and that the **benefits of EU coordinated RD&I action through Horizon Europe, the primary EU instrument to stimulate RD&I, would roughly amount to around €113 billion of gross domestic product (GDP) growth over 25 years** (cumulatively). In both cases, the required actions are primarily EU-driven and as a result, not implementing these actions would result in a Cost of non-Europe.

[3] Extension to other sectors in the economy that are not currently included in ETS.

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List of abbreviations

Abbreviation	Full name
ACER	The European Union Agency for the Cooperation of Energy Regulators
BECCS	Bioenergy with CCS
BSL	Baseline
CAGR	Compound Annual Growth Rate
CBA	Cost-benefit analysis
CBAM	Carbon border adjustment mechanism
CCS	Carbon Capture and Storage
CCUS	Carbon Capture Utilisation and Storage
CEF	Connecting Europe Facility
CO_2	Carbon dioxide
CSP	Concentrated Solar Power
DA	Day ahead
DG RTD	Directorate-General for Research and Innovation
DR	Demand Response
EED	Energy Efficiency Directive
EFSI	European Fund for Strategic Investments
ENTSO-E	European Network of Transmission System Operators for Electricity
EPC	Energy Performance Contracting
ETD	Energy Taxation Directive
ETIP	EU Technology and Innovation Platform
ETS	Emission Trading Scheme
EU	European Union
FP	Framework Programme
FP7	Seventh Framework Programme
FP6	Sixth Framework Programme
FTT	Future Technology Transformation
GBARD	Government budget allocations for R&D
GDP	gross domestic product
GHG	greenhouse gas
Gt	giga tonnes
GVA	gross value added
ICE	internal combustion engine
IPCEI	Important Projects of Common European Interest
JRC	Joint Research Centre
LULUCF	Land use, land use change and forestry
MEPS	Minimum Energy Performance Standards
MFF	multiannual financial framework
MIX	MIX55 scenario
Mt	million tonnes
OTC	over the counter
R&D	research and development
R&I	research and innovation
RD&I	research, development and innovation

RES	renewable energy sources
TEN-E	Trans-European Networks for Energy
TYNDP	Ten-Year Network Development Plan
UK	United Kingdom
VAT	value-added tax
WTO	World Trade Organization

1. Introduction

The objective of this report is to estimate the net cost if no further action is taken at EU level to decarbonise the EU energy system by 2050, to efficiently ensure security of energy supply and to provide competitive and affordable energy supply to EU citizens and businesses via properly integrated energy systems and markets. This **net cost comprises different dimensions and includes economic, environmental, social and geopolitical costs.** Within this report these costs are also referred to as the **cost of non-Europe** per the concept applied more widely in studies on the topic.[4] Moreover, the net costs of non-Europe can also be understood as the potential added value of further EU action. Throughout this report, we use those concepts interchangeably.

For a proper computation of a forward-looking estimate of the cost of non-Europe, it is important to clearly define which actions and policies have been implemented already as those are part of the **baseline trajectory** to compare the added value of further EU action to. Hence, past EU initiatives to integrate EU energy markets, stimulate renewable energy sources, promote energy savings, safeguard security of supply, etc. are not taken into account when calculating the cost of non-Europe, notwithstanding the benefits they delivered and will continue to deliver. We consider as baseline projection the EU policy package agreed in 2018 that aimed to deliver a 32 % share of renewable energy sources (RES) in 2030, 32.5 % energy consumption reduction and contribute to greenhouse gas (GHG) emission reductions of at least 40 % by 2030. Further EU actions beyond those already implemented, such as the increased ambitions put forward under the EU Green Deal, including the forthcoming 'fit for 55 %' package that will align EU climate and energy legislation with an agreed target of 55 % GHG emission reductions by 2030, are not considered part of the baseline trajectory as the relevant legislation and detailed policies to deliver these ambitions were still under development at the time of writing this report (January – May 2021).

The first step to estimate the cost of non-Europe in the area of energy is to identify the main **challenges** that need to be overcome to efficiently realise the energy transition. For this exercise we compare the required trajectory to realise climate neutrality by 2050 as set out in the Climate Target Plan[5] with the baseline projection, covering developments in energy supply (production, infrastructure, markets) and demand (energy efficiency, fuel switching, demand response). Any area where a substantial gap exists between the baseline projection and the required trajectory is considered a challenge and a potential opportunity for additional EU policies to add value. Due to the breadth of the exercise it was not feasible to assess the specificities of the individual EU instruments within the scope of this study. This limitation is the reason that we work with the Climate Target Plan to identify any gaps between the baseline developments (based on the current policies) and the required developments (the climate neutrality scenarios). This way, we can assess the 'fitness' of the current policies in a practical way. The results of this assessment are presented in chapter 2: Key challenges for the energy transition.

The second step is to identify how **EU policy measures** can contribute to address the key challenges for the energy transition. For this exercise we first identify the underlying gaps and barriers for each challenge and identify the most appropriate policy measures to address those. Next, we estimate the most appropriate level of public intervention per policy measure, categorising measures into those where the EU could take the primary action, those where Member States could take the primary action and those where a joint EU-Member State action could be most appropriate. Finally,

4 The concept of the 'cost of non-Europe' was introduced by Michel Albert and James Ball and first applied by Paolo Cecchini on the topic of realising a single market in Europe (Commission on the European Communities, Europe 1992, the Overall Challenge, SEC (1988) 524).

5 SWD(2020)176 final – Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan).

we design a package of additional policy measures that can be taken to realise the energy transition and a selection of variants which omit EU-driven initiatives to enable a quantitative assessment of the cost of non-Europe. The results of this exercise are presented in chapter 3: Potential EU policy measures to address the key challenges.

The third step is to conduct a **quantitative assessment of the cost of non-Europe**. For this assessment we evaluate the impacts of the policy packages developed in the previous step through the macroeconomic model E3ME. By comparing the results of a scenario in which the full policy package is implemented, with variants in which the most important EU level policies are omitted, we get an estimate of the added value of additional EU level policies and the cost of not implementing such policies. Additionally, some complementary analyses based on a literature assessment are provided to estimate the cost of non-Europe for measures that cannot be fully evaluated with the E3ME model. The results of this assessment are presented in chapter 4: Assessing the cost of non-Europe.

The final step is to consolidate the findings and draw conclusions on where further EU action is most needed and advise on the priority measures to pursue at EU level, which is the subject of the final chapter.

2. Key challenges for the energy transition

2.1. Introduction

2.1.1. Objective and approach

The objective of this chapter is to identify the most substantial challenges for realising the energy transition which are not addressed sufficiently with the policy measures that have been adopted so far. Within this context we define 'realising the energy transition' as achieving climate-neutrality by 2050, in line with the ambitions set out by the EU Green Deal.

The identification of key challenges will be performed by comparing the baseline trajectory that would be achieved if no further policy measures are applied, with the projected trajectory for reaching the 2050 ambition level. Any area where there is a significant gap between the baseline projection and the climate-neutrality scenarios is considered a 'challenge' for realising the energy transition.

The recently adopted (September 2020) Climate Target Plan and in particular the accompanying Impact Assessment[6] serve as the basis for this exercise as it is both comprehensive in scope and aligned with the most recent ambitions. The Impact Assessment includes a baseline (BSL) projection which represents the existing 2030 climate and energy legislative framework that implements the 'at least 40 %' GHG emission reduction target and the 32.5 % energy efficiency and 32% renewable targets (by 2030) and reaches a 59 % GHG emission reduction by 2050 (compared to the 1990 level). We use this BSL projection also as the baseline for our analyses in this chapter.[7] Furthermore, a range of scenarios which realise 50-55 % GHG emission reductions by 2030 and net zero[8] emissions by 2050 are included. The scenarios differ in terms of their emphasis on regulatory or carbon pricing instruments and in terms of the short-term (2030) ambition level (50 or 55 % GHG emission reduction), but all achieve climate-neutrality by 2050 and the trajectories are relatively similar in terms of the uptake of specific technologies. As a result, the choice of one scenario over another does not lead to materially different challenges which is why we don't discuss the differences in detail in this analysis. We have chosen to present the **data from the MIX55 scenario** which represents a mix between regulatory and carbon pricing instruments and a short-term target (55 % GHG emission reduction by 2030) aligned with the agreed ambition level.[9]

For a number of topics, the Climate Target Plan is not detailed enough to identify the challenges. For instance for electricity markets' coupling and interconnection between EU Member States there is no detailed analysis with assumed policy interventions (e.g. funding of interconnectors) and expected interconnection levels reported. Similarly, the role of RD&I policies is not explicitly treated. For such topics we performed additional research to identify the most likely baseline projection and the need for additional policy measures.

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6 SWD(2020)176 final – Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan).

7 As a consequence, the baseline does not include raising the 2030 targets, not does it include the additional EU budgets coming from the recovery package (NextGenerationEU).

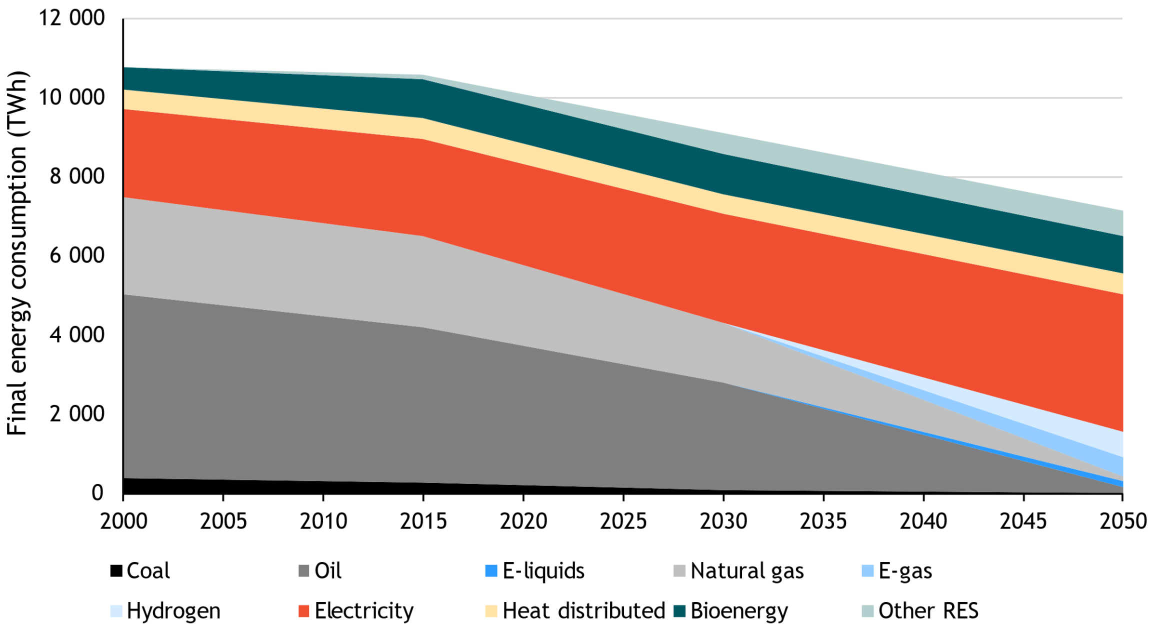
8 Net zero refers to the fact that the net GHG emissions should be zero which is slightly different from reducing emissions to zero as there is some, limited room for emissions as long as carbon sinks compensate for those.

9 Regulation (EU) 2021/1119 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law').

2.1.2. Sectoral breakdown and consumption trends per sector

The identification of challenges is sub-divided in the main energy supply and demand sectors. In the supply-side sections we cover challenges around energy production, infrastructure and markets, focusing on the dominant energy carriers in the transition: electricity and gases. Electricity is expected to account for almost 50 % of final energy consumption by 2050 and gases[10] should account for close to 20 % (Figure 2-1). In both cases, there are many different supply sources (renewable and non-renewable) that (partly) use the same transmission, distribution and storage infrastructure and markets. Hence, there are often related and overlapping challenges which are best discussed for the energy carrier (electricity or gas) as a whole. Oil and coal consumption should strongly diminish and should be almost fully phased out by 2050. Oil and coal will not be discussed separately but will be implicitly treated in the other sections, in particular when challenges for fuel switching and energy efficiency are discussed. Several other carriers should deliver important contributions to the climate neutrality scenario too, in particular bioenergy (13 % in 2050[11]), distributed heat (8 % by 2050) and other RES (9 % by 2050). The challenges associated with those carriers are discussed in a specific section on 'other energy carriers'.

Figure 2-1: Historical and projected EU27 final energy consumption by energy carrier (MIX55 scenario)



Source: SWD(2020)176 final – [Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan)](#).

Note: Values up to 2015 are historical figures. 2020 and onwards are projections.

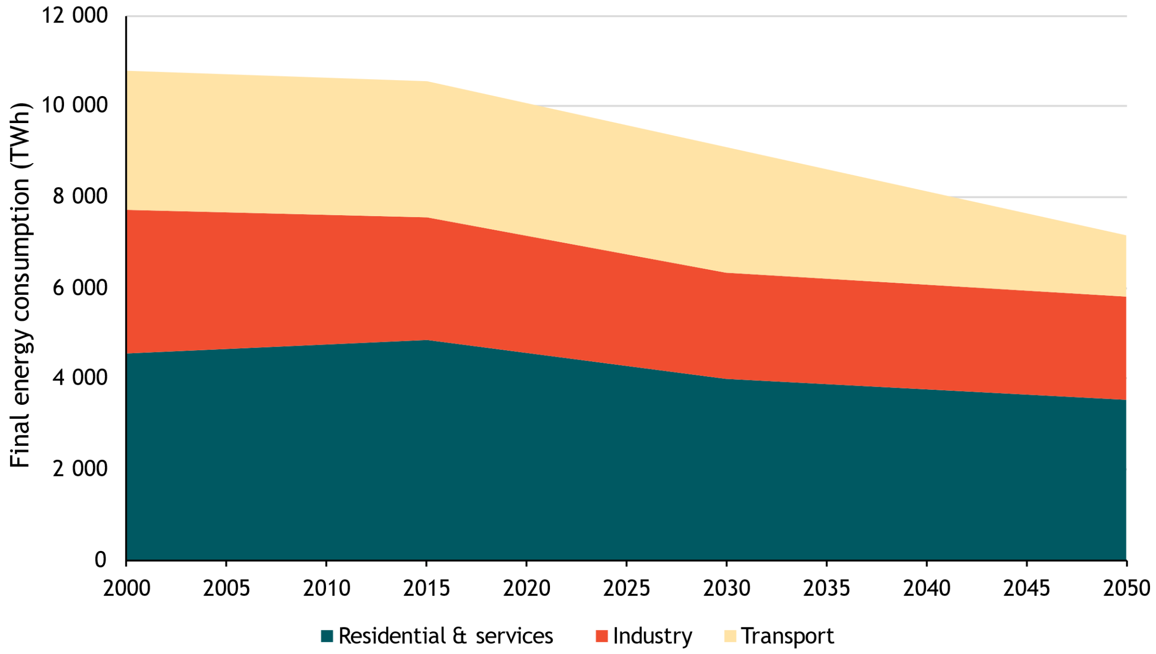
In the demand-side sections we cover challenges with respect to energy efficiency, fuel switching and demand response. In the climate neutrality scenarios of the Climate Target Plan, the overall energy demand is projected to decline by more than 30 % between 2020 and 2050. The demand can be broken down into residential and services (incl. agriculture), industry and transport. The residential and services sector is expected to be the largest energy consumer in 2050, accounting for 49 %, followed by the industrial sector with 32 %. Both categories will see an increase in their

10 Including hydrogen and synthetic gases. Excluding biogas, which is reported as part of bioenergy.

11 Including biogas.

shares in final energy consumption compared to the historical values, while the share of the transport sector is projected to fall from 28 % in 2000 to 19 % in 2050.

Figure 2-2: Historical and projected EU27 final energy consumption by end-use categories[12] (MIX55 scenario)



Source: SWD(2020)176 final – Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan).

Note: in the category Residential & services, the agriculture sector is also included

In the next sections we discuss the supply sectors (electricity, gases, other energy carriers) first and the demand sectors (residential & services, industry, transport) second. The overall trends in energy supply sector (Table 2-1) and consumption sector (Table 2-2) are summarised below, distinguishing between the baseline projection and the MIX55 climate neutrality scenario.

Table 2-1: Final energy consumption (TWh) by supply sector (carrier) for the baseline and climate neutrality (MIX55) projections

	2015	2030		2050	
Sector	Actual	BSL	MIX	BSL	MIX
Electricity	2 453	2 769	2 742	3 183	3 439
Gases	2 291	1 864	1 530	1 891	1 256
Oil & coal	4 219	2 967	2 800	1 827	169
Other energy carriers	1 610	1 868	2 038	1 878	2 293
Total	**10 573**	**9 468**	**9 109**	**8 779**	**7 158**

Source: SWD(2020)176 final – Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan).

[12] There are some differences in the final energy consumption disaggregated per end-user in the following chapters (sections 2.5, 2.6 and 2.7) with the results of the graph, due to inconsistencies in the data presented in the Climate Target Plan.

Table 2-2 Final energy consumption (TWh) by demand sector for the baseline and climate neutrality (MIX55) projections

	2015	2030		2050	
Sector	Actual	BSL	MIX	BSL	MIX
Residential & services	4 856	4 150	3 978	4 020	3 516
Industry	2 711	2 472	2 354	2 482	2 289
Transport	2 996	2 846	2 777	2 277	1 353
Total	**10 563**	**9 468**	**9 109**	**8 779**	**7 158**

Source: SWD(2020)176 final – Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan).

Notes: in the category Residential & services, the agriculture sector is also included. Minor difference between total 2015 consumption values for supply and demand due to differences in source tables.

2.2. Supply - Electricity

2.2.1. State of play

Over the past two decades, EU electricity consumption has remained relatively stable, with EU27 consumption levels just below 3 000 TWh/year between 2005 and 2019, after an initial increase from 2 650 TWh/year in 2000 (Figure 2-3). During this time, the electricity mix transitioned from one based on fossil fuels, nuclear and hydropower, to a mix with increasing shares of wind and solar power. In 2019, solar and wind contributed 17 % to EU gross electricity generation compared to 5 % in 2010 and 1 % in 2000. In the same period, the share of fossil fuels declined from 51 % in 2000 to 38 % in 2019. [13,14]

In the **baseline scenario** of continuing current policies, a modest increase in electricity consumption is foreseen, growing to values of over 3 600 TWh by 2050 (Figure 2-3). The trends in the electricity mix are expected to continue with solar and wind's share growing to around 40 % in 2030 and close to 55 % in 2050. In some EU Member States, the share of these intermittent RES would already reach much higher shares in 2030 though (e.g. Denmark (68 %), Greece (65 %), Ireland (67 %) and Spain (61 %)) [15], leading to challenges for balancing supply and demand, both short-term (intraday) and over the seasons. Fossil fuel-based electricity generation will decline further towards a share of around 15 % in 2050, with coal-fired power almost completely phased out by 2040. Nuclear power generation is expected to decrease from 25 % in 2020 to 14 % in 2050. Both hydropower and bioenergy are expected to remain at similar production levels as today. [16]

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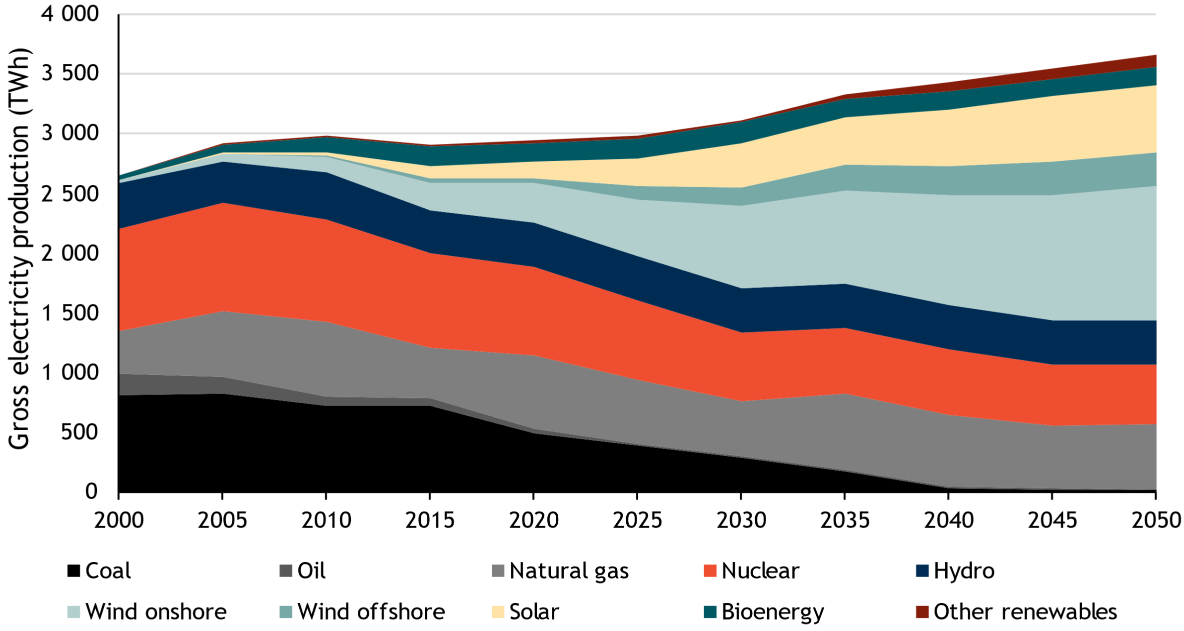
13 Eurostat: table NRG_BAL_C.

14 SWD(2020)176 final – Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan).

15 Results of the EUCO3232.5 scenario on Member States.

16 SWD(2020)176 final – Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan).

Figure 2-3: Historical and projected EU27 gross electricity production by source (baseline scenario)



Source: SWD(2020)176 final – [Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan)].

Note: Values up to 2015 are historical figures. 2020 and onwards are projections.

The trends in the baseline projection generally don't involve a significant departure from the trends experienced in the past decades (Table 2-3). The growth rates for the 2020-2030 decade are the most ambitious but are largely similar to the rates experienced between 2010 and 2015 and require a slight net increase in generation capacity compared to the period between 2015 and 2020. From 2030 onwards, relatively modest growth rates are required to reach the baseline projection. In terms of absolute volumes, the required capacity additions should not be underestimated though. 2020-2030 solar and wind capacity additions for the baseline amount to more than 350 GW and more than double the installed capacity in 2020, for example.[17]

Table 2-3: Compound Annual Growth Rate (CAGR) of gross electricity generation (GWh) per source

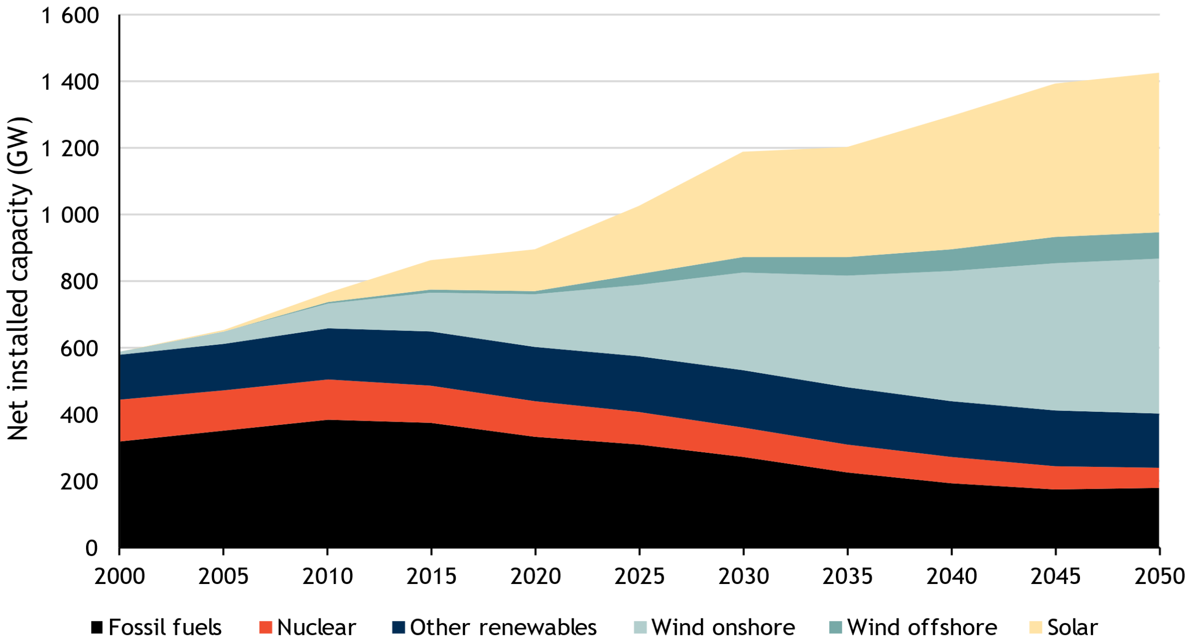
Growth rate	Actual				Forecast - Baseline					
Source	'00-'05	'05-'10	'10-'15	'15-'20	'20-'25	'25-'30	'30-'35	'35-'40	'40-'45	'45-'50
Fossil	2%	-1%	-3%	-1%	-4%	-4%	2%	-5%	-3%	0%
Climate neutral	1%	2%	2%	1%	3%	3%	1%	2%	1%	1%
RES	2%	7%	5%	3%	5%	5%	2%	3%	2%	1%
Intermittent RES	27%	19%	17%	7%	10%	8%	3%	3%	3%	1%

Source: SWD(2020)176 final – [Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan)].

[17] SWD(2020)176 final – [Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan)].

An important feature of solar and wind power plants is their intermittency and relatively low capacity factor. As a result, higher power production capacities are required than in a conventional electricity system using dispatchable fossil fuel based or nuclear power plants. The projected growth in installed capacities illustrates this phenomenon clearly (see Figure 2-4), with overall production capacity expected to grow 60 % between 2020 and 2050, compared to 25 % projected growth in electricity generation. Another consequence of the variability of solar and wind power plants and their decentralised location is the need for grid reinforcements and extensions as well as flexibility measures to absorb the fluctuating electricity supply. Innovation and digitalisation will be highly important to enable an efficient transition to an electricity system that will be mainly based on variable RES.

Figure 2-4: Historical and projected EU27 net installed electricity production capacity by source (baseline scenario)



Source: SWD(2020)176 final – Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan).

Note: Values up to 2015 are historical figures. 2020 and onwards are projections.

To accommodate the increasing shares of intermittent electricity generation, the baseline projection expects growing electricity storage capacities and the introduction of power-to-hydrogen[18] plants at commercial scale after 2030. Pumped hydro capacities are expected to grow from 45 GW in 2015 to approximately 65 GW in 2030 with limited growth afterwards. Battery storage is expected to grow from negligible capacities in 2015 to 20 GW in 2030 and more than 50 GW in 2050. Electricity based hydrogen production capacity is expected to reach only 1 GW in 2030 but would grow more considerably after 2030 to a level around 25 GW by 2050.

Increasing the physical and commercially available interconnection capacity between EU electricity markets is another measure to accommodate increasing shares of intermittent generation in a cost-

[18] Hydrogen (H^2) is a gaseous energy carrier that is used as feedstock or fuel across many applications and does not release any carbon emissions at the point of use. Hydrogen can be produced through several processes, including processes based on electricity (electrolysis) or on fossil fuels (methane steam reforming) (see COM(2020) 301 – A hydrogen strategy for a climate-neutral Europe). In this context, we refer to electricity-based hydrogen.

effective manner, while also contributing to security of supply and competitiveness of EU industry.[19] Current policies aim to increase physical interconnection capacity to at least 15 % of installed power generation capacity by 2030 and apply three further criteria[20] to prioritise where increasing interconnection capacities are most urgently needed.[21] The EU actively stimulates the availability of higher interconnection capacity through funding Projects of Common Interest (PCIs)[22], by imposing that income resulting from the allocation of cross-zonal capacity should be used to guarantee the actual availability of allocated capacity or to maintain or increase cross-zonal capacities,[23] and by imposing that at least 70 % of the capacity should be made available for cross-border trade.[24] While these measures have clearly contributed to increased cross-border flows, there remains significant room for improvement as high congestion rents[25] remain[26] as well as substantial wholesale price divergence.[27] Furthermore, some EU electricity markets are not coupled yet, limiting the efficient use of interconnection capacity.[28]

2.2.2. 2050 ambition

The Climate Target Plan scenarios for reaching climate neutrality in 2050 project similar electricity generation mixes. Hence, we do not differentiate between the different scenarios in this discussion and only present the results of the MIX55 scenario which employs a mix of carbon pricing and regulation to achieve 55 % GHG emissions reduction by 2030 and climate neutrality by 2050.[29]

The projected evolution of electricity generation shows a marked increase in electricity consumption, growing from values around 3 000 TWh/year up to 2030 to values close to 7 000 TWh/year in 2050 (see Figure 2-5). This is due to electrification of various end-uses, rather than an absolute increase in overall energy demand, and will be discussed in more detail in the analysis of the end-use sectors.

Fossil fuel use for power generation will be phased out more rapidly than in the baseline scenario and part of the fossil-based power plants will be equipped with installations for carbon capture and storage (CCS). Solar and wind energy-based power generation need to be scaled up more rapidly, in particular post-2030, with projected generation of 1 500 TWh in 2030 (Baseline: 1 200 TWh) growing to more than 4 500 TWh in 2050 (Baseline: 2 000 TWh). A considerable share of the wind power will be generated offshore (1 200 TWh). 'Other renewables' and 'bioenergy with CCS' (BECCS)

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[19] Towards a sustainable and integrated Europe - Report of the Commission Expert Group on electricity interconnection targets. November 2017.

[20] The criteria concern the price differential between the markets, transmission capacity as a share of peak load, and transmission capacity as a share of renewable generation capacity.

[21] ENTSO-E – Power Facts Europe 2019.

[22] The total grant budget to support energy projects for the 2014-2020 period under the CEF Energy programme was €4.5 billion. Electricity infrastructure PCIs represented 39 % of the funding; several large priority corridors have been constructed thanks to this CEF funding.

[23] Article 19 of Electricity Regulation EU 2019/943.

[24] ACER Recommendation 01-2019.

[25] Congestion income originates in the situation where transmission capacity between bidding zones is not sufficient to fulfil demand. The congestion splits the bidding zones into separate price areas; in that case the TSOs receive congestion income from the user of the congested interconnection based on the commercial flows on the day-ahead market and the price difference. The existence of congestion income is an indication that the optimal interconnection level is not available and that investments in additional capacity might be appropriate.

[26] ACER Market Monitoring Report 2015; CREG study (F)1958 of September 2019; Julius Rumpf, Congestion displacement in European electricity transmission systems – finally getting a grip on it? Revised safeguards in the Clean Energy Package and the European network code. February 2020.

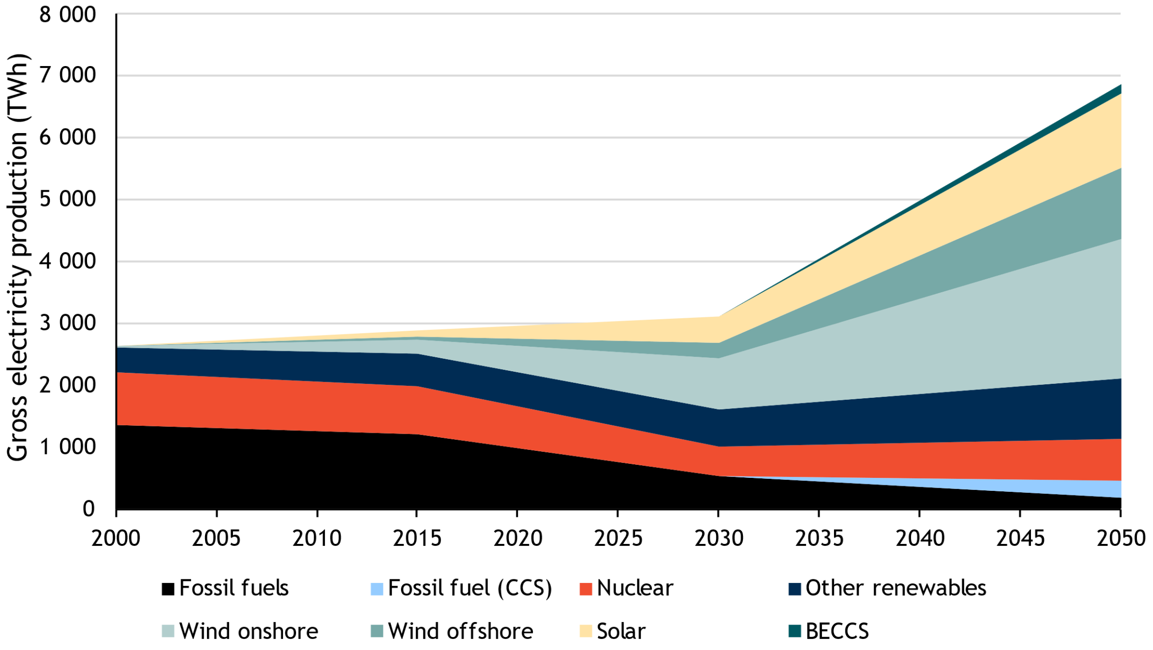
[27] ACER calculations based on ENTO-E data. Data extracted from ACER Market Monitoring Report 2019, Excel tables.

[28] ACER Market Monitoring Report 2019.

[29] SWD(2020)176 final – Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan).

will also grow considerably in this scenario, delivering 1100 TWh in 2050 compared to 600 TWh in the baseline). Nuclear energy's contribution will remain relatively stable.

Figure 2-5: Historical and projected EU27 gross electricity production by source (MIX55 scenario)

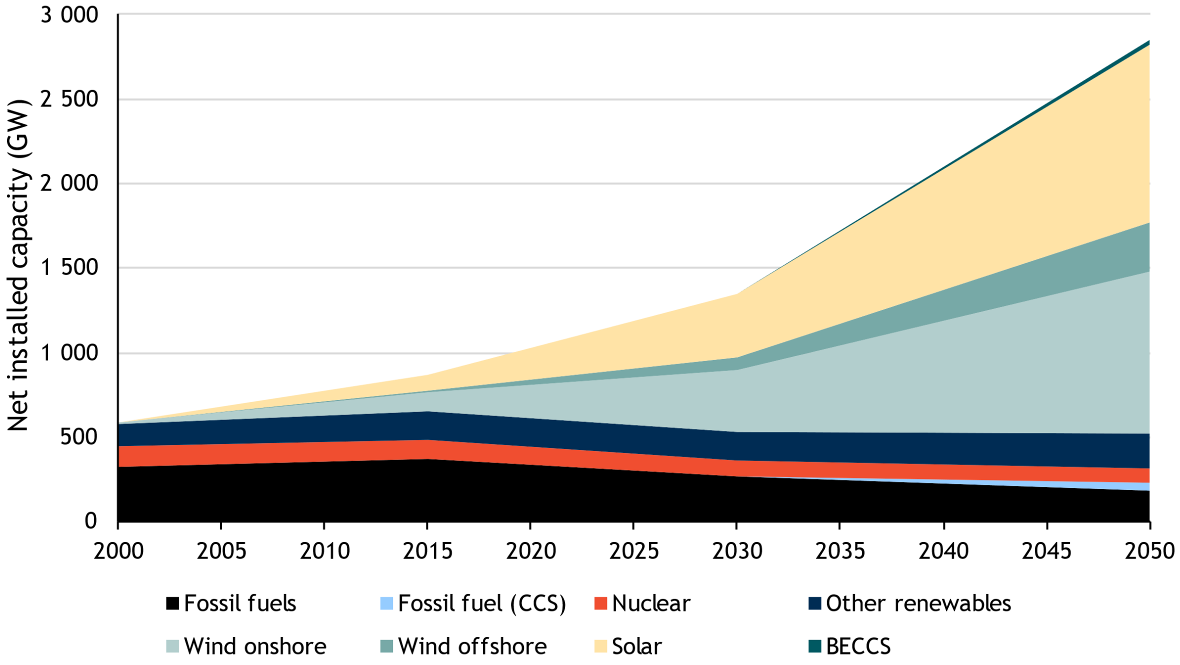


Source: SWD(2020)176 final – [Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan)].

Note: Values up to 2015 are historical figures. 2020 and onwards are projections.

The projected installed capacities (Figure 2-6) show a similar pattern with strong growth for solar and wind and declining fossil fuel capacities. Due to the low load factor of solar PV and wind energy, the increase in installed generation capacity will be much higher than the demand increase. As a result, very high capacities will be required for reaching climate neutrality, almost tripling 2020 capacities, also requiring grid extensions and reinforcements and flexibility measures. A further observation is that the projected decline in fossil fuel-based power generation capacities is not as sharp as the decline in their output, which is due to capacities remaining online as back-up generation to ensure system stability and security of supply.

Figure 2-6: Historical and projected EU27 net installed electricity production capacity by source (MIX55 scenario)



Source: SWD(2020)176 final – Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan).

Note: Values up to 2015 are historical figures. 2020 and onwards are projections.

The climate neutrality scenarios in the Climate Target Plan all project a large increase in battery storage capacities, in particular after 2030, with 2050 capacities amounting to 120 GW (Baseline: 50 GW).[30] The projected capacity increases for power-based hydrogen production capacity (electrolysers) are even more impressive with capacities reaching 550 GW in 2050 (Baseline: 25 GW). Additionally, significant capacities for other power-to-x technologies are projected with around 75 GW power-to-gas (other than power-to-hydrogen) and 50 GW power-to-liquids capacity projected for 2050 (Baseline: 0 GW for both).

The development of interconnection capacity is not explicitly treated in the Climate Target Plan, which can therefore not be used for a comparison between the baseline and the climate neutrality scenarios. As baseline projection we therefore assume that current policies realise the 15 % interconnection target by 2030 but do not facilitate capacity increases beyond 15 %. Considering the current levels of price convergence in the highly interconnected Nordics markets for example[31], there is substantial potential for further benefits even in markets which meet the 15 % interconnection target. Hence, we conclude that further policies to stimulate higher interconnection levels and market coupling could contribute to reaching the climate neutrality objective in a cost-efficient way.

30 SWD(2020)176 final – Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan).

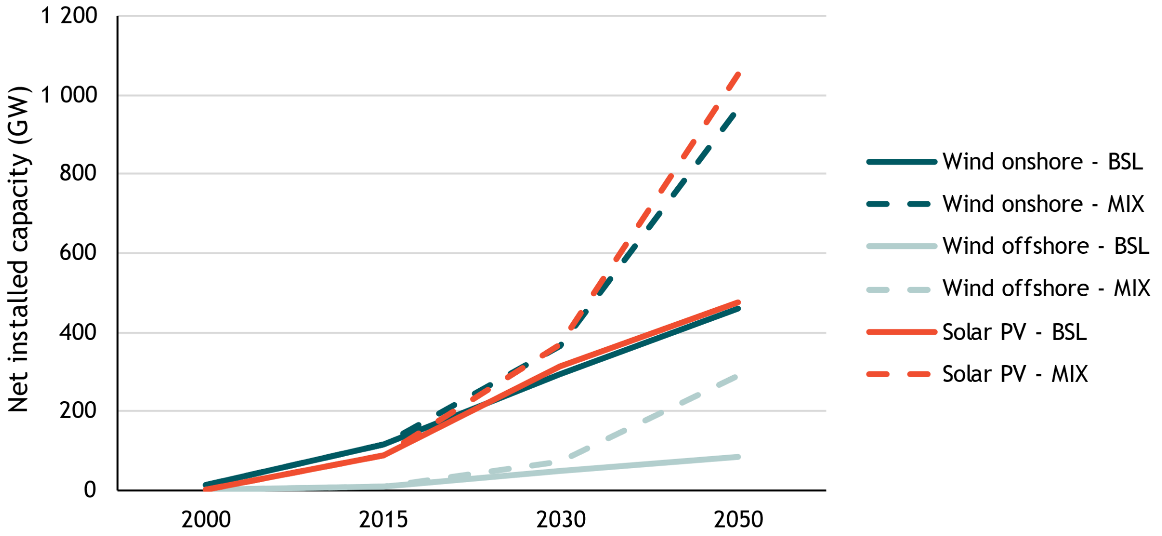
31 ACER calculations based on ENTO-E data. Data extracted from ACER Market Monitoring Report 2019, Excel tables.

2.2.3. Key challenges

Accelerate solar and wind energy deployment

All Climate Target Plan scenarios for reaching climate neutrality by 2050 indicate the need for a sharp increase in the deployment of solar and wind power. When we compare the projected installed capacities in the baseline scenario and the MIX55 scenario (Figure 2-7) it becomes clear that the required growth will not be delivered without further policy measures. Hence, a key challenge is to accelerate solar and wind energy deployment.

Figure 2-7: Projected installed capacities for solar and wind energy per the Baseline (BSL) and MIX55 (MIX) scenarios of the Climate Target Plan



Source: SWD(2020)176 final – [Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan)].

Scale up electricity storage and power-to-x

All scenarios for reaching climate neutrality project strong growth in battery storage for the whole period considered and the introduction of power-to-x[32] (including power-based hydrogen production via electrolysers) at scale post 2030. For these technologies, the growth needs to be stimulated from very small capacities at present. Therefore, the challenge is not only to accelerate deployment (as for solar and wind energy) but also to go through the initial phases of market formation and scaling up of novel technologies, in particular for power-to-x, allowing to improve the energy efficiency of the conversion processes and reduce their costs.

Develop and scale up use of carbon capture and storage (CCS) in power plants

All climate neutrality scenarios project significant volumes of electricity production with carbon capture and use or storage, including fossil fuel-based and bioenergy-based (BECCS), compared to negligible CCS volumes in the baseline scenario. As CCS is currently almost non-existent in the EU market, the challenge will be to introduce the technology to the market and scale it up to commercial volumes.

[32] Power-to-x refers to technologies that convert power to gaseous (power-to-gas) or liquid fuels (power-to-liquids).

Accelerate phase out of fossil fuel-based power generation

Fossil fuel-based electricity generation without CCS needs to decrease by 90 % compared to 2015 for reaching climate neutrality, while the baseline projection only expects a 50 % decrease. Hence, a challenge will be to accelerate the phase out of fossil fuel-based power generation without CCS.

Promote further cross-border integration of electricity systems and markets

Increased interconnection levels and market coupling will contribute substantially to absorbing intermittent electricity generation while keeping costs down and enhancing market competition and security of supply. Current policies promote further system and market integration already to a certain extent (15 % interconnection[33]) but there is room for further benefits beyond this level. Hence, we conclude that promoting further system and market integration is an important challenge to realise climate neutrality in a cost-effective manner.

Stimulate digitalisation and sector integration

Large-scale implementation of digital technologies and sector integration[34] should facilitate the shift towards a highly intermittent and decentralised power generation system and enable end-users to participate in the electricity market (on-site electricity production, storage, demand response). Smart equipment (network, meters, end-use appliances) and smart processes and data management are set to make the energy systems more connected, intelligent, efficient and reliable. Optimal integration between energy sectors on the one hand (electricity, power-to-gas, electricity and gas storage, heating) and between energy supply and demand on the other hand, will reduce the overall costs and increase the efficiency of the energy system, and hence allow to reach the energy and climate objectives more efficiently.

2.3. Supply - Gases

2.3.1. State of play

In 2019 natural gas was the dominant source of gas consumption in the EU27, reaching more than 4 300 TWh. Due to decreasing domestic natural gas production, EU's natural gas import dependency reached an all-time high of 89.5 % in 2019. Almost three quarters of the EU's imported gas came from Russia (40 %), Norway (18 %) and Algeria (11 %). Substituting imported natural gas with domestically produced renewable and low-carbon gas would reduce the EU's energy dependence, and lower the security of energy supply risks.

Biogas contributed only by 3.6 % to the gas consumption in 2019. 8 % of the biogas production was further converted to biomethane[35]. According to the Climate Target Plan, the projections in the **baseline scenario** for 2030 present a downward gas consumption trend, mainly due to the significant decrease of natural gas to 3 150 TWh. Biogas consumption is expected to increase moderately between 2019 and 2030 (+14 TWh). Green hydrogen, produced from renewable electricity,[36] plays a minor role at the moment and its share will still be limited in 2030, but will be more significant in 2050, reaching 87 TWh. The consumption of natural gas is expected to remain

[33] Note that there is also still work to do to reach the previous 10 % interconnection level which was not met by eight Member States (COM(2020) 950 final).

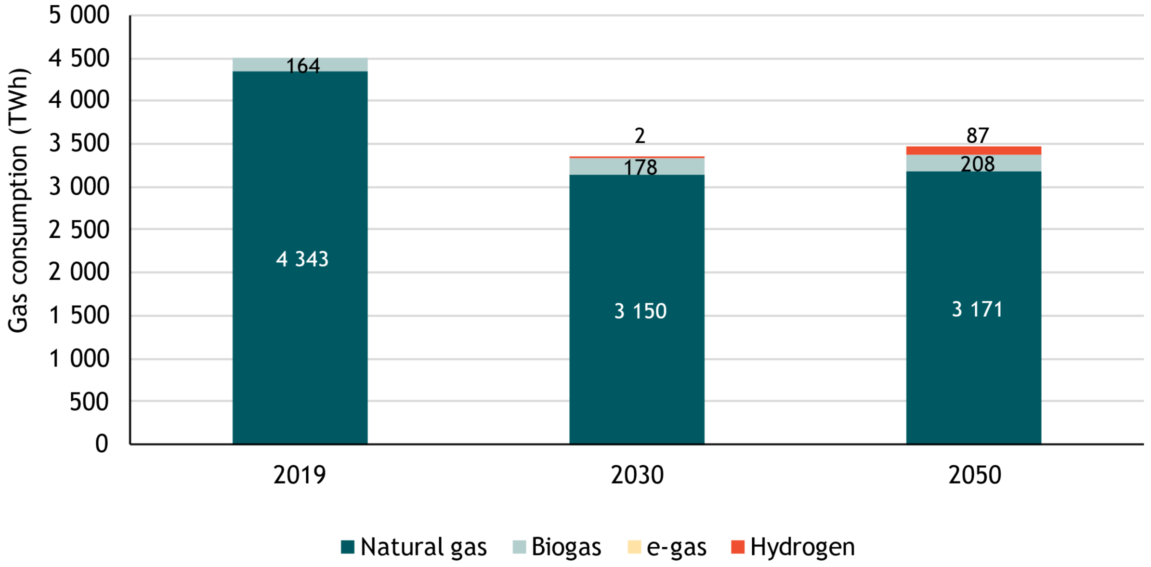
[34] Sector integration means linking the various energy carriers - electricity, heat, cold, gas, solid and liquid fuels - with each other and with the end-use sectors, such as buildings, transport or industry. Power-to-hydrogen and dynamic EV charging are good examples of the potential for sector integration.

[35] EBA (2020) Statistical report 2020.

[36] When referring to hydrogen in this chapter we refer to green hydrogen, produced with renewable electricity, unless stated otherwise.

stable between 2030 and 2050, while biogas consumption is projected to grow moderately (+30 TWh) to 208 TWh.

Figure 2-8: EU27 historical and projected gas consumption per fuel according to the baseline



Source: SWD(2020)176 final – Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan), Eurostat NRG_CB_GAS and NRG_CB_RW.

Note: Hydrogen refers to green hydrogen only (produced with renewable energy). Hydrogen does not appear in the graph for 2019 since no data are available from Eurostat.

The interconnectivity between national natural gas systems and the integration of gas markets have substantially improved, thanks to investments in interconnectors, including reverse flows, implementation of new rules for capacity allocation (e.g., UIOLI), and the development of liquid gas hubs. The most advanced hubs in the EU are the TTF (Netherlands) and the NBP (UK). Other hubs in Germany, Italy, France, Austria and Belgium are considered 'advanced' too, while those in the Czech Republic, Romania, Denmark, Hungary, Slovakia and Ireland are still emerging or illiquid.[37] There is hence still potential for improvement, in particular in some EU-regions, but this process is ongoing and is not considered as a major medium or long-term challenge in the context of this study. While the need for additional natural gas interconnectors in the EU is very limited, the potential future use of existing pipelines for transport of renewable and/or low-carbon gas (including hydrogen) is being assessed at the present. These issues are being addressed by EU legislators in the ongoing revision of the TEN-E regulation.

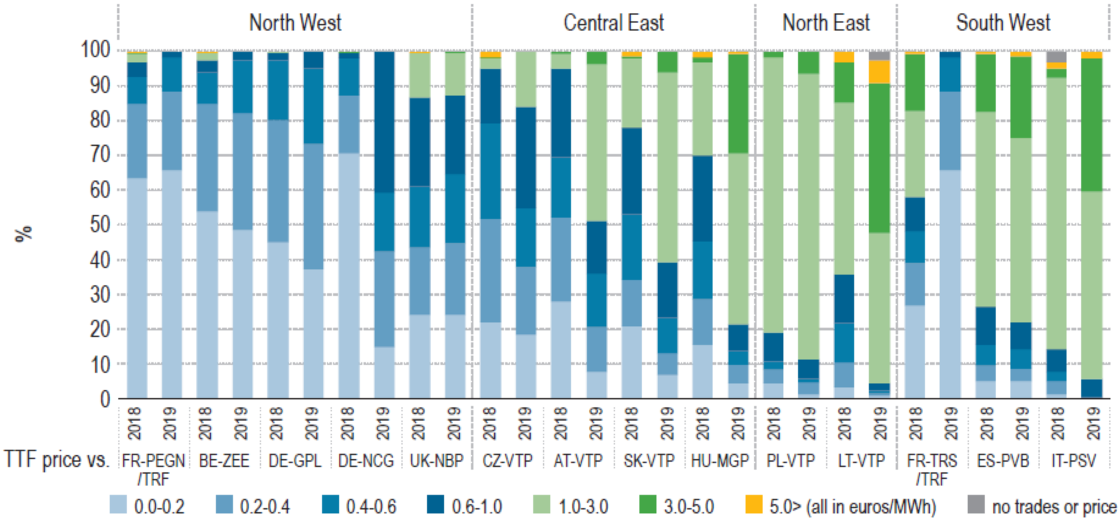
Thanks to the EU policy measures to enhance national gas systems and markets' integration, physical and contractual congestion at the borders has substantially decreased[38] and the wholesale gas prices are increasingly converging. As Figure 2-9 indicates, the price convergence is in particular high between the Dutch TTF and the North West EU hubs. This result can be attributed to factors such as the sufficient availability of pipeline capacity, the similar market fundamentals, the structural

[37] ACER (2020) ACER Market Monitoring Report 2019 – Gas Wholesale Market Volume.

[38] According to the 7th ACER report (2020) on congestion in the EU gas markets, physical congestion occurred in 2019 only at 7 Interconnection Point sides with varying frequencies, while contractual congestion occurred occasionally at 37 (out of 239) IP sides.

fostering of hub trading and the low tariffs of interconnecting transportation capacity[39]. In some other EU markets, the price convergence is still rather low, but it is expected to further improve in the coming years as a result of current EU and national regulation.[40]

Figure 2-9: Day-ahead price convergence between Dutch TTF and other EU hubs for the period 2017-2019 (% of trading days within given price spread range)



Source: ACER (2020) ACER Market Monitoring Report 2019 – Gas Wholesale Market Volume.

On the basis of the current analysis, the need for additional investments in natural gas interconnection infrastructure is hence very limited, and the focus should be on optimal use of existing capacity and on further enhancing market integration and liquidity, in particular in some EU-regions.

2.3.2. 2050 ambition

The scenarios provided under the Climate Target Plan describing the 2050 ambition do not demonstrate significant differences in absolute numbers, therefore only the results of the MIX55 scenario are presented in this section.

The consumption of natural gas in the EU 27 is projected to decrease in an accelerated pace, falling to 1 111 TWh in 2050 (compared to 3 171 TWh in the baseline scenario). No major differences are expected in biogas consumption by 2030 compared to the baseline scenario, however a significant increase is anticipated by 2050, which will result in almost 690 TWh of biogas use (baseline value 208 TWh). Bioenergy production growth should mainly come from better use of biomass wastes and residues and a sustainable cultivation of energy crops, replacing the production of first generation food-crop-based biofuels[41]. Furthermore, the estimations under the MIX55 scenario suggest that in 2050 green hydrogen will be the dominant gaseous fuel (1 127 TWh), surpassing the consumption of natural gas. Also, e-gases[42] would play a significant role, accounting for 16 % of the total gas

39 ACER (2020) ACER Market Monitoring Report 2019 – Gas Wholesale Market Volume.

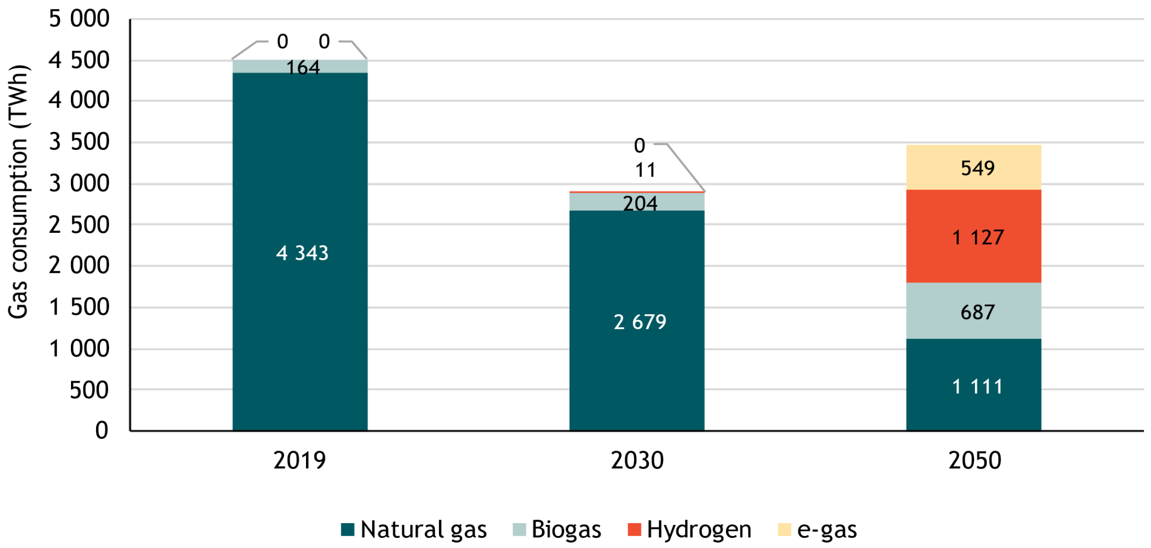
40 See for instance ACER Gas Market Report 2019: The building blocks of market price convergence in the CEE region, like infrastructure investments that enabled firm transportation capacity from the West to the East, market liberalisation and Network Codes based hub development will continue to have an effect and are likely to facilitate higher price convergence in the future.

41 SWD(2020)176 final – Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan).

42 E-gas refers to gaseous fuels produced on the basis of hydrogen obtained from electricity via electrolysis, according to the definition of the Climate Target Plan.

consumption in 2050 (549 TWh), while in the baseline scenario they are not expected to be used. Overall, while renewable and low carbon gases are estimated to contribute to the gas supply by 2030 only to a limited extent, they are projected to be the dominant gaseous fuels by 2050, accounting for 68 % of the EU 27 gas demand.

Figure 2-10: EU 27 historical and projected gas consumption per fuel according to the MIX55 scenario



Source: SWD(2020)176 final – Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan), Eurostat NRG_CB_GAS and NRG_CB_RW.

2.3.3. Key challenges

According to all the scenarios considered in the Climate Target Plan, in order to reach climate neutrality by 2050, it is necessary to gradually phase out natural gas and to substantially increase the supply of renewable and low carbon gases. Specifically, it is expected that in 2050 the share of natural gas will drop to around 30 %, while the shares of hydrogen and e-gases will increase significantly to approximately 30 % and 15 % respectively. The rest of the gaseous consumption is expected to be covered by biogas and biomethane. The main challenges to realise the transition to a carbon-neutral gas supply, are hereafter briefly presented.

Enhance production of sustainable biogas/biomethane

In order to be aligned with the climate neutrality and sustainability objectives, the EU needs to produce renewable and low carbon gases in a sustainable manner. The production of biogas and biomethane is at the moment mainly based on biomass, waste food and feed crops, therefore a key challenge is to produce biogas in a sustainable way considering the climate, pollution and biodiversity risks[43]. Furthermore, an adequate regulatory framework should provide guidance in view of an optimal use of biomass (primarily as feedstock or for food/feed, and secondarily for energy purposes) and an optimal use of biogas, either directly or via conversion to biomethane.

Develop and scale up production of renewable and low-carbon hydrogen

As hydrogen should gradually play a major role in the energy mix, not only to offer an adequate alternative for hard-to-decarbonise end-uses (feedstock in industry, high temperature processes),

[43] European Commission (2020) Powering a climate-neutral economy: An EU Strategy for Energy System Integration.

but also to facilitate the development of intermittent renewable electricity generation via power-to-hydrogen facilities (electrolysers), a key challenge will be to reduce its costs, both for low carbon and renewable hydrogen, in order to be competitive against fossil-based hydrogen[44]. As the production of renewable hydrogen will to a large extent be linked to the electricity production from wind and solar PV technologies and subsequently to their costs, the downward trend of wind and solar PV cost levels is expected to offer opportunities for the development of renewable hydrogen, onshore but also offshore where grid capacity may be a more significant issue for transporting the electricity generated by offshore wind farms. Furthermore, in order to meet the projected 32 %[45] share of low-carbon/renewable hydrogen in the gaseous fuel mix in 2050, significant performance improvements (e.g. efficiency) of the respective technologies need to be achieved[46].

Also, with regards to hydrogen produced via electrolysers, the challenge will be to produce it in a clean manner, i.e., by using only renewable electricity, mainly from wind and solar technologies, hence minimizing the negative climate and environmental impacts[47].

Implement an enabling regulatory framework for transporting and storing low-carbon/renewable hydrogen

The large-scale deployment of low-carbon/renewable hydrogen and the phase out of natural gas will create significant challenges to the current gas infrastructure. The existing natural gas network can be used for the integration of renewable and low carbon hydrogen in a cost-efficient way, specifically for lower volumes during the transitional phase. However, as blending of hydrogen with natural gas impedes to optimally value its specificities[48], and also affects the gas quality and hence the well-functioning of the natural gas network equipment and end-user appliances, blending should not be considered as an adequate option for higher hydrogen volumes.

For this reason, the deployment of a dedicated cross-border transportation infrastructure for hydrogen will be needed, which at the moment is in the EU limited to about 1650 km of private pipelines (without third party access) in Central-Western Europe. Next to additional dedicated hydrogen pipeline and storage infrastructure with regulated third-party access, new ship designs might be needed that would allow to carry liquified hydrogen. Existing natural gas infrastructure (transportation pipelines, storage facilities, LNG terminals, end-user equipment) might need to be refurbished in view of using them for hydrogen.[49]

[44] Ibid.

[45] SWD(2020)176 final – Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan).

[46] IRENA (2019), Innovation landscape brief: Renewable Power-to-Hydrogen, International Renewable Energy Agency, Abu Dhabi.

[47] European Commission (2020) Powering a climate-neutral economy: An EU Strategy for Energy System Integration.

[48] An advantageous property of hydrogen (H_2) is that it does not include any carbon (C) atoms and thereby does not release any carbon dioxide (CO_2) when it is used. Once hydrogen is blended with natural gas (CH_4) the resulting blend is not carbon-free anymore and could therefore be less valuable depending on the use and applicable regulatory framework.

[49] A 2020 German study (Options of Natural Gas Pipeline Reassignment for Hydrogen: Cost Assessment for a Germany Case Study) shows that it might be economically and technically feasible to repurpose more than 80% of the German pipeline network for hydrogen transportation. Pipeline reassignment could reduce the hydrogen transmission costs by more than 60%. A countrywide analysis of pipeline availability constraints for the year 2030 shows a cost reduction of the transmission system by 30% in comparison to a newly built hydrogen pipeline system. The German utility E.ON is currently investing together with gas DSO Westnetz €1 million to make a public distribution grid in the community of Holzwickede suitable for hydrogen. The ongoing H21 Leeds City Gate project also shows in practice that an existing natural gas network can be converted to hydrogen. Some types of natural gas storage facilities, in particular salt caverns and depleted gas fields, would also be technically suitable for hydrogen storage. While the technical

Finally, due to the fact that low-carbon/renewable gas, including hydrogen, will enter the gas network from different supply sources, both domestically and abroad, the quality parameters of the gas might change across EU, and it will be important to ensure the interoperability of the gas systems and the uninterrupted flow of gases across the borders of the EU Member States[50].

Develop a liquid cross-border market for hydrogen

The transition of the gaseous fuel mix from fossil to low-carbon and renewable gases should be accompanied with the appropriate adjustments in the energy market. While biomethane can be traded and supplied under the same contracts as natural gas (using GOs[51] to distinguish them), there will be a need for developing a specific liquid hydrogen market accessible to all the potential application sectors (e.g., transport, industry, power). In principle, the existing market platforms and rules for natural gas can also be used for hydrogen. However, to have a liquid and properly functioning hydrogen wholesale market, larger supply volumes and a higher number of market participants (both at the supply and demand side) are preliminary conditions. Once a minimum threshold in terms of market volumes and participants will have been reached, appropriate instruments will be needed such as over the counter (OTC) platforms and centralised exchanges and adequately designed market products.

2.4. Supply - Other energy carriers

2.4.1. Bioenergy

Bioenergy includes solid, liquid and gaseous fuels that can be produced from a wide variety of feedstocks through a wide variety of conversion routes. These feedstocks can to a certain extent be utilised flexibly and be used for applications where they offer the highest value. An increasing volume of biomass is expected to be used for conversion to biogas for which the MIX55 scenario projects 240 % growth compared to the baseline projection, which estimates relatively stable biogas consumption between 2015 and 2050 (Table 2-4). Additionally, the MIX55 scenario projects 25 % growth of solid biomass use for energy purposes and close to 300 % growth of liquid biofuel consumption compared to the 2015 consumption level, while the baseline scenario projects reduced solid biomass consumption and much more modest liquid biofuel consumption growth (40 %). As a result, additional feedstocks and improved conversion technologies will be required, which is challenging due to sustainability concerns and limited suitable biomass supply.[52] [53] Furthermore, there are competing uses for biomass such as use as food, feed or feedstock for industry. Hence, we define **'increasing biomass supply in a sustainable manner'** as a challenge for reaching climate neutrality.

feasibility of hydrogen underground gas storage facilities is proven, adaption and research are still needed to meet standards and safety regulations.

50 Ibid.

51 The renewable origin of biomethane can be proven via Guarantees of Origin (GOs), a credit-based chain of custody system that is already widely used in the EU to guarantee the source of electricity is renewable. The revised EU Renewable Energy Directive (2018/2001/EU) extended the scope of GOs to renewable gas, including biogas/biomethane and hydrogen.

52 PWC et al. (2017) – Sustainable and optimal use of biomass for energy in the EU beyond 2020.

53 PBL (2020), Availability and application of sustainable biomass. Report on a search for shared facts and views.

Table 2-4: Gross inland consumption of biomass and waste for energy (TWh)

	2015	2030		2050	
Source	Actual	BSL	MIX	BSL	MIX
Bio - Solids	1 042	986	1 036	866	1 300
Waste Municipal Solid	199	186	186	185	185
Waste Industrial Solid	48	57	61	58	64
Biofuels	169	237	290	236	658
Biogas	130	153	185	172	582
Waste Gas	26	24	25	23	26
Total	**1 614**	**1 644**	**1 783**	**1 541**	**2 815**

Source: SWD(2020)176 final – Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan).

2.4.2. Renewable heat

The projected pathway to decarbonise the heating and cooling sector involves a mix of solutions, including renewable fuels of non-biological origin (RFNBOs), ambient heat and renewable derived heat. For each of those, an increasing contribution is required for realising the climate neutrality scenario, compared to 2015 (Table 2-5). However, for derived heat the increase is largely in line with the baseline scenario, which signals that there are no large challenges to realise this potential.

For ambient heat which refers to heat captured by heat pumps, the increase is much stronger though and a sizeable gap exists between the baseline projection and the MIX55 scenario. Hence, we identify **scaling up of heat pumps** as a challenge for realising the 2050 ambition.

For RFNBOs there is a large volume projected for 2050, which relates to the large increase in power-to-x discussed in the section on electricity. Hence, this is not a separate challenge but is part of the challenge to scale up power-to-x capacities.

For other RES, the baseline and MIX55 scenarios provide similar consumption levels in 2030. In 2050, however, a substantial gap appears between the baseline scenario and the MIX55 scenario. While this is partly due to increasing overall renewable heating and cooling consumption in the MIX55 scenario, a large part is due to decreasing renewable energy consumption in the baseline scenario, a result for which the underlying reason is not clear.

Table 2-5: Historical and projected EU27 renewable heating and cooling consumption (TWh)

	2015	2030		2050	
Source	Actual	BSL	MIX	BSL	MIX
Derived heat	154	234	258	190	220
Ambient heat	65	272	408	386	502
RFNBOs	0	0	0	0	607
Other renewable energy sources	824	841	852	748	912
Total	**1 043**	**1 347**	**1 517**	**1 325**	**2 241**

Source: SWD(2020)176 final – Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan).

2.5. Demand - Residential and services

2.5.1. State of play

Residential and services embody some of the greatest challenges to achieving the ambition in the Climate Target Plan and account for the largest share of energy use in the EU27 (46 % in 2015)[54] 35 % of the building stock is 50 years or older, 75 % is energy inefficient[55] and 76 % are heated with fossil-fuels.[56]

The state of play outlined below summarises the baseline scenario (BSL) in the Climate Target Plan. In summary, the state of play is that total energy use in the residential sector barely decreased between 2000 and 2015. However, homes became more energy efficient at an annual rate of – 1 % reduction in energy consumption. The home renovation rate was also about 1 % in recent years. Energy use increased by a quarter in the services sector during the same period. Services also became more efficient; energy use per Euro of gross value added decreased at – 1 % per year and the services sector renovation rate was 0. 6 % annually in recent years. Overall, energy use deceases 35 % in homes and 51 % in services by 2050 compared to 2015 in the baseline scenario.

Residential

Energy demand

Final energy demand in the residential sector nominally declined between 2000 and 2015 (CAGR=-0. 1 %) from 2 900 to 2 800 TWh. In the baseline (BSL) scenario, demand decreases -0. 9%/year between 2015 and 2030, and then -0. 2 % between 2030 and 2050 (Figure 2-12). Electricity consumption as a share of total demand grows from 24 % in 2015 to 35 % in 2030 in BSL due to higher penetration of heat pumps,[57] electric water heaters, and other electrical devices, while the share of fossil fuels drops 16 % relative to 2015.

The distribution of energy consumption by end use hardly changed between 2008 and 2018 (Figure 2-11), with heating dominating energy use; fossil fuels comprised 60 % of heating demand, and electricity 6 %, although large variation exists between Member States. But improved heating and cooling efficiencies and building shell improvements result in -27 % in heating and cooling consumption in 2030 relative to 2005 in BSL, while growing demand for household devices increases lighting and appliance loads 40 %; overall household energy use drops by a fifth during this period in the baseline scenario.

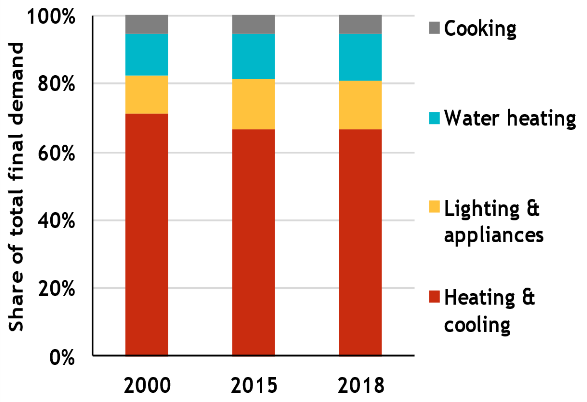
54 According to the SWD(2020)176 final – *Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan)*.

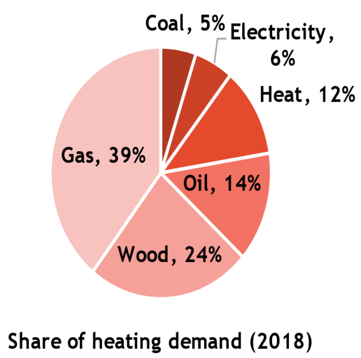
55 European Commission – DG ENERGY. Energy Efficiency in Buildings. 17 February 2020.

56 European Commission. Communication to the European Parliament and the Council on the Renovation Wave. October 14, 2020.

57 The share of electricity in heating demand should grow to 40 % by 2030 and to 50-70 % by 2050 (EU System Integration Strategy).

Figure 2-11: Share of total residential energy demand by end use in the EU27 (left) and share of heating demand by carrier(right)





Source : ODYSSEE.

Energy efficiency

Homes are getting more efficient in the EU27, a trend driven by increasingly stringent minimum energy performance standards (MEPS) for lighting and appliances, as well as energy standards for new homes, and home energy renovations. Energy consumption per dwelling (or home) declined 1 % per year between 2000 and 2018,[58] from 16 MWh/year to 13 MWh/year (Figure 2-12). During the 2016-20 period the average home energy renovation rate was 1 %/year (Figure 2-13).[59] Energy use per home declines 1.7 %/year in BSL between 2015 and 2030 to 10 MWh/dwelling, and then at 1 %/year between 2030 and 2050 to 9 MWh/dwelling. Overall, in the baseline scenario, energy use per home drops 35 % by 2050 relative to 2015.

Services

Energy demand

Final energy demand in the services sector increased by a quarter between 2000 and 2015 (CAGR=1.4 %) from 1 200 to 1 500 TWh. In the BSL scenario, demand declines -0.5 %/year between 2015 and 2030, and then -0.1 % between 2030 and 2050. (Figure 2-14). Electricity consumption as a share of total demand somewhat grows from 48 % in 2015 to 54 % by 2030 in BSL while the share of fossil fuels falls 26 %, mostly reflecting an increase in electricity used for heating and cooling (mainly heat pumps).

Energy efficiency

As with homes, the EU services sector is becoming more energy efficient. Energy consumption per Euro gross value added (GVA) declined -1 % per year between 2000 and 2018,[60] from 0.23 to 0.19 kWh/2015€. The main reasons are building energy renovations (0.6 % per year on average; see Figure 2-13), increasingly stringent energy standards for new buildings and lighting and appliances, and increased use of building automation systems. Energy intensity of the sector declines -29 % in BSL between 2015 and 2030 (CAGR=-2 %) to 0.15 kWh/€, and then to 0.10 kWh/€ between 2030 and 2050 (CAGR=-1.9 %). In the long run, the energy intensity of the sector drops 51 % by 2050 compared to 2015 in the baseline scenario.

Building energy intensity (e.g., kWh/m^2) is another common metric used to evaluate energy efficiency of the services sector. While data of building area for services is not available from

[58] 2019 was an exceptionally warm winter, therefore the historical CAGR was calculated using 2000-18 data.

[59] Includes 'Type I' renovations of the building shell (e.g., insulation and air sealing).

[60] 2019 was an exceptionally warm winter, therefore the historical CAGR was calculated using 2000-18 data.

transversal sources for all MS, data from seven MS accounting for 60 % of services GVA in 2018 in the EU27 (Germany, Denmark, Netherlands, France, Finland, Sweden, and Spain) shows buildings used by the sector generally became more energy efficient since 2000. In total, services in the group of seven MS became 8 % less energy intense, dropping from 0.23 kWh/m^2 to 0.21 kWh/m^2. Decreases between 2000 and 2018 ranged from -20 % in Germany to -7 % in Sweden, while energy intensity increased 32 % in Spain.[61]

Smart meters

Smart meters are an integral part of the European Union's digitalisation and building decarbonisation strategies. They facilitate energy savings through building automation and enable buildings to be used as active energy market participants, e.g., for local production and demand response.[62] A 2019 European Commission study found that three-quarters of MS had the regulatory frameworks in place for smart meter roll-outs and that 34 % of electricity retail customers were equipped with smart meters, which is well below the aspirational goal of 80 % smart meter deployment by 2020. However, this target only applies in cases where a cost-benefit analysis of smart meter deployment has been carried out and has yielded positive results, which is not the case for all EU Member States. The expectation is that smart meter penetration will grow to 92 % by 2030.[63]

2.5.2. 2050 ambition

The long-term ambition for GHG savings in the residential and services sector captured in the MIX55 scenario mainly involves moderate increases in building renovation rates, as well as increases in renovation depths, and moderate increases in incentives for uptake of renewables for heating and cooling.

The 2050 ambition in MIX55 scenario for the residential sector reflects:

- a -1.2 % annual decline in energy demand between 2015 and 2030, and a -0.7 % decline between 2030 and 2050 (compared to -0.9 % and -0.2 % in BSL) (Figure 2-12);
- a 23 % increase in electricity use by 2050, relative to 2015 (versus +28 % in BSL; MIX55 includes some e-gas and hydrogen for residential, whereas BSL does not);
- a -44 % drop in energy use per dwelling by 2050, relative to 2015, compared to -35 % in the baseline;
- a sustained renovation rate of at least 2 %/year (at least double current levels)[64] (Figure 2-13);
- a 215 % increase in demand for renewable heat relative to 2015 levels in the MIX55 scenario; this is 170 % more than the projected level of renewable heat in 2050 in BSL. MIX55 and BSL have comparable growth in heat pumps, about an eight-fold increase relative to 2015. The big increase in MIX55 over BSL is in the use of RFNBOS which are covered as part of the challenge to scale up power-to-x which has been introduced in the section on the supply sectors.

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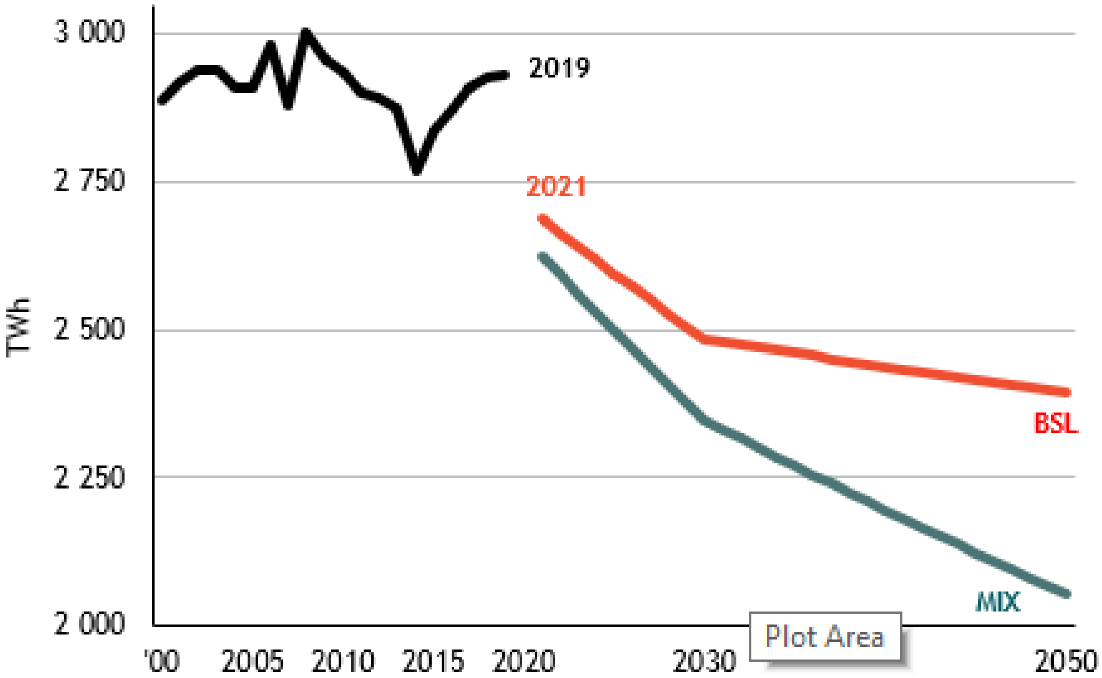
[61] *ODYSSEE.*

[62] European Commission. Impact Assessment Study on Downstream Flexibility, Price Flexibility, Demand Response and Smart Metering, July 2016.

[63] European Commission. Benchmarking smart metering deployment in the EU-28, December 2019.

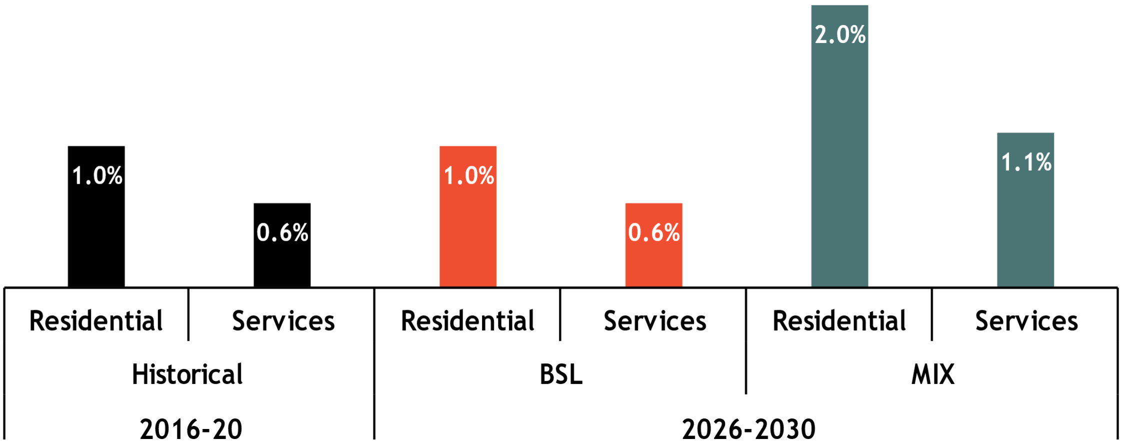
[64] The Climate Target Plan includes renovation rate assumptions for 2026-30, but it is noted in the plan that, 'While the focus of the policy options described across scenarios is 2030, increased rate and depth of renovation will have to be maintained also post-2030.'

Figure 2-12: Residential final energy demand in the EU27 (TWh)



Source: ODYSSEE; SWD(2020)176 final – [Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan)](#).

Figure 2-13: Building renovation rates in the EU 27 (% of existing stock)[65]



Source: SWD(2020)176 final – [Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan)](#).

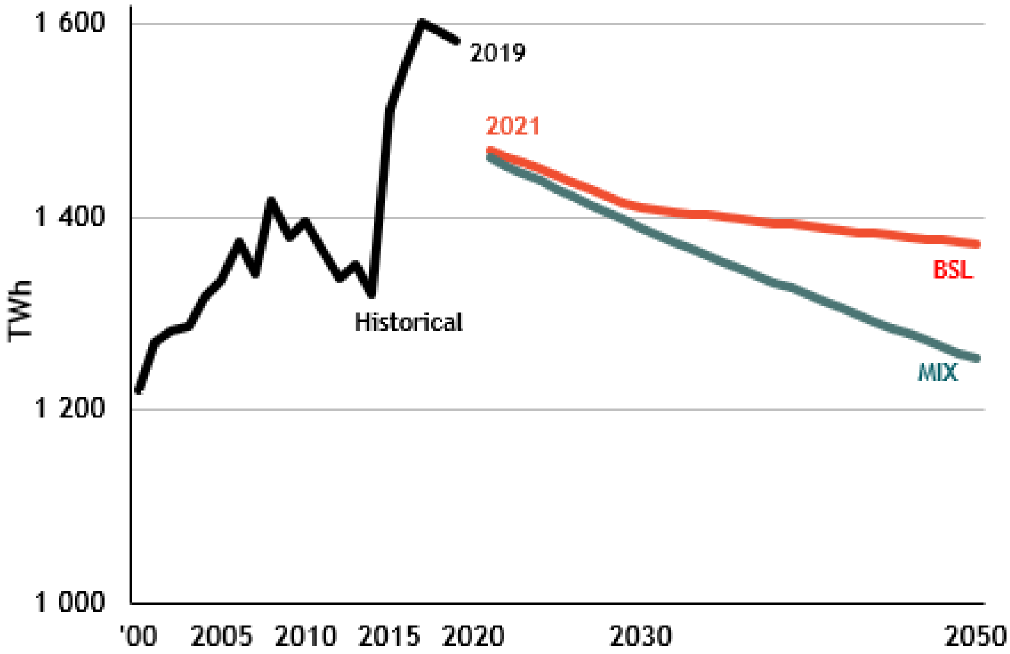
The ambition for services captures:

- a -17 % decline in energy demand relative to 2015, versus -9 % in BSL (Figure 2-14);
- a 2 % increase in electricity use, versus 10 % in BSL (MIX55 includes some e-gas and hydrogen for residential, whereas BSL does not);

[65] Deep renovations that reduce energy consumption by at least 60 % are carried out only in 0.2 % of the building stock per year and in some regions, energy renovation rates are virtually absent ([Communication to the European Parliament and the Council on the Renovation Wave, October 14, 2020](#)).

- a -56 % drop in energy use per €GVA by 2050, relative to 2015, compared to -51 % in the baseline;
- a sustained renovation rate of 1.1 %/year (at least double current levels) (Figure 2-13).

Figure 2-14: Services final energy demand in the EU27 (TWh)



Source: ODYSSEE; *SWD(2020)176 final* – Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan).

2.5.3. Key challenges

Increase renovation rates

Current renovation rates have stagnated at 1 %/year for residential and at 0.6 % in residential, while realising the ambitions set out in the Climate Target Plan requires renovating at double those rates (Figure 2-13). Hence, we identify 'increasing the renovation rates' as a key challenge for realising the energy transition.

Scale up electrification of building end uses

Electricity demand will increase by at least a quarter in homes and by up to 10% in services by 2050 (see section 2.5.1). Heating and cooling in buildings is still dominated by fossil fuel furnaces and boilers, and in some locations by fossil fuel-powered district heating (e.g., combined heat and power). As of 2015, only 6 % of home heating was electric. Water heating and cooking are other end-uses with potential for further electrification. While further electrification of end uses is not the only solution for climate neutrality, increased use of low-carbon gases plays a key role as well in the MIX55 scenario for instance, it would be beneficial for absorbing higher shares of intermittent renewable electricity generation and could be a suitable pathway to pursue for phasing our fossil fuel use in buildings. Hence, we consider 'scaling up electrification of building end uses' as one of the challenges of the energy transition.

Promote electricity demand response

As buildings continue to electrify, their potential as a demand response resource increases commensurately. Demand response (DR) is, 'the intentional modification of normal consumption patterns by end-use customers in response to incentives from grid operators.'[66] DR is an important contributor to system decarbonisation because it lowers overall system demand, and enables greater system integration of wind and solar.[67] And it benefits consumers by lowering energy bills up to 10 % or more.[68] Despite these benefits, only 10-20 % of the 50 GW in achievable DR potential is realised in Europe today.[69] [70] While this is an improvement over 2013, when DR was nearly non-existent in Europe, there are still substantial barriers for further uptake of DR.[71] As such, we identify further 'promotion of electricity demand response' as a challenge for realising the energy transition cost-effectively.

2.6. Demand - Industry

2.6.1. State of play

Industry forms many links within value chains critical to the EU, including transport, construction and power; it also produces goods enabling emissions reductions in other sectors. And industry has made great progress itself towards decarbonisation – between 1990 and 2015, energy intensive industries (EIIs) reduced their carbon emissions by 36 %.[72] In 2015 the sector accounted for 26 % of energy demand in the EU27.[73]

The state of play in industry is that final energy demand declined 10% between 2000 and 2019, while becoming 20 % more efficient. In the baseline scenario, electricity use as a share of total industrial demand grows from 23 % in 2015 to 40 % by 2050 and energy intensity continues declining -2 % through 2030 and -1 % thereafter (Climate Target Plan).

Energy demand

Final energy demand in the industrial sector increased between 2000 and 2008 at 0.6 % CAGR, then decreased in the wake of the financial crisis through 2019 at -1,3 %/year. Overall, industrial demand fell 10 % between 2000 and 2019. In the baseline scenario, demand declines -0.7 %/year between 2015 and 2030, and then at -0.1 % between 2030 and 2050. Electricity consumption as a share of total demand grows from 23 % in 2015 to 35 % by 2035 and to 40 % by 2050, driven by electrification of industrial heat and of processes, while the share of fossil fuels declines from 63 % in 2015 to 40 % in 2050.

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66 European Commission, Strategic Energy Technologies Information System (SETIS). Demand response - empowering the European consumer. 2014.

67 European Commission. Incorporating demand side flexibility, in particular demand response, in electricity Markets. 5 November 2013.

68 Id.

69 European Commission, DG ENERGY. Impact assessment study on downstream flexibility, price flexibility, demand response and smart metering. July 2016.

70 Regulatory Assistance Project (RAP). The potential of Demand Response in Europe. October 2017.

71 European Commission, DG ENERGY. Impact assessment study on downstream flexibility, price flexibility, demand response and smart metering. July 2016.

72 European Commission. Final Report of the High-Level Panel of the European Decarbonisation Pathways Initiative. November 2018.

73 SWD(2020)176 final – Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan).

Energy efficiency

Energy savings rate

European industry has become much more energy efficient in recent years. As stated in the Climate Action Plan:

> *The industrial sector has already significantly invested in improving its energy efficiency, mainly to address its high energy costs compared to its international competitors.*

Measures taken by industry resulted in a 21 % improvement in energy efficiency in 2018 relative to 2000 in the EU28.[74] This is attributable to implementation of energy management systems, participation in the ETS, and adoption of new advanced technologies.[75]

Energy intensity

Energy consumption per Euro gross value added (GVA) declined -1 % per year between 2000 and 2019, from 4.6 to 3.8 kWh/2015€.[76] Energy intensity of the sector declines -26 % in BSL between 2015 and 2030 (CAGR=-2 %) to 3.0 kWh/€, and then to 2.4 kWh/€ between 2030 and 2050 (CAGR=-1.1 %). Overall, energy intensity drops 41 % by 2050 compared to 2015 in the baseline scenario. Forecasts of industrial energy efficiency are dependent on estimates of GVA. Because this is a long-term forecast, for this analysis we assumed industrial GVA grows at the same rate through the forecast period in the baseline scenario as it did during the entire historical period of 2000-19, at 1 %/year. Higher estimates of GVA will result in lower estimates of energy intensity; conversely lower estimates of GVA will result in higher estimates of energy intensity.

2.6.2. 2050 ambition

The 2050 ambition in MIX55 for industry shows:

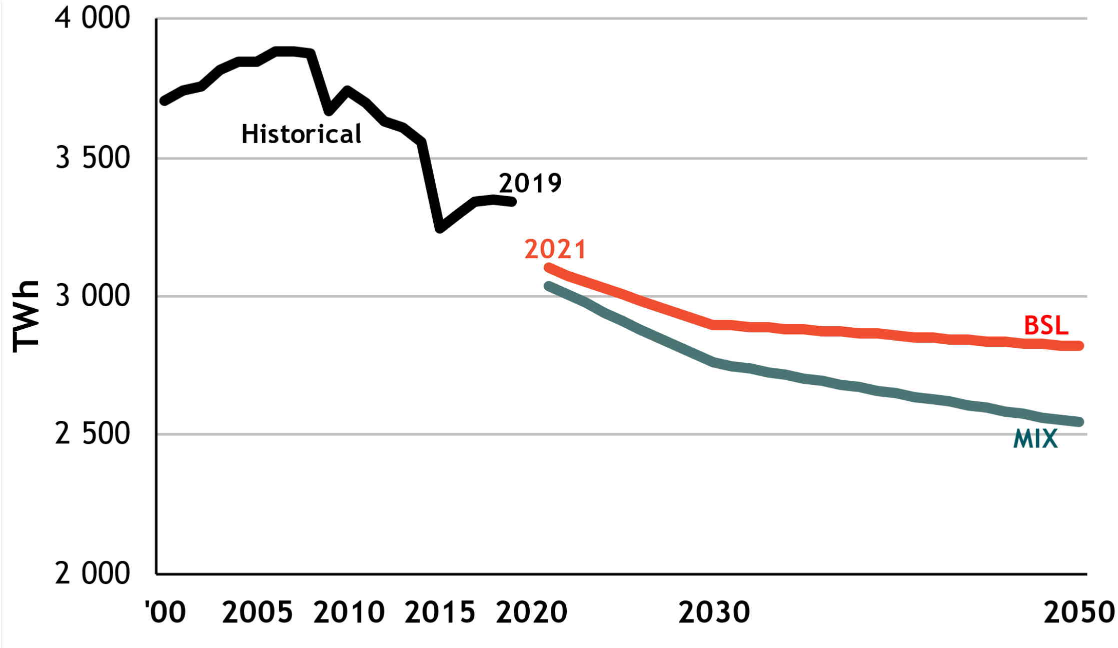
- a -1.1 % annual decline in energy demand between 2015 and 2030, increasing to -0.4% between 2030 and 2050, compared to -0.7 % and -0.1 % in BSL (Figure 2-15)
- a -47 % drop in energy use per €GVA by 2050, relative to 2015, compared to -40 % in the baseline
- electrification of half of energy demand by 2050 – double the 2015 share compared to 40 % in BSL (up 16 % from 2015).

[74] The total industrial energy savings rate is a composite measure of energy efficiency progress. It is calculated as a weighted average of industry sub-sectoral indices of energy efficiency progress, e.g., kWh per unit of production. Enerdata calculates the industrial savings rate using data from 12 industrial sectors including 7 main sectors (chemicals, food (beverage and tobacco), textile (and leather), wood, machinery (and metal products), transport vehicles and other manufacturing; 3 energy intensive sectors (steel, cement and pulp & paper); 2 residual sectors (other primary metals (i.e. primary metals minus steel); non-metallic minerals (i.e. non-metallic mineral minus cement); and mining and construction. The indices are expressed in terms of energy used per ton produced for energy intensive products (steel, cement and paper) and in terms of energy used related to the production index for the other sectors. The energy savings rate for the EU27 was not available at the time of this writing. The energy savings rate accounts for but does not necessarily indicate the energy use baseline of industry within each MS. For example, the low energy savings rates for Finland, Germany and Sweden indicate industries in these countries were already relatively energy efficient in 2000.

[75] European Commission. Final Report of the High-Level Panel of the European Decarbonisation Pathways Initiative. November 2018.

[76] Source: ODYSSEE; SWD(2020)176 final – Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan).

Figure 2-15: Final industry energy demand (TWh)



Source: ODYSSEE; SWD(2020)176 final – [Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan)].

2.6.3. Key challenges

Accelerate implementation of carbon-neutral technology in industrial processes

While there is a need for further energy savings in industry, such savings alone will not be sufficient to decarbonise industrial energy consumption fully. For that, carbon-neutral production processes need to be implemented which are at present either not available yet or not cost-competitive given the current price of carbon (Table 2-6).

Proving the technical feasibility of new technologies is a central barrier to industrial decarbonisation. This is particularly relevant for process-heavy energy-intensive industries such as chemistry, steel and cement, that face daunting decarbonisation challenges as cost-efficient, near-zero-carbon technological options for these sectors are currently either non-existent or not well-proven.[77]

Further, the cost of proving such technologies is not something industry is willing to leverage on its own, and even if the technologies do breakthrough to commercialisation, operational barriers could prevent substantial uptake.[78] As such, we conclude that 'accelerating the implementation of carbon-neutral technology in industrial processes' is the key challenge for decarbonising industry.

[77] European Commission. Final Report of the High-Level Panel of the European Decarbonisation Pathways Initiative. November 2018.

[78] Institute for European Studies.

Table 2-6: Readiness levels, CAPEX and OPEX costs of new low-carbon technologies for use in industry

Technology	Technology readiness	CAPEX costs, compared to baseline tech	OPEX costs, compared to current
Electrification of heating	**High** - Except for glass and cement	**Variable**, e.g., low for boilers, high for process heat	**Varies**, depending on energy prices and efficiency gains from process heat electrification
Electrification of processes	**Very low** - Few demonstrations performed	**High**	**Highly dependent on electricity prices**
Process integration	**Low** - Moving towards pilot plants	**Medium**	**Higher**
Hydrogen	**Low** - Moving towards pilot plants	**High**	**Higher**
Biomass	**Variable** - Some pilot plants	**High** as feedstock to new tech, **Low-Med** as fuel for existing tech	**Higher** as feedstock to new tech, **comparable** as fuel for some existing tech
CCU	**Medium** - Moving towards commercialisation	**Med-High**	**Higher**
CCS	**Low** - Moving towards pilot plants	**High**	**Higher**

Source: Institute for European Studies.

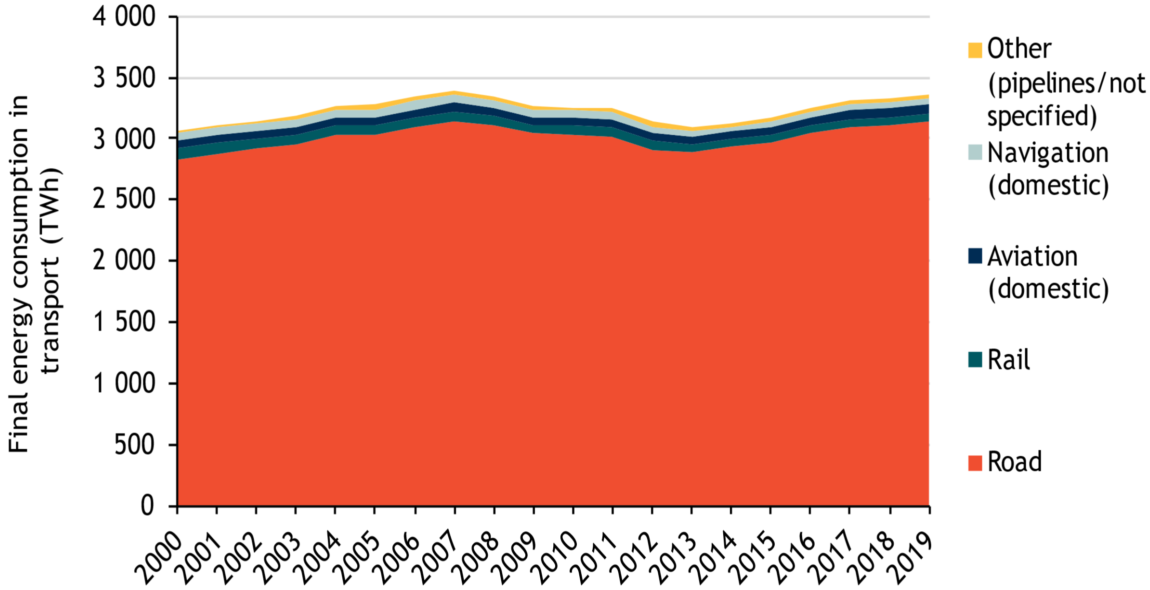
2.7. Demand - Transport

2.7.1. State of play

In 2019 the transport sector consumed 3 360 TWh, accounting for 31 % of the final energy consumption in the EU27, an increase of 3 % from 2015. According to the Climate Target Plan baseline scenario, the sector's energy consumption is expected to decrease by only 3 % between 2015 and 2030, and up to 13 % by 2050, reaching about 2 780 TWh by 2050.

Road transport consumed in 2019 more than 93 % of the total demand in the sector, i.e. 3 144 TWh (Figure 2-16). Domestic aviation and rail consumed 77 TWh and 61 TWh respectively, accounting for roughly 4 % of the sector's demand. Domestic navigation consumed almost 50 TWh, accounting for around 1 % of the sector's energy demand.

Figure 2-16: Historical EU27 final energy consumption per type of transport



Source: Eurostat (2021). Complete energy balances [NRG_BAL_C]. Final energy consumption excludes international aviation and international maritime navigation.

Fuel consumption of international aviation and international maritime bunkers is not accounted for in the EU27 final energy consumption. In 2019 international navigation consumed over 500 TWh, while international aviation reached 485 TWh.

In 2019 oil products were still the dominant energy fuel in the transport sector.[79] Oil products accounted for 93 % of the final energy consumption in the sector. [80] Since 2014 oil consumption has been following an upward trend at an average rate of almost 2 % per year. The main reasons for the increasing energy consumption were the growth in transport activity, the shift towards larger cars and the low oil prices.[81]

Liquid biofuels are the second largest fuel source with 4 % of the consumption, followed by electricity (1.4 %) and natural gas (1 %). As a result, the transport sector had the lowest shares of renewable energy in 2019, with only 8.9 %.[82]

The fuel mix of the sector is projected to change modestly: the share of oil products is projected to remain dominant, decreasing from 95 % in 2015 to 89 % in 2030 and down to 77 % in 2050 (Figure 2-17). Electricity's share is expected to increase from 1.2 % in 2015 to 3.4 % in 2030, and up to 8 % in 2050. Natural gas role in transport will also increase slightly, from 0.5 % in 2015, to 3 % in 2030 and up to 7 % in 2050. Liquid biofuels will experience only a minor change between 2015 and 2030, rising up to almost 5 % in 2030, but by 2050 their relative share will remain the same as in 2015 (around 4 % of the fuel mix). According to the baseline scenario hydrogen and biogas would only play a marginal role in transport in 2030-2050.

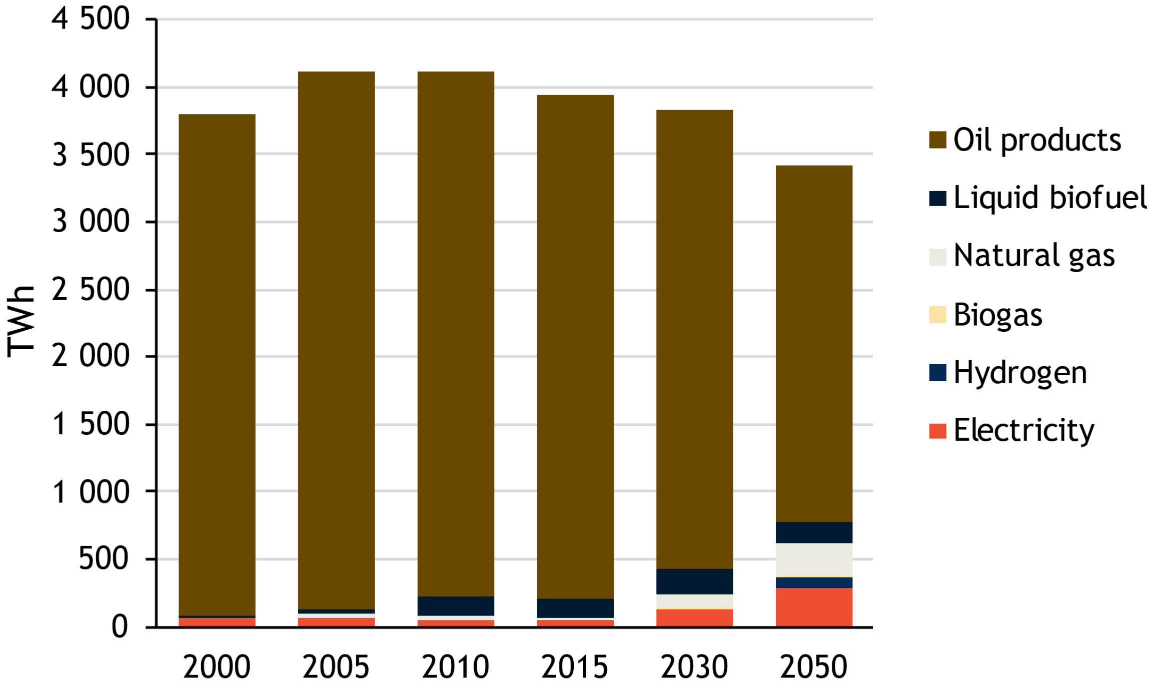
79 Eurostat , Complete energy balances [NRG_BAL_C].

80 To ensure alignment with the Climate Target Plan baseline and policies scenarios, historical figures of the fuel mix of the transport sector include international aviation and maritime navigation, but exclude inland navigation.

81 SWD(2020) 331 final. Sustainable and Smart Mobility Strategy – putting European transport on track for the future.

82 Eurostat SHARES summary results 2019. SHARES tool version 2019 takes into account specific calculation provisions according to Directive 2009/28/EC, in addition to the new possibility to allocate domestically produced biomethane to the transport sector on the basis of the mass-balance system (with appropriate traceability requirements). Available at: https://ec.europa.eu/eurostat/web/energy/data/shares.

Figure 2-17: Historical and projected EU27 final energy consumption in transport per fuel (baseline scenario)



Source: SWD(2020)176 final – Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan).

Note: Values up to 2015 are historical figures from Eurostat. 2020[83] and onwards are projections. Including international aviation and maritime navigation, excluding inland navigation.

Road transport

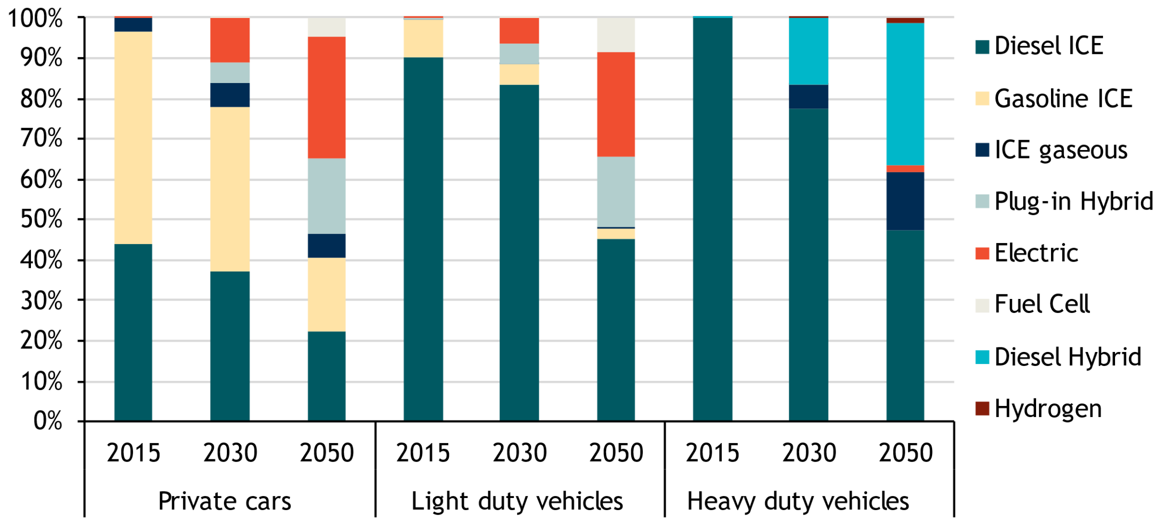
The rise of electricity consumption in transport will be mainly driven by an increasing penetration of electric and hybrid vehicles in the light duty segment (see Figure 2-18). The share of electric cars is projected to rise to 11 % by 2030 and 30 % by 2050 in the baseline scenario. The new standards, applicable from respectively 2025 and 2030, set binding targets for automotive manufacturers to reduce CO_2-emissions and thus fossil fuel consumption.[84] After 2030 the electrification of light duty vehicles is expected to increase rapidly due to the fleet renewal – as standards and targets apply to new vehicles, there is a delay between their introduction and the powertrain changes in the stock of vehicles – driving down greenhouse gas emissions more intensely than in the period up to 2030. Fuel cells[85] will in the time horizon 2050 only play a minor role in the light duty vehicles fleet. With existing policies and targets, low emission vehicles are projected to reach 54 % of the stock of passenger cars and 52 % of vans in 2050.

83 Eurostat (n.d.) Complete energy balances [nrg_bal_c]. Available at: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_bal_s&lang=en.

84 Regulation (EU) 2019/631 Setting CO2 emission performance standards for new passenger cars and for new light commercial vehicles.

85 Fuel Cell vehicles use a propulsion system similar to that of electric vehicles, where energy stored as hydrogen is converted to electricity by the fuel cell. Unlike conventional internal combustion engine vehicles, these vehicles produce no tailpipe emissions.

Figure 2-18: Private cars and vans (light duty vehicles) stock by type of drivetrain in 2015, 2030 and 2050 (baseline scenario)



Source: SWD(2020)176 final – [Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan)].

In the heavy-duty vehicles segment, diesel hybrids are in the BSL scenario projected to represent around 16 % of the stock in 2030 while internal combustion engine-vehicles (ICE) running on gaseous fuels (LPG and LNG) around 6 % of the stock. With current policies the share of conventional diesel vehicles would decrease from almost 100 % in 2015 to 47 % in 2050. Diesel hybrid drivetrains are projected to account for 35 % of the heavy-duty stock by 2050, while ICE using gaseous fuels will account for 15 %.

Other (rail, aviation, navigation)

For rail, the baseline scenario projects that around 89 % of the rolling stock used for passenger transport is estimated to be electric by 2050, and 79 % for freight rail.

At present, air transport relies entirely on petroleum products, with a marginal contribution of liquid biofuels (less than 0.1 %). The baseline scenario expects liquid biofuels (i.e., bio-kerosene) to represent around 0.2 % of energy demand in air transport by 2030, and almost 3 % by 2050.

Moreover, the baseline scenario projects a large share (88 %) of the vessels fleet for inland waterways and national maritime navigation to be powered by liquid biofuels by 2050. LNG vessels would account for 12 % of the 2050 fleet, driven by CEF funding and the assumed availability of LNG refuelling infrastructure, plus the Sulphur Directive (EU 2016/802), regulating air pollution deriving from sulphur content in marine fuels that is also relevant for national maritime transport.

2.7.2. 2050 ambition

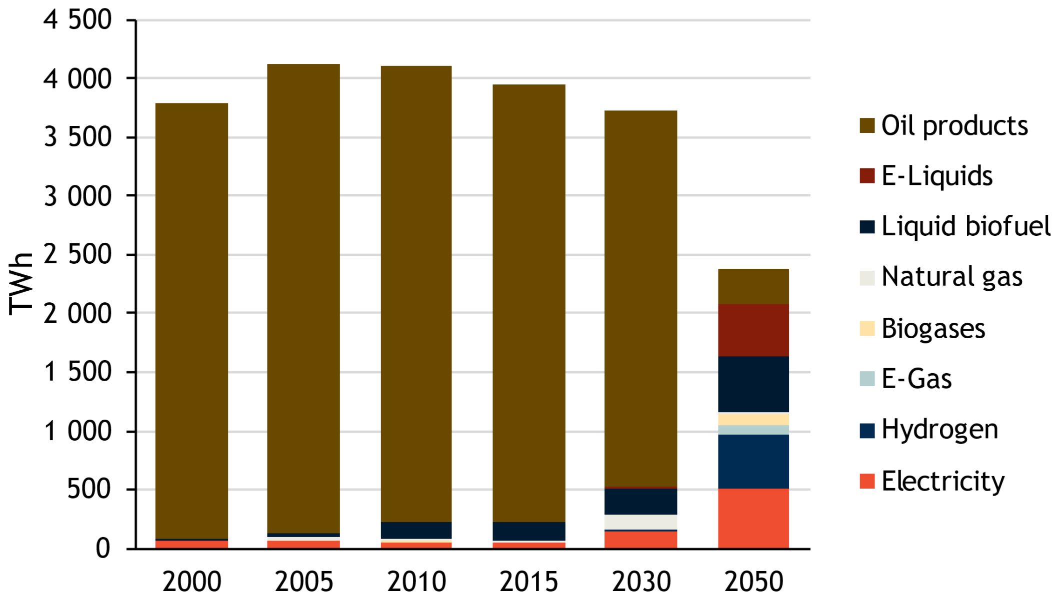
The 2050 ambition as envisaged in the MIX55 policy scenario of the Climate Target Plan projects a decrease in the transport sector's energy consumption of 5 % in 2030 and 39 % in 2050 when compared to 2015, driven by improvements in energy efficiency and in the efficiency of the transport system (see Figure 2-19 below).

When compared to the baseline, the MIX55 scenario projects for 2030 a slightly lower share of oil products (86 %), taken up by higher shares of electricity (4 %) liquid biofuels (6 %) and the participation of hydrogen and biogas (0.3 % each) and of E-liquids (0.2 %). The role of natural gas in the MIX55 scenario for 2030 is expected to be the same as in the baseline (3 %).

The differences between the fuel mix in both scenarios become more significant in the projections for 2050. In the MIX55 scenario the role of oil products is reduced to only 13 % of the energy consumed in the transport sector, and the share of natural gas is also reduced to 1 %. The use of oil products will remain mainly for the aviation and maritime sectors.

Electricity, liquid biofuels, hydrogen and E-liquids have a dominant role in the MIX55 scenario of 2050. Electricity will account for 21 % of the share of fuels in transport, as a consequence of stricter CO_2 emission standards for vehicles and increased availability of charging infrastructure. Together, liquid biofuels and biogas will account for 24 % of the fuel mix thanks to dedicated fuel policies, including for aviation and maritime navigation. Finally, hydrogen and E-liquids will each account for 19 %, while E-gas will reach 3 %, driven by fuel obligations for aviation and maritime navigation.

Figure 2-19: Historical and projected EU27 final energy consumption in transport per fuel (MIX55 scenario).



Source: SWD(2020)176 final – Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan).

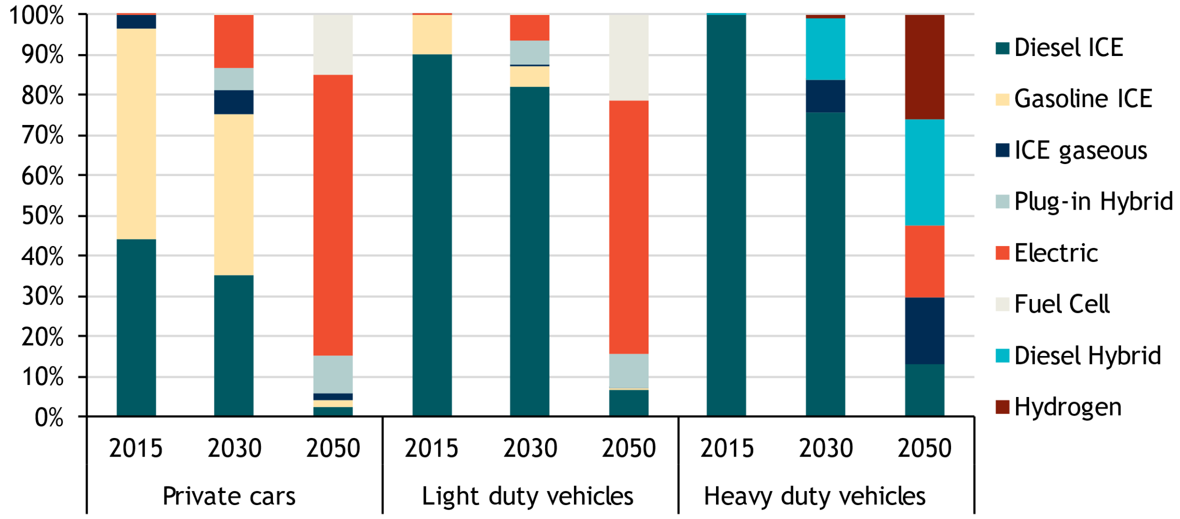
2050 ambition for road transport

The Impact assessment of the Climate Target Plan suggests that by 2050, almost all cars (between 88-99 % of the vehicle stock) need to be low or zero emission in order to reach the climate neutrality target (Figure 2-20).[86]

Electrification in road transport will further increase, as a consequence of economic and technical improvements, stricter CO_2 emission standards for vehicles and increased availability of charging infrastructure.

[86] SWD(2020)176 final – Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan).

Figure 2-20: Private cars and vans (light duty vehicles) stock by type of drivetrain in 2015, 2030 and 2050 (MIX55 scenario)



Source: SWD(2020)176 final – Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan).

Regarding the heavy-duty segment, 2050 projections of the MIX55 scenario foresee that diesel hybrid and hydrogen will account for 26 % of the fleet each, followed by electric and ICE using gaseous fuels drivetrains with 18 % and 17 % respectively (Figure 2-20). In this scenario the share of diesel conventional trucks will by 2050 account to only 13% of the stock.

In the policies scenarios of the Climate Target Plan, the electric rolling stock would by 2050 represent around 94-95 % for passenger **rail transport,** and 88-89 % for freight rail. To support such significant changes, rail infrastructure would need to be largely electrified by 2050. Hydrogen powertrains would contribute to around 1 % of the passenger rolling stock, and around 2 % for freight rail in the MIX55 scenario, providing a viable option for rail sections that are difficult to electrify.

With regards to **aviation**, the policies scenarios project renewable and low carbon fuels to represent around 5 % of the energy use in 2030 and between 63 % to 68 % in 2050, driven by fuel policies such as ReFuelEU aviation. The largest part of renewable and low carbon fuels by 2030 would be provided by liquid biofuels, with e-fuels accounting for between 0.7 % and 2 % of the energy use. E-fuels are projected to provide up to 35 % of the energy used in transport by 2050. Despite this uptake of liquid biofuels and e-fuels, fossil fuels would still account for 32 to 37 % of the energy fuels used in aviation by 2050.

The policies scenarios would expect energy intensity of **inland waterways** and national maritime vessels to go down by 36-38 % during 2005-2030, and a decrease of 45-49 % for 2005-2050. Renewable and low carbon fuels would represent 8 to 13 % of the fuel mix by 2030 and 85-90 % by 2050. Liquid biofuels would provide the largest share by 2030, but by 2050 e-liquids would represent 37 to 42 % of the energy use in inland waterways and national maritime, followed by liquid biofuels (30-38 %) and decarbonised gases (9-10 %). Electricity and hydrogen contribute together 9 to 13 % of the fuel mix by 2050. In the **international maritime transport sector**, renewable and low carbon fuels are projected at 5.5 to 13.5 % of the fuel mix by 2030 (7.5 % in the MIX55 scenario). By 2050 they would represent 86-88 % of the energy use in international maritime. The uptake of renewable and low carbon fuels in both types of navigation is driven by fuel policies including the FuelEU maritime initiative and supported by the deployment of refuelling infrastructure.

The ambition for 2050 for transport also includes improving the **overall efficiency of the transport system, and changes towards more sustainable transport modes** (energy efficient and less carbon intensive). According to the Sustainable and Smart Mobility Strategy[87], green mobility in Europe should be based on '*an efficient and interconnected multimodal transport system for both passengers and freight, enhanced by affordable high-speed rail network, by abundant recharging and refuelling infrastructure for zero-emission vehicles and supply of renewable and low-carbon fuels, by cleaner and more active mobility in greener cities that contribute to the good health and wellbeing of their citizens.*' As such, the ambition set out for 2050 for the transport sector also include the following changes[88]:

- High-speed rail traffic will grow threefold;
- Rail freight traffic will increase by 50 % by 2030 and double by 2050;
- Transport by inland waterways and short sea shipping will increase by 25 % by 2030 and by 50 % by 2050.

2.7.3. Key challenges

Accelerate electrification of passenger and light duty vehicles

The climate-neutrality scenarios project high penetration of electric vehicles for passenger and light duty vehicles, compared to much more moderate growth of electric vehicles in the baseline scenario. Hence, we identify 'accelerating electrification of passenger and light duty vehicles' as a key challenge for realizing the energy transition.

Develop and implement carbon-neutral options for heavy duty road transport, navigation and aviation

There are greater challenges to heavy duty road transport, air and waterborne transport: currently there is a lack of market ready zero emission technologies for those transport modes, as well as long development and life cycles of vessels. However, zero-emission heavy duty road transport, ocean-going vessels and large zero-emission aircraft need to become market ready a decade from now to realise the climate ambitions.[89] Hence, we identify the 'development and implementation of carbon neutral options for heavy duty road transport, navigation and aviation' as a key challenge for the energy transition.

2.8. Overview of key challenges

The assessment above provides insight into the breadth of the developments and challenges associated with realising the energy transition. Based on our assessment of the current developments and the projections for realising climate-neutrality, we arrived at a list of thirteen key challenges for realising the energy transition, which are listed in Table 2-7 below. Those challenges are largely a summary of the challenges identified in the previous sections, with a few modifications, mainly to merge challenges that are relevant for more sectors. The list below forms the basis for the remainder of this study and is further analysed in the next chapter.

[87] COM(2020) 789 final. Sustainable and Smart Mobility Strategy – putting European transport on track for the future.

[88] When compared to 2015 activity.

[89] COM(2020) 789 final. Sustainable and Smart Mobility Strategy – putting European transport on track for the future.

Table 2-7: Condensed list of key challenges for realising the energy transition

#	Challenge
1	Accelerate solar and wind energy deployment
2	Develop and scale up CCUS for power plants and industry
3	Accelerate phase out of fossil fuel use for power generation
4	Scale up battery storage
5	Scale up low-carbon hydrogen production and power-to-x
6	Promote further cross-border integration of electricity systems and markets
7	Promote electricity demand response
8	Increase bioenergy supply in a sustainable manner
9	Increase renovation rates of buildings
10	Scale up electrification of building end uses
11	Accelerate implementation of carbon-neutral technology in industrial processes
12	Accelerate electrification of passenger and light duty vehicles
13	Develop and implement carbon neutral options for heavy duty road transport, navigation and aviation

Source: own elaboration

2.9. Consistency with scenarios made in other studies

The challenges summarised in the previous section rely for a large part on a comparison between the baseline projection and the climate-neutrality scenarios delivered for the Impact Assessment of the Climate Target Plan. In this section we compare the findings to the results of other scenarios to check the consistency of the scenarios with scenarios delivered in other studies and thereby assess the robustness of the main challenges that we identified. We first compare to several scenarios that have been made for the EU specifically and have been summarised in a recent study by the EU Joint Research Centre (JRC).[90] A second comparison is against the 2021 study by the IEA on reaching net zero globally.[91]

2.9.1. Comparison to EU net zero scenarios

For this assessment we present a summary of trends found in other EU long-term energy scenarios that reach at least 50 % emission reduction in 2030.[92] The analysis is largely based on the findings of the JRC study[93] 'Towards net-zero emissions in the EU energy system by 2050', which compared the results of different scenarios that met the mid-term ambition (i.e. emission reduction of 50 %-56 %

90 Tsiropoulos I., Nijs W., Tarvydas D., Ruiz Castello P. (2020), Towards net-zero emissions in the EU energy system by 2050 – Insights from scenarios in line with the 2030 and 2050 ambitions of the European Green Deal, EUR 29981 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-13096-3, doi:10.2760/081488, JRC118592.

91 IEA (2021), Net Zero by 2050 – A Roadmap for the Global Energy Sector.

92 The projections of these scenarios present results aggregating EU27 with UK as EU28.

93 Tsiropoulos I., Nijs W., Tarvydas D., Ruiz Castello P. (2020), Towards net-zero emissions in the EU energy system by 2050 – Insights from scenarios in line with the 2030 and 2050 ambitions of the European Green Deal, EUR 29981 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-13096-3, doi:10.2760/081488, JRC118592.

by 2030 compared to 1990), and those that met the long-term ambition ((i.e. near-zero emissions or emission reduction of at least 90 % by 2050 compared to 1990).

Table 2-8: Scenarios that meet the mid-term and long-term ambition for emission reduction in the EU28

Publisher	Scenario abbreviation	Mid-term ambition 2030	Long-term ambition 2050
Joint Research Centre	LCEO Zero Carbon	-54 %	-100 %
International Energy Agency	IEA ETP B2DS	-63 %	-92 %
European Climate Foundation	ECF Shared effort	-52 %	-92 %
European Climate Foundation	ECF Demand-focus	-56 %	-90 %
Oeko-Institut	Oeko Vision	-55 %	-99 %
Teske et al. 2019	IFS 2C	-59 %	-100 %
Teske et al. 2019	IFS 1.5C	-77 %	-100 %
WindEurope	WindEurope PC	-55 %	-90 %

Source: Adapted from Tsiropoulos, et al. (2020) Towards net-zero emissions in the EU energy system by 2050.

Most of these energy scenarios show a reduction in the final energy consumption, and a considerable rise in the share of RES in all the sectors by 2030, while major transformations are expected by 2050 for all sectors. Key sector-specific trends are discussed below.

There is a rapid expansion of renewable **electricity** in all scenarios, mainly from wind and solar. However, there is some variation across models regarding the assumptions of the size of the electricity sector in terms of the sector output: A couple of scenarios (ECF scenarios) expect the electricity sector to shrink, while the rest of the scenarios foresee an increase in the electricity generation. In both groups the scenarios expect renewable capacity to increase due to the replacement of decommissioned coal plants. The share of gas-fired electricity is expected to decrease between 2030-2050 in most scenarios, except for WindEurope PC, where the share is expected to be maintained. The scenarios do not explicitly mention if battery storage is used.

Natural gas is expected to be almost fully phased out between 2030 and 2050 in most scenarios, with the exception of the IEA ETP B2DS, where its role is reduced but it still plays a role in fulfilling inland consumption. The specific trends of other **gases** (biogas and hydrogen) are not available.

Regarding **residential and services** (buildings), the trends identified across scenarios are reduced energy demand and electrification of heating. Most scenarios project an increase of electricity consumption.[94] District heating is expected to either maintain or increase its weight in the sector by 2030, while the use of heat pumps is expected to increase, which is the primary reason for the electrification of heating and cooling. By 2050, buildings consume significantly less energy than today due to building renovation and the use of fossil fuels in the sector is practically phased out, replaced mainly by electricity, and an increase in the use of district heating.

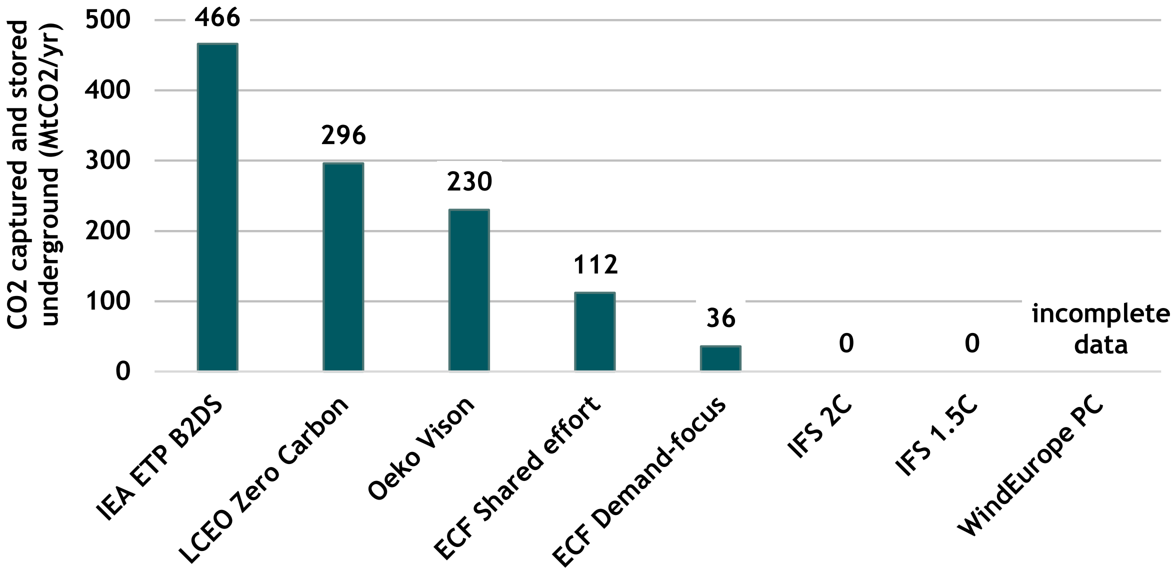
The different scenarios are mostly consistent regarding trends in the **industry** sector. Most of them show a reduction in energy demand equally distributed among the main fuels by 2030, possibly as a result of energy efficiency measures and partly also due to a lower output from industry. Only two

[94] With the exception of the ECF scenarios (ECF Shared effort and ECF Demand-focus), in which electricity consumption decrease, possibly due to assumed high efficiency improvements in the sector.

scenarios (LCEO Zero Carbon and Oeko Vision) expect the emergence of hydrogen consumption in the industry by 2030. By 2050 the sector will consume significantly less fossil fuels. The highest fossil fuel consumption across scenarios is observed in IEA ETP B2DS with 35 % of the sector's energy needs. The sector is largely electrified in all scenarios, and hydrogen emerges as a significant energy carrier by 2050 in all scenarios with 5-20 % of energy consumption in the sector.

Five scenarios include the use of **CCS** to abate emissions from fossil fuel use in 2050, ranging from 36 to 466 Mt CO_2 per year (see Figure 2-21). The ECF Shared effort scenario require all remaining gas plants after 2030 to be equipped with CCS, while in the case of Oeko Vision CCS is only used by the industry sector. Two scenarios don't include the use of CCS in their projections (IFS 2C and IFS 1.5C), and there is not enough data to estimate the use of CCS in the WindEurope PC scenario.

Figure 2-21: CO_2 underground storage in 2050 in scenarios



Source: Adapted from Tsiropoulos, et al. (2020) Towards net-zero emissions in the EU energy system by 2050.

In the **transport** sector the scenarios present a consistent outlook for 2030 in terms of reduced final energy demand, switching from oil to electricity and biofuels, and penetration of new technologies. The main technologies considered are electric vehicles, plug-in vehicles and/or fuel cell vehicles for road transport, and advanced biofuels and synthetic fuels from hydrogen (e-fuels) or syngas (synfuels) for airplanes, ships and heavy duty vehicles (road transport). Most scenarios do not expect a significant deployment of advanced fuels or hydrogen in transport by 2030, with the exception of LCEO Zero Carbon and Oeko Vision. By 2050 the scenarios' outlooks vary greatly depending on their underlying assumptions.

2.9.2. Comparison to the global net zero scenario elaborated by the IEA

The IEA prepared a comprehensive roadmap for the global energy sector with the aim of reaching net zero by 2050.[95] This roadmap has been developed in the context of preparing for the 26th Conference of the Parties (COP 26) which will take place in November 2021 and is the most recent major study on reaching net zero at the time of writing (May 2021). In Table below we list the main findings and challenges suggested in IEA's scenario for each of the main challenges that we identified for this study.

95 IEA (2021), Net Zero by 2050 – A Roadmap for the Global Energy Sector.

Table 2-9: Comparison of key milestones and challenges identified in this study and in recent IEA study

#	Key challenges identified in this study	Milestones / challenges suggested in IEA net zero pathway
1	Accelerate solar and wind energy deployment	• Rapid scale up of solar and wind required, reaching annual additions at 4x the 2020 record levels by 2030 • Advanced economies reach net-zero emissions electricity in 2035 • Globally, almost 70 % of electricity generation is from solar PV and wind by 2050
2	Develop and scale up CCUS for power plants and industry	• 4 Gt CO_2 captured in 2035, growing to 7.6 Gt in 2050 (>20 % of current global emissions (35 Gt)) • Every month from 2030 onwards, ten heavy industrial plants are equipped with CCUS • Identified as innovation priority • Infrastructure to be rolled out between 2020 and 2030 • Deployment of CCUS identified as a major uncertainty
3	Accelerate phase out of fossil fuel use for power generation	• No new unabated coal fired power plants approved from 2021 • Unabated coal in advanced economies phased out in 2030
4	Scale up battery storage	• Electricity system flexibility needs quadruple by 2050 • Major increases in battery storage required • Identified as innovation priority
5	Scale up low-carbon hydrogen production and power-to-x	• 150 Mt low-carbon hydrogen produced in 2030 growing to 435 Mt in 2050 • Identified as innovation priority • Infrastructure to be rolled out between 2020 and 2030
6	Promote further cross-border integration of electricity systems and markets	• Investments in transmission and distribution grow >3-fold between 2020 and 2030
7	Promote electricity demand response	• Electricity system flexibility needs quadruple by 2050 • Major increases in demand response required
8	Increase bioenergy supply in a sustainable manner	• Role as flexible source of electricity supply • Availability of sustainable bioenergy identified as a key uncertainty • Phase-out of traditional solid biomass, increasing use of modern bioenergy • Sustainable bioenergy identified as innovation priority

9	Increase renovation rates of buildings	• 50 % of existing buildings retrofitted to zero-carbon ready levels by 2040 • Increasing to 85% of buildings by 2050
10	Scale up electrification of building end uses	• No sales of new fossil fuel boilers from 2025 • 50 % of heating demand met by heat pumps in 2045
11	Accelerate implementation of carbon-neutral technology in industrial processes	• Large share of required technologies are not on the market yet. 2020-2030 should be used to bring them to the market • Strong electrification foreseen for industry, growing to 53 % of steel production and 76 % of light industry processes by 2050 • More than 90 % of heavy industrial production is low emissions by 2050
12	Accelerate electrification of passenger and light duty vehicles	• 60 % of global car sales are electric by 2030 • No new internal combustion engine car sales allowed from 2035 • 86 % of global car stock is electric by 2050
13	Develop and implement carbon neutral options for heavy duty road transport, navigation and aviation	• Large share of required technologies are not on the market yet. 2020-2030 should be used to bring them to the market • 50 % of heavy truck sales are electric by 2035 • 50 % of aviation fuels are low emissions by 2040

Source: IEA (2021), Net Zero by 2050 – A Roadmap for the Global Energy Sector.

As can be observed from the overview above, there is a great degree of consistency between the key challenges that we identified in this study and the findings from the IEA. Both studies foresee a major role for solar and wind and rapid decarbonisation of the electricity supply, a large degree of electrification for road transport and building end-uses, and a strong need for scaling up sources of energy system flexibility such as battery storage and demand response. Additionally, both studies foresee a significant role for hydrogen and CCUS, a need for higher rates of building renovation and a more uncertain outlook in terms of the technological pathway for decarbonising industry, navigation and aviation with a relatively large need for RD&I.

2.9.3. Conclusions on consistency with other projections

Overall, the different scenarios mostly point to the same key challenges as identified based on the Climate Target Plan and supporting analyses. As a result, we consider the list of key challenges (Table 2-7) a robust summary of where additional public intervention to support the energy transition should be targeted and will use it as the basis for the identification of additional policy measures in the next chapter.

3. Potential EU policy measures to address the key challenges

In this chapter we detail the key challenges identified in the previous section in order to understand the underlying reasons and the ability for EU policies to address those. For each challenge we first identify the underlying gaps and barriers that cause the challenge to exist. Depending on the challenge, the barriers and gaps can differ in nature and may include technological, economic, social as well as regulatory/political issues. The main objective here is to answer the question: why do the required developments not happen without further public intervention?

The second step is to identify the most relevant policy measures that can be used to address the challenge. Here we distinguish the following categories of policy measures:

- Carbon pricing
- Co-funding of investments
- Subsidies
- Loans and guarantees
- RD&I funding
- Tax reform
- Standards and minimum requirements
- Bans on specific energy vectors/technologies/applications
- Market design and market regulation
- Strategy development, infrastructure planning and target setting
- Communication and training

In the third step we estimate what the most appropriate level of intervention would be (EU or MS) in order to lay the foundation for assessing the cost of non-Europe in the final part of the study. In this assessment consideration is given to whether or not the EU has the mandate to enact the policies, to what extent such measures would be enacted without EU action, and whether or not acting at EU level is more efficient than at national level. Based on this assessment we categorise each policy action accordingly in terms of the most appropriate level of EU intervention. Here we distinguish the following categories:

- EU primary action: The influence and responsibility for action resides mostly at the level of EU institutions.
- EU-Member States joint action: The influence and responsibility for action is distributed fairly equally between EU institutions and Member States.
- Member State primary action: The influence and responsibility for action resides mostly at the level of Member State institutions.

In the next section we perform the first two steps (identifying barriers and most relevant policy measures) for each challenge individually. The challenges are presented in order of their identification in the previous chapter, starting with supply-side challenges followed by demand side challenges. This does not infer anything about the relative importance of the challenges.

In the subsequent section we consolidate the most relevant policy measures across the challenges and estimate the appropriate level of intervention per policy measure. We want to emphasise that while this exercise is informed by various studies and the analyses in the previous chapter, the identification of the most important barriers, selection of the most relevant policy measures, and estimation of the appropriate level of intervention is in the end primarily our expert judgment.

3.1. Identification of barriers and policy measures

3.1.1. Accelerate solar and wind deployment

While solar and wind deployment has accelerated tremendously in recent years, a further acceleration is needed to reach climate neutrality. The reason that such acceleration is not expected to happen naturally is threefold. Firstly, in spite of spectacular cost reductions, solar and wind energy projects are **not always profitable enough** to trigger private investment, necessitating continued support measures.[96] [97] Secondly, the **capacity of the electricity grid is not always sufficient** for connecting additional solar and wind capacities, or the necessary grid does not exist yet (in case of offshore renewables). Finally, even if projects are profitable and there is enough grid capacity, the deployment may not happen as quickly as desired due to **other non-market barriers**, such as assigning land and sea for RES deployment, launching calls for tenders and obtaining the required permits.

The issue of a lack of profitability[98] can be further broken down into three sub-barriers. The first sub-barrier concerns **too high technology costs for investment and/or operation** of solar/wind power plants. The most common policy measures for addressing this barrier are various types of subsidies that compensate part of the costs (including feed-in-tariffs/premiums). Additionally, RD&I funding can be used to accelerate the cost reductions of solar and wind energy. The second sub-barrier is **too high capital costs** either due to the technology perceived as being risky or because investing in the country is perceived as risky.[99] The most relevant policy measures for addressing this issue are the provision of cheap loans and/or guarantees to drive down the cost of capital directly. Alternatively, the risk profile may be reduced for example through a feed-in-tariff/premium which insulates the project from the risk of market price volatility. A third sub-barrier concerns **too low sales prices** for the electricity that is generated. This can be addressed through carbon pricing which raises the costs of fossil-fuel based power generation and hence increases electricity market prices[100], and through phasing out fossil fuel-based power which reduces the capacity in the market. Additionally, flexibility measures such as demand response, storage, power-to-x and interconnections may increase the average sales prices of solar and wind power due to shifting demand to times of high generation output. This way, price erosion for intermittent generation is mitigated.

Issues around insufficient grid capacity are generally caused by high costs and long lead times. However, the most relevant policy measures and in particular the scope for EU action differ considerably for onshore and offshore development. Hence, enhancing the onshore and enhancing the offshore grid are treated as separate sub-issues. The **onshore grid needs to be reinforced and extended** to accommodate the increased generation capacity. This issue is primarily domestic in

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[96] IEA (2020) GHG abatement costs for selected measures of the Sustainable Recovery Plan.

[97] Trinomics and Enerdata (2020) - Study on energy prices, costs and their impact on industry and households, task 3.

[98] A lack of profitability in this discussion should be understood as the case where the Internal Rate of Return (IRR) of the average renewable energy project (e.g. a solar farm) is not sufficiently high for investors to invest (i.e. below their 'hurdle rate'), resulting in discontinuing the project.

[99] Trinomics, Cambridge Econometrics and E3M (forthcoming) - Study on the Macroeconomics of the Energy Union, Report on literature review and stakeholder interviews regarding the representation and implications of the financing challenge.

[100] Tax reform may be considered for this purpose as well, but since power generation is already covered by the EU ETS and currently mostly exempted from fuel taxes, we consider it more logical to focus on the EU ETS as the most important measure to drive up the costs of fossil fuel use.

nature with more limited scope for action at EU level[101] and is therefore not discussed in detail in this report. The **offshore grid needs to be developed further** to accommodate increased offshore wind capacities in particular and potentially also other offshore renewables. For this issue there is considerable scope for EU action, for instance through (co-)funding of investments and through strategy development and target setting.[102]

The other non-market barriers that prevent accelerated deployment of solar and wind are not fundamental in nature and largely a result of **a lack of political priority** and consequently insufficient resources assigned to delivering at the speed and capacity required. A key policy measure to assure sufficient political priority is to assign renewable energy targets with a governance process that incentivises delivering per the assigned targets (e.g. by means of binding targets or political pressure).

3.1.2. Develop and scale-up CCUS for power plants and industry

Carbon capture and utilisation/storage (CCUS) is virtually non-existent currently on a commercial basis but is expected to play a significant role in delivering climate neutral electricity and decarbonising the industry by 2050. The most important barriers for CCUS deployment are a **lack of profitability** and a **lack of infrastructure for transporting and storing CO_2**.

The issue of a lack of profitability can be broken down in several sub-barriers. The first sub-barrier concerns **high technology costs** for the equipment to capture the CO_2 and reuse or inject it in the transport infrastructure. As the technology is not applied at scale yet, innovation funding is one of the most relevant policy measures. Additionally, subsidies may be applied for covering the losses in the first wave of operational plants. The second sub-barrier concerns the **low carbon prices** which at present still fail to provide a sufficient incentive for triggering investment in CCUS. Important to note is that this primarily concerns the expected future carbon prices rather than the current prices as investments are made for a relatively long time horizon. The third sub-barrier concerns **a lack of regulatory pressure** which may be applied to force investments in CCUS even without a sufficiently robust business case. Such regulatory pressure may take a similar shape as what is already implemented through the industrial emissions directive for emitting various other gases: a cap on the maximum GHG emissions allowed per unit of production based on the best reference technique.

The issue of lacking infrastructure for transport and storage is driven by two sub-barriers. The first one concerns the **lack of profitability** of this infrastructure, which can be addressed by (co-)funding of investments or subsidies. The second sub-barrier concerns **public opposition** to the development of storage sites which is of particular importance for onshore storage sites. Addressing such a barrier is typically a Member State responsibility with limited scope for EU action and is therefore not discussed in detail in this study.

3.1.3. Accelerate phase out of fossil fuel use for power generation

In the baseline scenario fossil fuels are still used without CCUS for a considerable part of power generation by 2050, while the climate neutrality scenarios require virtually no fossil fuel use (without CCUS) for power generation anymore. Hence, the phase out of fossil fuel use for power generation needs to be accelerated, even though most EU countries already are committed to phasing out coal-

[101] It should be noted that domestic investments with major impact on neighbouring systems are also reflected in the (non-binding) EU-wide ten-year network development plan (TYNDP). Major network investments are hence planned based on a cost-benefit evaluation from a pan-European perspective. The EU steers this process, and EU authorities can influence national investment decisions to some extent through this process.

[102] A relevant example of EU strategy development to address this issues is COM(2020) – An EU Strategy to harness the potential of offshore renewable energy for a climate neutral future.

fired power production by 2030.[103] The most important barriers for an accelerated phase out of fossil fuel-based power generation are that it is **often still economical to run fossil-fuel based power plants** and that the **available low-carbon electricity generation is insufficient** to cover demand.

The issue that running fossil fuel-based power plants is often still economical should not be confused with fossil fuel-based power plants being profitable, which is often not the case. However, it may still be economical to run the plant at times when the market price exceeds its variable costs, even though the price may not be sufficient to recover the fixed costs. The power mix does not decarbonise at the speed required, due to relatively **cheap fossil fuels** and **low carbon prices**. Fossil fuel prices are primarily driven by the dynamics in the producing countries and the world market and are therefore mostly not directly under influence of EU policy makers. The carbon price, however, could be directly influenced by increased carbon pricing through the EU ETS, which is therefore the most relevant policy measure to address this challenge.

The second barrier for phasing out fossil fuel-based power faster is a **lack of low-carbon electricity generation**. If insufficient alternative capacity is available, raising carbon prices will primarily lead to higher consumer prices rather than substitution of fossil fuel-based power. The scale-up of alternative low-carbon sources is treated in other challenges (e.g. on accelerating solar and wind deployment) and is therefore not discussed in detail in this section.

3.1.4. Scale up battery storage

Stationary batteries[104] will play an important role for balancing supply and demand in a climate-neutral energy system. Current battery capacities are very limited and need to be scaled up considerably to realise the climate neutrality scenario in a cost-effective way. The primary barrier for scaling up battery storage is a **lack of profitability** of battery storage installations. For a part this will improve automatically as price volatility is expected to increase due to increased penetration of intermittent electricity sources (solar and wind), creating larger price differences that battery storage can benefit from. But there are also barriers that require more active involvement of policy makers, most notably the high costs of batteries. Inappropriate grid tariff principles and energy taxation rules may also negatively affect the business case of grid connected storage.

The **high technology costs** can be addressed either by realising cost reductions or by increasing the technological performance of batteries (e.g. reducing losses). In both cases, RD&I funding is one of the most relevant policy measures, in particular for battery technologies that are not commercially mature yet. Additionally, subsidies can be applied to accelerate the market uptake, economies of scale and learning-effects of more mature battery technologies. Finally, target setting and strategy development can play an important role by stimulating industrial investments in the supply chain, as is currently done through the European Battery Alliance.[105]

The **double application of grid tariffs and energy consumption taxes** occurs in some EU countries when electricity taken off from the grid is stored in batteries and reinjected later in view of final consumption. These rules constitute a significant penalty for battery storage.[106] The most relevant policy measures to address this are tax reform and redesign of grid tariffs.

[103] COM(2020)564 Driving forward the green transition and promoting economic recovery through integrated energy and climate planning.

[104] Batteries in electric vehicles are discussed separately as part of the challenge on the electrification of passenger and light duty road transport.

[105] European Battery Alliance.

[106] Trinomics (forthcoming) - The role of energy taxation and prices for the clean energy transition in the context of sector integration and carbon border mechanisms, based on inputs from Acer (2019) – ACER Practice report on transmission tariff methodologies in Europe, and Artelys, Trinomics and Enerdata (2020) - Study on energy storage – Contribution to the security of the electricity supply in Europe.

3.1.5. Scale up low-carbon hydrogen production and power-to-x

Low-carbon hydrogen and synthetic fuels volumes produced via electrolysis are negligible at present but are expected to play a central role in the future energy system, contributing to flexibility of electricity demand, decarbonising the gas sector and enabling sector integration at large. Hence, these technologies need to be scaled up significantly. The primary barriers to this are **a lack of profitability** and **a lack of accessible dedicated transport and storage infrastructure for hydrogen**.

The lack of profitability is due to **high technology costs** for installations using power to produce hydrogen and synthetic fuels (e.g. electrolysers). This can be addressed either by reducing the technology costs directly, or by improving the conversion efficiency. In both cases, RD&I funding is one of the most relevant instruments. Additionally, subsidies may be considered to support the scale up of the industry and target setting and strategy development can be important to stimulate investments in the sector. Initiatives such as the Fuel Cells and Hydrogen Joint Undertaking and the EU Hydrogen Strategy are primary examples of how such strategy development can take place. Another factor that negatively affects the profitability of hydrogen production via electrolysis is the availability of **cheap fossil fuels**, which makes hydrogen production via steam reforming of natural gas still more competitive. Carbon pricing and tax reform are the most relevant policy instruments to address this gap.

The lack of accessible dedicated transport and storage infrastructure for hydrogen is at present mostly a result of the low uptake of low-carbon hydrogen via electrolysis (fossil fuel based hydrogen is partly produced on-site and transported via private pipelines). However, increased volumes of low-carbon hydrogen do not automatically trigger sufficient investment in dedicated hydrogen infrastructure due to a **lack of profitability** and potential **misalignment between the benefits and the costs for the concerned operators**. In both cases, public co-funding of investments and regulation of investments in and access to transport and storage infrastructure (that represents a natural monopoly) are the most relevant policy instruments, for example through InvestEU. Additionally, EU coordinated infrastructure planning and cost allocation arrangements may be implemented to address this issue.

3.1.6. Promote further cross-border integration of electricity systems and markets

Further cross-border integration of 'national' electricity systems and markets could bring considerable benefits to the EU and make the transition to a climate neutral energy system more efficient. The potential for further integration is driven by the fact that the current integration level is not optimal yet, leaving substantial room for further system and market coupling, and the fact that increasing intermittent capacities (solar and wind) will lead to higher price volatility and hence price divergence between national/regional markets that can be mitigated through increased integration. There are two primary barriers to further integration: a **lack of interconnection capacity** and **sub-optimal use of the available interconnection capacity**.

A key reason for the low interconnection level at some EU MS borders is that the **benefits of interconnectors are not always aligned with the costs** for deploying those. This can be addressed through public co-funding of investments through instruments such as InvestEU and the Connecting Europe Facility, and through EU coordinated infrastructure planning and cost allocation arrangements such the ten-year network development plans and TEN-E. Another reason is a lack of **ambition to realise interconnection capacities** that are optimal from an EU perspective, taken into account the broader energy and climate policy objectives. More ambitious and differentiated targets for interconnection capacities (as opposed to the current target of 15% interconnection capacity by 2030 that applies to all countries) could be envisaged to address this.

Sub-optimal use of available interconnection capacity does in several EU MS limit the effective benefits realised by interconnectors and therefore also constitutes a barrier to reaping the benefits of further cross-border integration. Sub-optimal use is largely the result of **inadequate capacity allocation rules and incomplete market coupling** which do not proceed at the speed required due to **conflicting national and/or commercial interests**. The most relevant policy measure to address this is to strengthen the governance framework, in particular via Commission regulations and ACER decisions.

3.1.7. Promote electricity demand response

Demand response can play an important role in making electricity demand more flexible, thereby accommodating higher shares of intermittent electricity generation in a cost-effective way. Demand response could be promoted better by addressing the **lack of sufficient financial incentives** and the **lack of awareness of energy end-users**. Additionally, several **system and market design barriers** need addressing.

An important reason for the lack of financial incentives is the **current design of energy taxes and grid tariffs**, which are mostly based on fixed amounts per unit of energy consumed irrespective of the time of use. If taxes and levies would be designed in a way that they fluctuate with the value of the energy that is consumed, similar to VAT for example, they would amplify the price signal and increase the potential cost saving of shifting demand to the most favourable time. Tax reform and implementation of time-of-use grid tariffs are the most relevant policy measures for addressing this barrier. Another barrier for demand response is the **lack of dynamic retail pricing**, in particular for households and small businesses, which prevents consumers from paying real-time electricity prices. Without such contracts, consumers are not exposed to the volatility in wholesale prices and cannot capture the full benefits of demand response. This barrier has already been addressed in the recast Electricity Directive (Art. 11)[107], but large-scale implementation of demand response is still hindered by limited availability of dynamic price contracts. Moreover, in some EU Member States, not all households are equipped with smart meters yet, which is a prerequisite for dynamic price contracts and demand response.

Another barrier for increased demand response is the **lack of consumer awareness** of the potential benefits of demand response and the way to realise such benefits. This issue can be addressed through involvement of aggregators, communication programmes and training initiatives.

The final barrier is a range of system and market design features that do not facilitate demand response in an optimal way. This concerns for instance the **lack of enabling rules and instruments for participation of demand response** in ancillary services and intraday/balancing markets and the **lack of standards and data communication protocols for smart appliances**[108]. Such issues can be addressed through market regulation and standardisation initiatives, preferably at EU level, in order to benefit of economies of scale and to lower market entrance barriers for new operators, e.g. aggregators.

3.1.8. Increase bioenergy supply in a sustainable manner

The climate neutrality scenarios project a growing volume of bioenergy that should be sourced sustainably (all forms: liquid, gaseous and solid). 'Sustainable' in this context refers to those bioenergy sources that comply with the sustainability criteria set out in the renewable energy directive.[109] There are three challenges for realising this growth: high costs for sustainable bioenergy

[107] Directive (EU) 2019/944 on common rules for the internal market for electricity.

[108] Smart appliances are appliances that includes the intelligence and communications to enable automatic or remote control based on user preferences or external signals from a utility or third party energy service provider.

[109] Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources.

sources, limited availability of sustainable bioenergy sources, and a potential need to phase out sources of supply that no longer meet the sustainability criteria.

Sustainable bioenergy sources include a wide array of feedstocks and conversion processes including various waste streams, non-food crops and more advanced feedstocks such as algae. Many of these are **not competitive at present**, either due to low and dispersed volumes (lack of economies of scale), low conversion efficiencies, high technology costs or cheap prices for competing, fossil fuels. The most relevant policy measures for addressing this issue include RD&I funding for the more immature technologies and subsidies (e.g. via tenders) for scaling-up of the most mature technologies. Additionally, carbon pricing could be applied to increase the costs of competing, fossil energy sources.

Apart from the cost-competitiveness of the concerned feedstocks, there is also **a limit on the availability of suitable biomass in an absolute sense**. Moreover, the available sources have competing uses including use as animal feed and feedstock / raw material for manufacturing processes, where biomass may provide a higher added value. This barrier can be partly alleviated by improved conversion efficiencies which would enable a higher yield from the available supply, but is mostly an intrinsic barrier that cannot be addressed effectively.

The final barrier to increased bioenergy supply is **a potential need to phase-out unsustainable supply sources**. Sustainability criteria for bioenergy have become increasingly stringent and clearly defined over time, which may mean that part of the current bioenergy supply does not comply with the criteria any more. As a result, this supply would need to be phased out, which makes it even more challenging to increase the overall bioenergy supply. This barrier cannot be addressed by additional policy measures as the sustainability criteria need to be respected.

3.1.9. Increase renovation rate of buildings

Realising the climate-neutrality scenarios requires doubling the renovation rate to accelerate energy efficiency improvements. We identified three main barriers to increasing the renovation rate: high upfront costs, long payback periods and a lack of access to capital.

The **high upfront costs** of renovations constitute an important barrier because building owners are naturally cautious when spending such large amounts of money even though the business case may be attractive. One of the most relevant policy measures for addressing this issue are subsidies, grants and tax allowances that reduce the net investment for the building owner. Additionally, energy performance contracting (EPC) may be applied to outsource the upfront investment. While energy performance contracting is available in most EU markets, it is applied at a limited scale and would benefit from policy measures to create a larger market and realise demonstration projects.[110] A relevant policy measure for this is public procurement of EPC services for public buildings. Furthermore, energy savings obligations imposed on energy suppliers may drive investment with the help of the supplier.

Renovations can also have **long payback periods** which make the investment less attractive overall. Tax reform is one of the most relevant policy measures for addressing this issue, as tax rates and levies on energy are often too low to stimulate investment in energy efficiency measures such as building renovation. Alternatively, carbon pricing may be applied to raise the costs of (fossil) energy. Additionally, minimum requirements on energy efficiency could be implemented or raised, either as a minimum energy performance that should be realised when renovating a building (such as already required by the Energy Performance of Buildings Directive) or that should be met when selling or renting out a building. This way, the payback period is no longer the leading criterion for

[110] JRC (2017) – Energy Service Companies in the EU: Status review and recommendations for further market development with a focus on Energy Performance Contracting.

choosing whether or not to renovate and how deep the renovation would be and issues such as split incentives between landlords and tenants are addressed. Finally, long payback periods can be addressed through standardisation measures which make the industry less fragmented and more efficient overall.

A final barrier to increased renovation rates is a **lack of access to capital** for certain building owners. In particular for low-income households this may be an important barrier as there can be little savings available and financial institutions may be reluctant to provide capital. The most relevant policy measure for addressing this issue is to make cheap loans available with less stringent conditions than those applied in the market.

3.1.10. Scale up electrification of building end uses

The climate-neutrality scenarios require a substantial degree of electrification of building end-uses. The most significant non-electric end-uses are heating and cooking which are commonly performed with fossil fuel-fired appliances. The key barriers to electrify these uses are high upfront costs, long payback periods, a lack of awareness and outdated electricity distribution networks.

High upfront costs are a main barrier for electrifying heating as the installation of a heat pump is more expensive than a conventional boiler and often requires a replacement of the heat exchangers. For cooking, electric equipment may be more expensive too, in particular the more efficient appliances. The most relevant policy measure for addressing this barrier is to subsidise the purchase costs of heat pumps and electric cooking stoves. Additionally, energy savings obligations imposed on energy suppliers may drive investment with the help of the supplier.

Another barrier is the **long payback period,** which is mainly due to the high price of electricity (which internalises the GHG emission cost) compared to fossil fuels (which are in several EU MS not yet subject to carbon taxes). A relevant policy measure for addressing this issue is energy tax reform, lowering the surcharges on electricity and/or increasing the levies on fossil fuels. Alternatively (and preferably), carbon pricing may be extended to fossil fuel use in buildings.

A **lack of public awareness** on the available technologies, subsidies and associated benefits may also constitute a barrier for (parts of) certain end-user groups. This could be addressed through communication (e.g. on labelling) and education programmes.

Finally, a **lack of grid capacity** may constitute a barrier to quick electrification of end uses. In particular when whole districts switch to electrical heating the grid capacity may be exceeded. Addressing this issue is a Member State responsibility with little scope for EU action and is therefore not discussed in detail in this study.

3.1.11. Accelerate implementation of carbon-neutral technology in industrial processes

The implementation of carbon-neutral technologies in industrial processes needs to be accelerated to transition to carbon-neutral manufacturing in time. A specific characteristic of this challenge is that the solutions for low-carbon production are not always fully clear yet and several options are still under development. Hence, one of the barriers is the low technology readiness level of carbon-neutral solutions. Another barrier is the lack of competitiveness of low carbon solutions versus conventional fossil fuel-based manufacturing processes. Finally, the risk of carbon leakage needs to be mitigated to avoid industry relocating rather than actually reducing its emissions.

The **low technology readiness** of potential solutions for carbon-neutral manufacturing requires further research and development as well as demonstration projects to test the solutions in practice and at scale. Increased RD&I cross-border cooperation and co-funding is the most relevant policy measure for addressing this challenge. Horizon Europe is obviously relevant but also the Innovation Fund is highly relevant as it targets low-carbon manufacturing directly.

The solutions for carbon-neutral manufacturing that are market ready often suffer from **a lack of competitiveness** versus traditional manufacturing technologies. This issue can be addressed through a range of policy measures, including subsidies, carbon pricing and tax reform to shift the cost comparison in favour of the low-carbon solutions. Additionally, maximum carbon emission levels may be imposed on manufacturing, similar to what is already in place through the Industrial Emissions Directive for several other emissions. This way, production processes with high carbon emissions are effectively banned, thereby reducing the relevance of a lack of competitiveness for low-carbon production processes.

The final barrier for implementing carbon-neutral technology is the **risk of carbon leakage**. If efforts to push carbon-neutral manufacturing technologies result in industry moving to locations with lower pressure to reduce emissions, emissions are not actually reduced but only relocated. One of the most relevant policy measures for addressing this issue is to implement the carbon border adjustment mechanism that is currently designed within the context of the EU Green Deal. Additionally, exemptions and compensation for industry may be applied, such as the free emission allowances that are currently in place for emissions governed by the EU ETS.

3.1.12. Accelerate electrification of passenger and light duty vehicles

Based on the latest trends and projections outlined in the previous chapter, it seems most likely that electrification will be the main pathway for decarbonising passenger and light duty vehicles. Other pathways, in particular fuel cell vehicles using hydrogen, might be relevant for specific sub-segments. There are three main barriers to accelerated uptake of electric vehicles. First, the initial purchase cost is often considerably higher than for conventional vehicles. Secondly, there is a lack of public awareness on fuel economy and CO_2 emissions. Thirdly, a lack of charging infrastructure can constitute a barrier in certain regions.

The **higher initial purchase costs** for electric vehicles are an important barrier because it requires more access to capital as well as a willingness to make a relatively high initial investment. The most relevant policy instrument for addressing this are subsidies, including tax allowances to compensate part of the investment.

The **lack of public awareness on fuel economy and CO_2 emissions** of vehicles concerns the lack of understanding of end-users on whether or not electric vehicles are more expensive and polluting over their lifetime than conventional vehicles. This comparison is highly dependent on the specific vehicles that are compared and where they are used, which influences energy prices, tax rates and the emissions factor of the electricity consumed. The most relevant policy measures for addressing this barrier are labelling and communication and training.

The final barrier concerns the **lack of charging infrastructure** in most countries and regions as well as a lack of interoperability across the EU. This is best addressed with target setting for the roll-out of public charging infrastructure, supported by co-funding of investments or subsidies and technical standards to ensure interoperability of systems and equipment.

3.1.13. Develop and implement carbon neutral options for heavy duty road transport, navigation and aviation

The pathway for decarbonising heavy duty road transport, navigation and aviation is less clear-cut. Solutions may include hydrogen, synthetic fuels, biofuels and potentially some electrification, but it is not clear which solution will be preferred for which application. Hence, the first barrier to decarbonise these transport modes is the lack of market-ready zero-emission technologies. A second barrier is a lack of regulatory pressure to decarbonise these transport modes, as fuels are often exempted from taxes and emission standards are non-existent. The final barrier is a potential lack of refuelling infrastructure and equipment, depending on the solution chosen.

The **lack of market-ready zero-emission technologies** includes two sub-barriers. First, the investment required for research and development of these technologies is high and should preferably be coordinated across the EU. RD&I cooperation and funding through instruments such as Horizon Europe is the most relevant policy instrument to target this issue. Secondly, there is uncertainty regarding the most adequate solution for decarbonisation, with several technologies that could be considered. This issue can be targeted through EU coordinated RD&I priority setting, for example through an EU Technology and Innovation Platform (ETIP).

The **lack of regulatory pressure applies primarily to** aviation and maritime transport and is particularly relevant due to the long life cycles of aircrafts and vessels. We identified two sub-issues. First, fossil fuels are generally exempt from taxes for navigation and aviation, which does not incentivise the transition to lower carbon transport equipment. This could be addressed through tax reform and carbon pricing, including the extension of the EU-ETS to other transport modes than intra-EU aviation (intra-EU aviation is already in scope of the EU ETS). Secondly, there is a lack of emission standards for existing and new fleet which does not incentivise the uptake of lower carbon aircrafts and vessels. The introduction of emission standards for aviation and navigation, similar to those applied for road transport, could be a relevant measure to address this issue. Additionally, targets could be introduced to reduce the carbon intensity of the existing fleet.

The final issue is the **lack of refuelling infrastructure and equipment**, which would be costly to implement/adapt at existing airports and harbours as well as along highways. Coordinated planning and public co-funding of investments (e.g. through InvestEU), incentives, as well as target setting and strategy development may be applied to address this issue.

3.2. Estimating the appropriate level of public intervention

In this section we define the main policy measures in more detail, summarise their relevance per challenge and identify the most relevant EU instruments that are available. Based on this assessment, we draw conclusions on the most appropriate level of public intervention (EU, MS, or jointly). As the policy measures where the primary action resides with the EU are most relevant for assessing the cost of non-Europe, we first discuss those, followed by policy measures with joint EU-MS action and measures with primary action residing at Member State level.

3.2.1. EU primary action

Carbon pricing

Carbon pricing concerns assigning a cost to GHG emissions and can be implemented either through a cap-and-trade system or through a carbon tax. Additionally, GHG emissions of imported goods can be priced through a carbon border adjustment mechanism, if no sufficient pricing is applied in the country of origin.

Carbon pricing is relevant for many challenges as it improves the business case of low-carbon technologies versus fossil fuel-based technologies and improves the payback period of energy efficiency investments (Table 3-1). The key EU instrument in this regard is the EU Emissions Trading System (EU ETS) which may be extended in scope to include buildings and transport. Additionally, the Carbon Border Adjustment Mechanism could play an important role in assuring effective carbon pricing, although the design and application of it are still very uncertain at the time of writing.

As both the EU ETS and the Carbon Border Adjustment Mechanism are EU driven, we consider carbon pricing an instrument where intervention at EU level is most appropriate and categorise it as 'EU primary action'.

Table 3-1: Relevance of carbon pricing per challenge

Challenge	Relevance
1. Accelerate solar and wind	Improves competitiveness of renewable energy versus conventional electricity
2. CCUS for power plants and industry	Improves profitability of CCUS
3. Phase out fossil fuel use for power	Decreases profitability of fossil power generation
5. Hydrogen and power-to-x	Increases costs of fossil fuel-based hydrogen without CCUS
8. Sustainable bioenergy supply	Improves sales prices
9. Building renovation	Reduces payback period of investments
10. Electrification of building end uses	Reduces payback period of investments
11. Carbon-neutral industrial processes	Improves competitiveness of low-carbon processes
12. Electrifying passenger and light duty vehicles	N/A[111]
13. Carbon neutral heavy duty transport, navigation and aviation	Improves pressure to develop carbon-neutral options

Source: own elaboration.

Energy markets design and regulation

The design of the EU electricity and gas markets and the national regulations that govern them can constitute a barrier for addressing the key challenges of the energy transition. Examples include the actual rules for participation in national markets for ancillary services and short-term electricity products that may not incentivise demand response and battery storage, and the lack of full market coupling which may provide a barrier to optimal trade and price formation (see Table 3-2 for the relevance across all challenges).

The EU policies and institutions (including ACER) play a key role in the design of the principles and rules for the EU energy markets' functioning through several regulations, directives, network codes and guidelines, while the actual implementation is delegated to national authorities and operators. In some cases, barriers may exist due to specific Member State interests that are not aligned with overall EU interests; in those cases, EU involvement is required to mediate. Hence, we classify this instrument as 'EU primary action'.

[111] In theory carbon pricing may be applied for this challenge too, but in practice taxes on gasoline and diesel are already higher than the carbon price and the externality is therefore already priced in, reducing the need for carbon pricing to address this issue.

Table 3-2: Relevance of market design and market regulation per challenge

Challenge	Relevance
4. Battery storage	Enabling rules for participation of battery storage in markets
5. Hydrogen and power-to-x	Regulation for transport and storage infrastructure and cost allocation
6. Electricity systems/markets	Strengthened governance to accelerate market coupling
7. Demand response	Entitlement to dynamic pricing contracts Enabling rules for participation of DR in markets

Source: own elaboration.

Technical standards and minimum energy performance requirements

Standards and minimum requirements can be applied to raise the minimum performance levels in line with the policy objectives, for instance by imposing minimum energy efficiency performance levels for new equipment or renovations. Such measures are particularly relevant for end-use equipment (vehicles, appliances, buildings) as indicated by the relevance per challenge in Table 3-3 below.

There are many relevant EU instruments in this regard, including the Energy Efficiency Directive (EED), Energy Performance of Buildings Directive, Ecodesign Directive, Energy Labelling Regulation, the Industrial Emissions Directive and the Alternative Fuel Infrastructure Directive. This makes sense as such regulation is most effective if it is applied consistently across the EU. Hence, we classify this instrument as 'EU primary action'.

Table 3-3: Relevance of standards and minimum requirements per challenge

Challenge	Relevance
2. CCUS for power plants and industry	Maximum emission regulation
7. Demand response	Standards communication protocols for smart appliances
9. Building renovation	Minimum energy efficiency requirements Standardisation to address industry fragmentation Energy savings obligations
10. Electrification of building end uses	Energy savings obligations
11. Carbon-neutral industrial processes	Emission standards
12. Electrifying passenger and light duty vehicles	Product labelling for vehicles Technical standards for charging infrastructure
13. Carbon neutral heavy duty transport, navigation and aviation	GHG emission standards for new fleet

Source: own elaboration.

Energy strategy development, infrastructure planning and target setting

Strategy development, infrastructure planning and target setting concern the development of long term plans and ambitions that direct policy development and long-term investment. The EU has put in place many instruments over time including the renewable energy, energy efficiency and greenhouse gas emission reduction targets, infrastructure planning via the TEN-E projects of common interest and ten-year network development plans for electricity and gas networks, the offshore renewable energy strategy, the hydrogen strategy as well as the European Battery Alliance and the Fuel Cells and Hydrogen Joint Undertaking (see Table 3-4 for more examples). Additionally, the option to support industrial projects of strategic importance as a 'project of common European interest (IPCEI)' has gained increased attention in recent years and could be very relevant for addressing the challenges for the energy transition. Two such IPCEIs have been approved for the battery value chain in recent years. Similar IPCEIs could be envisaged for the challenges related to scaling up hydrogen production, power-to-X, and CCUS for instance.

Those strategies, plans and targets need to be regularly adapted though and there is scope for additional strategies and targets, for example for increased electricity interconnection levels (beyond the current 15 % target) and for reducing the carbon intensity of heavy duty transport, necessitating the need for further EU action. Member States have many complementary strategies too, which together contribute to a clear signal to the market.

In terms of the most appropriate level of intervention we consider this an 'EU primary action' instrument as for many of those challenges it is important to move forward collectively.

Table 3-4: Relevance of strategy development and target setting per challenge

Challenge	Relevance
1. Accelerate solar and wind	Renewable energy target setting EU-wide planning of grid developments
4. Battery storage	Battery capacity target setting and strategy formation
5. Hydrogen and power-to-x	Hydrogen capacity target setting and strategy formation EU coordinated infrastructure planning
6. Electricity systems/markets	Increasing the ambition level for optimal interconnection capacities EU coordinated infrastructure planning
9. Building renovation	(Renovation wave)
12. Electrifying passenger and light duty vehicles	Targets for roll-out of charging infrastructure
13. Carbon neutral heavy duty transport, navigation and aviation	Targets to reduce carbon intensity of fleet Strategy for roll-out of EU-wide refuelling infrastructure

Source: own elaboration.

3.2.2. EU-Member State joint action and cooperation

Co-funding of energy-related investments

Co-funding concerns investment of public funds in projects with an active role of the government in shaping and selecting the investments needed. It is different from subsidies due to this active role in shaping the investment, whereas subsidies are provided to projects developed by market actors if they comply with certain conditions.

Co-funding is most relevant for challenges that require the development of public infrastructure, that can be used by multiple market parties via Third Party Access regulation, as summarised in Table 3-5 below. A key EU instrument in this regard is NextGenerationEU which includes particularly large funds available for its Recovery and Resilience Facility (€672.5 Billion in loans and grants)[112] of which at least 30% most go towards climate-related projects. Member States are encouraged to submit proposals for investments in seven flagship areas of which three are related to the energy sector (power up, renovate, recharge and refuel).[113] Additionally, significant funds are available through InvestEU which is the successor of the European Fund for Strategic Investments (EFSI), and includes several other funds such as the Connecting Europe Facility (CEF), which has a budget line specifically for energy infrastructure, and several other instruments.[114] Such investments may also be co-funded through several national instruments.

In terms of the most appropriate level of intervention we consider this an area where there is a fairly equal level of influence for the EU and Member States so we qualify it as 'EU-Member State joint action and cooperation'.

Table 3-5: Relevance of co-funding per challenge

Challenge	Relevance
1. Accelerate solar and wind	Electricity grid development
2. CCUS for power plants and industry	CO_2 transport and storage infrastructure
5. Hydrogen and power-to-x	Hydrogen transport and storage infrastructure
6. Electricity systems/markets	Interconnectors (in particular co-funding of PCIs by EU instruments or by neighbouring countries via CBCA procedures)
9. Building renovation	Public procurement of EPC contracts
12. Electrifying passenger and light duty vehicles	Charging infrastructure
13. Carbon neutral heavy duty transport, navigation and aviation	Refuelling infrastructure

Source: own elaboration.

Subsidies for energy assets

Subsidies concern compensation of costs or additional revenues to trigger private investment and/or continued operations of private equipment. Subsidies may compensate part of the investment or may provide additional revenue over the lifetime of the asset and can be designed in a way that also reduces exposure to market risks.[115]

Subsidies could be relevant for several challenges which require the deployment of technologies that are not commercially viable under the current market conditions (Table 3-6). Subsidies have mainly been a Member State responsibility although some EU instruments exist that also provide a subsidy, such as the recently introduced EU Renewable Energy Financing Mechanism. A shift from national schemes to EU wide subsidy measures could be beneficial as it can result in lower costs (e.g. by awarding subsidies to the lowest cost renewable energy projects across the EU) and prevents

[112] Recovery plan for Europe

[113] https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_1870

[114] About the InvestEU Fund

[115] In the energy production sector, subsidies are generally designed as an additional revenue stream through a feed-in-tariff/premium and are commonly financed through a levy on energy consumption. For the purpose of this report, we do not distinguish between different designs and approaches to financing though, as this would be beyond the scope of this study and does not materially affect the finding that the business case needs to be improved to trigger investments.

market distortion in the increasingly interconnected EU energy markets. It would also ensure a level playing field between MS, thus allowing EU businesses to fully benefit from the economic development potential offered by the Single Market and by the EMU. Furthermore, national subsidies may be driven by overarching EU regulation such as the Renewable Energy Directive and need to comply with the EU Guidelines on State aid for environmental protection and energy. Therefore, we classify this instrument as 'EU-Member State joint action and cooperation'.

Table 3-6: Relevance of subsidies per challenge

Challenge	Relevance
1. Accelerate solar and wind	Renewable energy projects
2. CCUS for power plants and industry	CCUS installations in industry and at power plants CO_2 transport and storage infrastructure
4. Battery storage	Battery storage facilities
5. Hydrogen and power-to-x	Hydrogen production and storage facilities
8. Sustainable bioenergy supply	Bioenergy production sites
9. Building renovation	Grants/tax allowances for building owners
10. Electrification of building end uses	Grants/tax allowances for new electric equipment
11. Carbon-neutral industrial processes	Carbon-neutral production processes and equipment
12. Electrifying passenger and light duty vehicles	Tax allowances for electric vehicles Charging infrastructure
13. Carbon neutral heavy duty transport, navigation and aviation	Refuelling infrastructure

Source: own elaboration.

Loans and guarantees to finance investments in energy assets

Loans and guarantees concern the provision of government-backed loans at better conditions than what is available in the market and the provision of guarantees that enable market players to benefit of better conditions. This way, the cost of capital is decreased and access to capital is facilitated, enabling more investments to proceed.

The provision of loans and guarantees is particularly relevant in case upfront investment costs are high and the investing parties do not have enough access to capital or if conditions are not favourable. Renewable energy projects in countries with higher cost of capital are a prime example of where this may be relevant. Additionally, facilitating access to capital to home owners for building renovations can play an important role. Furthermore, reducing cost of capital would be beneficial for many other challenges that require significant upfront investment, such as power-to-x plants and battery storage facilities, even though it is not identified as one of the key barriers for these challenges. Key EU instruments in this regard are InvestEU and the EU Renewable Energy Financing Mechanism. Additionally, EU initiatives such as the EU taxonomy for sustainable activities[116] can

116 EU taxonomy for sustainable investments

result in better access to capital and more favourable financing conditions for the investments required to fulfil the energy transition. Many instruments are available at Member State level too.

In terms of the most appropriate level of intervention we consider this an area where there is a fairly equal level of influence for the EU and Member States so we qualify it as 'EU-Member State joint action and cooperation'.

Table 3-7: Relevance of loans and guarantees per challenge

Challenge	Relevance
1. Accelerate solar and wind	Financing riskier RES projects
9. Building renovation	Financing building renovation

Source: own elaboration.

Energy related RD&I funding

Research, Development and Innovation (RD&I) funding targets technologies that are not technologically or commercially mature yet and includes funding for early stage R&D as well as more advanced stages, including demonstration projects. The public funding complements private funding to accelerate the development of technologies that are too resource-intensive or risky to be developed by the private sector alone. Funding may either target technology cost reductions or performance improvements, both leading to cost reductions per unit of output.

RD&I funding is particularly relevant for technologies that are not technologically mature yet or that require further cost reductions to compete with conventional technologies. Additionally, publicly funded projects may be important for directing the future research agenda for public and private actors. Table 3-8 summarises the relevance per challenge.

Key EU instruments in this regard include Horizon Europe, the Innovation Fund and InnovFin Energy Demonstration Projects. Additionally, significant funding is available at Member State level.

In terms of the most appropriate level of intervention we consider this an area where there is a fairly equal level of influence for the EU and Member States so we qualify it as 'EU-Member State joint action and cooperation'.

Table 3-8: Relevance of RD&I funding per challenge

Challenge	Relevance
1. Accelerate solar and wind	Reduce solar and wind technology costs
2. CCUS for power plants and industry	Reduce CCUS technology costs and demonstrate at scale
4. Battery storage	Reduce battery technology costs
5. Hydrogen and power-to-x	Reduce power-to-x technology costs and demonstrate at scale
8. Sustainable bioenergy supply	Reduce bioenergy technology costs
11. Carbon-neutral industrial processes	Develop competitive carbon neutral options
13. Carbon neutral heavy duty transport, navigation and aviation	Develop carbon neutral options, inform development trajectory

Source: own elaboration.

Reform of energy taxes and levies/charges

This policy measure includes changing tax rates and other charges or levies in order to better align the incentives provided by the taxation and charging system with the policy objectives. It can take many shapes including aligning tax rates to the carbon impact of the energy consumption in which case it fulfils a similar role as carbon pricing, changing tax bases and taxable events to avoid double taxation (e.g. for battery storage), and changing grid charging rules as well as promoting dynamic energy pricing to better pass on price signals (e.g. to incentivise demand response).[117] The relevance of this measure for specific challenges is summarised in Table 3-9.

The EU's primary instrument to influence tax rates is the Energy Taxation Directive (ETD) which sets out minimum tax rates among many other provisions. The ETD is under revision as part of the 'fit for 55 %' package to better align it with climate and energy goals. Still, taxation is largely a Member State responsibility as at present, EU legislation only sets harmonised minimum rates in view of avoiding market distortions and the requirement for unanimity by MS has been an obstacle to deliver ambitious reform. Principles regarding other energy charges and levies are also primarily determined by Member States. Therefore, we classify this instrument as 'EU-Member State joint action and cooperation'.

Table 3-9: Relevance of tax reform per challenge

Challenge	Relevance
4. Battery storage	Eliminate double taxation and grid charges
5. Hydrogen and power-to-x	Increases costs of fossil fuel based hydrogen
7. Demand response	Time-of-use electricity grid tariffs and dynamic retail pricing to improve business case
9. Building renovation	Reduces payback period of investments
10. Electrification of building end uses	Reduces payback period of investments
11. Carbon-neutral industrial processes	Improves competitiveness of low-carbon processes
13. Carbon neutral heavy duty transport, navigation and aviation	Improves pressure to develop carbon-neutral options

Source: own elaboration.

Communication and training on energy

Communication and training are mostly used for addressing barriers related to a lack of consumer awareness (mainly for households and SMEs). Examples include a lack of awareness of energy savings, payback periods and the technological options available in the market. This is particularly relevant for challenges such as building renovation, demand response and electrification of passenger transport (see Table 3-10).

Several EU initiatives aim at increasing consumer awareness such as legal requirements on energy suppliers to provide end-users with detailed information on their energy consumption and to disclose the energy sources. EU led energy labelling schemes of appliances and equipment also raise consumers' awareness. Furthermore, there is some scope for EU involvement through communication and training projects co-funded via Horizon Europe for instance. Therefore, we classify this instrument as 'EU-Member State joint action and cooperation'.

[117] Tax allowances are not treated as tax reform as those function similar to subsidies and are included under that section.

Table 3-10: Relevance of communication and training per challenge

Challenge	Relevance
7. Demand response	Lack of awareness on benefits of DR
10. Electrification of building end uses	Lack of awareness on benefits of electrification
12. Electrifying passenger and light duty vehicles	Lack of awareness on energy economy and CO_2 emissions

Source: own elaboration.

3.2.3. Member State primary action

Bans on specific energy vectors/technologies/applications

An effective measure to phase out high emission energy vectors, technologies and applications is to ban investing in or using them. This could be relevant for instance for phasing out fossil-fired power plants (e.g. legal ban on investments in coal fired plants), fossil fuel based heating (ban to install such installations in new or renovated buildings) and fossil fuelled internal combustion engine vehicles. We haven't identified banning any of those as a key policy instrument however, as we expect other policy instruments such as carbon pricing and emission standards to be sufficiently effective for realising this. Additionally, such measures would be largely Member State driven as the EU does not have a legal basis to ban particular vectors (MS primary action) and would therefore be of lesser interest in the context of this study.

Table 3-11: Relevance of standards and minimum requirements per challenge

Challenge	Relevance
3. Phase out fossil fuel use for power	(ban on investment in fossil power generation)
12. Electrifying passenger and light duty vehicles	(ban on selling/using fossil fuelled internal combustion engine vehicles)

Source: own elaboration.

3.3. Modelling of policy package to evaluate the cost of non-Europe

In this section we convert the relevant policies identified in the previous section to a policy package that can be evaluated with the macroeconomic model E3ME. This policy package includes a mix of EU and Member State-driven measures that collectively reach the climate neutrality ambitions. Throughout this report, we refer to this policy package as the 'net zero scenario'. Additionally, we design variants to this policy package which omit the main EU-driven policies and will be used to isolate the added value of EU action or conversely, the cost of non-Europe. The impact of the net zero scenario and the variants that are evaluated through the E3ME model are discussed in the next chapter.

3.3.1. About the E3ME model

Cambridge Econometrics' E3ME model is a computer-based model of the world's economic and energy systems and the environment. It was originally developed through the European Commission's research framework programmes and is now widely used in Europe and beyond for policy assessment. The model manual (Cambridge Econometrics, 2019) is available online at the model website www.e3me.com[118]. A short description of the model is provided in this section and the model is also described in Appendix A[119].

The E3ME model provides an economic accounting framework that can be used to evaluate the effects of the implementation of policies that deliver full decarbonisation of energy consumption on the wider economy. Behavioural relationships in the model are estimated using econometric time-series analysis based on a database that covers the period since 1970 annually. A core feature of the model is its treatment of technology, which will be key to meeting many of the policy challenges including full decarbonisation. The Future Technology Transformation (FTT) models of technology diffusion[120] in E3ME provide a representation of the adoption of new low carbon technologies. E3ME extends its treatment of the economy to cover physical measures of energy, food and material consumption. The main source of data for Europe is Eurostat.

The E3ME model baseline includes preliminary COVID impacts (2020 only) based on official projections from DG ECFIN, IMF and the World Bank, the latest renewables cost assumptions from the IEA, and current policies prior to the pandemic (DG Energy and IEA's World Energy Outlooks). The GHG emissions profile in the E3ME baseline is similar to the baseline (BSL) used in the Impact Assessment accompanying the Climate Target Plan[121].

3.3.2. Description of the Net Zero scenario

For the Net Zero scenario, a combination of climate and energy policies is used to achieve climate-neutrality by 2050 in a way consistent with the aims of the EU Green Deal. These policies, and how they will be implemented as modelling assumptions within E3ME, are outlined in this section.

The package of policies described represents those that will be included in the net zero scenario. Variants of this package will be run excluding aspects of the policy regime to assess the importance and contribution of specific policy measures decided at EU level towards achieving net-zero carbon emissions by 2050.

Table 3-12: Summary of main assumptions

Policy/ assumption	Primary action	2030	2050
ETS	EU	ETS price increase by 20 % from values used in the 55 % scenario of Climate Target Plan	Continue to increase
Carbon tax	EU (if implemented as extension to EU ETS)	All non-ETS sectors (same ETS price)	Continue to increase
Coal phase out	MS	Coal phase out consistent with announced national polices and 2030	Phase out of other fossil fuels in power plants by 2050 unless connected to CCS

118 A direct link to the manual is here: https://www.e3me.com/wp-content/uploads/2019/09/E3ME-Technical-Manual-v6.1-onlineSML.pdf.

119 The full list of equations are also available in Mercure, J-F, H Pollitt, NR Edwards, PB Holden, U Chewpreecha, P Salas, A Lam, F Knobloch and JE Vinuales (2018) 'Environmental impact assessment for climate change policy with the simulation-based integrated assessment model E3ME-FTT-GENIE', Energy Strategy Reviews, Volume 20, April 2018, pp 195–208.

120 Mercure, J-F (2012) 'FTT:Power : A global model of the power sector with induced technological change and natural resource depletion', *Energy Policy*, Volume 48, September 2012, pp 799-811.

121 SWD(2020)176 final – Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan).

		regulations for MS with no planned regulations (except Poland), unless connected to CCS	
Nuclear phase out in some MS	MS	Announced national policies	
Feed-in-premiums	EU-MS	Wind and solar subsidies at 30 % of investment costs	Wind, solar, bioenergy, and CCS technology subsidies at 30 % of investment costs
Steel	EU-MS	Small regulation of blast furnace (switch to recycled steel)	Investment subsidies for CCS-complemented steel production
Energy efficiency investment	EU-MS	Increase investment by 20 % from values used in MIX55 scenario of Climate Target Plan	Increase investment by 20% from values used in MIX55 scenario of Climate Target Plan
Fossil fuel boiler regulation	MS	Announced national policies	Ban of fossil fuel boiler
Ban on fossil fuelled internal combustion engines (ICEs)	MS	Announced national policies	All EU MS ban new fossil fuelled cars from 2030
Electric passengers' vehicles subsidies	EU-MS	EV investment subsidies starting from €2 000 per vehicle	
Loans and guarantees to finance investments in energy assets	EU-MS	Lower discount rate for renewable technologies to 7 % (from 10 %)	Lower discount rate for renewable technologies to 7 % (from 10 %)
Rest of the world	NA	Business as usual	Business as usual
Balancing public revenue	NA	Public revenue neutrality, i.e. additional revenues are recycled	Public revenue neutrality, i.e. additional revenues are recycled

Source: Cambridge Econometrics.

Greenhouse Gases Emissions Allowances Price

The Emissions Trading System (ETS) covers the following sectors in the E3ME model:

- power and transformation
- rest of energy branch
- iron and steel
- non-ferrous metals
- chemicals
- non-metallic minerals
- paper and pulp
- other industry
- commercial aviation within the EEC.

ETS prices are based on those estimated necessary for achieving a 55 % emission reduction in 2030 from the PRIMES model's COMB55 scenario prepared for the Climate Target Plan[122]. In the E3ME net zero scenario, these prices are scaled upwards by 20 % to reflect the need for more ambitious carbon emissions reductions to reach a pathway to achieve net zero by 2050.

Table 3-13: Carbon prices assumptions for the 2021-50 period

	2020	2025	2030	2035	2040	2045	2050
Emissions Allowance Price (2018 euro/ tCO_2)	31	49	74	104	146	205	289

Source: Based on PRIMES COMB55 scenario prepared for SWD(2020) 176 final, increased by 20 %.

The ETS price is one of the major policy measures that will help ETS sectors to decarbonise. We assume that ETS auctioning generates revenues to national governments in order to co-fund other policies.

Carbon pricing at EU level

Applying a carbon price to non-ETS sectors is equivalent to extending the ETS to other sectors, for a given carbon price. Therefore, the results can be interpreted as the impact of extending the ETS. Carbon prices are applied to the following non-ETS sectors:

- agriculture, forestry
- fishing
- non-energy mining;
- food, drink, and tobacco
- textiles, clothing, and footwear
- engineering
- construction
- road transport
- rail transport
- other transport services
- households
- commerce and other final use.

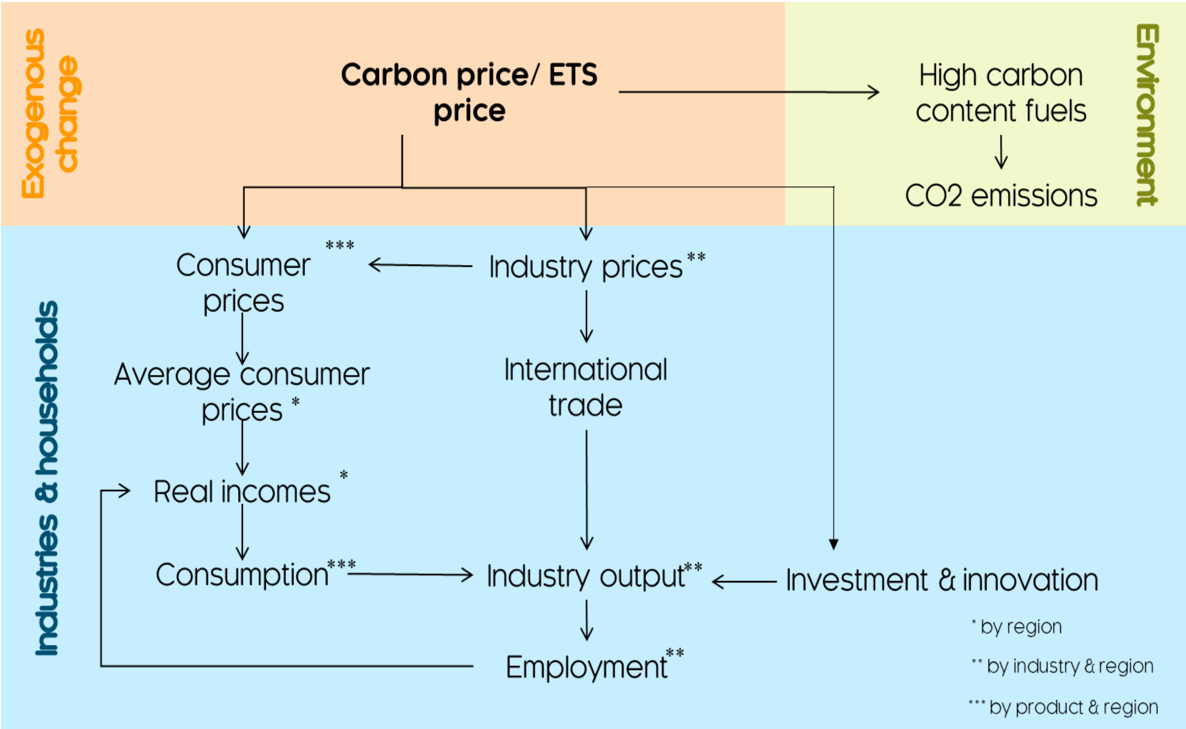
For non-ETS sectors, the carbon tax is assumed to be equal to the ETS price. The prices in Table 3.13 are introduced as a carbon price in the non-ETS sectors. This policy choice allows the same cost liability to be applied to sectors that might be administratively difficult to bring into the ETS. Similarly to the ETS (when allowances are auctioned), the carbon price generates revenues for national governments and is supplemented by other policies (energy efficiency, ban on fossil fuel ICEs, etc.) to accelerate decarbonisation in the non-ETS sectors. As shown in Cambridge Econometrics (2020)[123], a carbon price has a limited effect on decarbonisation certain sectors such as road transport and buildings, therefore energy efficiency, subsidies and other regulations are required to meet the target.

Figure 3-1 shows how the changes in the carbon price impact the wider economy within the E3ME framework. The figure shows the channel of transmission of implementing this policy independently of the implementation of other policies described in this section.

[122] SWD(2020)176 final – Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition' (Climate Target Plan).

[123] Cambridge Econometrics. (2020). Decarbonising European transport and heating fuels - Is the EU ETS the right tool?, Decarbonising European transport and heating fuels - Is the EU ETS the right tool? (camecon.com).

Figure 3-1: Macroeconomic effect of extension of ETS and carbon tax



Source: E3ME, Cambridge Econometrics.

The increase in carbon prices will lead to an increase in both consumer and industrial prices. Increases in consumer prices in turn lead to lower disposable incomes, which lead to lower spending on goods and services and demand for industrial output. Increases in industrial prices worsen EU competitiveness and demand for industrial output. Lower aggregate demand leads to lower employment which in turn affects disposable income.

On the environment side, an increase in carbon prices will lead to lower demand on high carbon content products which in turn will reduce CO_2 emissions. Member States that rely on energy imports may see improvements to their trade balance. A tax on carbon intensive fuels can also encourage new investment in renewable energy (as shown in the diagram) because the ETS price creates a signal for firms to switch (or re-orient investment) to the new technologies, through anticipated replacement of current equipment.

The increase in carbon prices has a two-fold effect on investment decisions: additional net investment (including the reduction in energy and energy mining sector investment) is created; and investment is re-oriented towards technology that reduces emission levels. Moreover, in the absence of ETS, coal plants would remain competitive for power generation and thus green technologies would not have the same level of investment and take up.

The revenues from ETS auctioning are used to pay for other low carbon policies (e.g. at least 50% of auctioning revenues or the equivalent in financial value should be used by Member States for climate and energy-related purposes[124]) and to reduce other taxes. Without ETS revenues the other policies' costs would lead to increases in other taxes which would lead to negative effects on the rest of EU economy.

[124] Auctioning | Climate Action (europa.eu).

Coal Phase Out for Electricity Generation

This policy is implemented in the period 2022-2050, as follows:

- From 2022 to 2030: Phase out of coal for power generation consistent with announced national polices.

Table 3-14: Announced national policies for phase out of coal for power generation by 2030

Announced phase out by	Member State
2020	Austria; Sweden
2021	Portugal
2022	France
2023	Slovakia
2025	Ireland; Italy
2028	Greece
2030	Finland; Hungary; Netherlands; Denmark; Spain
2038	Germany
Considering	Czechia; Slovenia
No phase out commitment	Bulgaria; Croatia; Poland; Romania
No coal in power generation	Estonia; Latvia; Lithuania; Belgium; Malta; Luxembourg; Cyprus

Source: Cambridge Econometrics.

- From 2031 to 2050: Reducing coal fired electricity generation [125] to zero is imperative for achieving net zero GHG emissions by 2050. Therefore, it is assumed that Member States without commitments in Table 3-12 (including Poland) will start to phase out of coal from 2031 onwards.

Cost of early decommissioning of Electricity Generating Infrastructure

The cost of decommissioning electricity generating infrastructure that is not fully depreciated is subtracted against any possible income from the carbon tax regime as part of the government revenue balancing assumption. More information on revenue recycling assumptions, and how government revenues are treated, is provided below.

Feed-in-premiums

Electricity

Feed-in-premiums for renewables, bioenergy, and CCS-complemented electricity generation to support more rapid market penetration are applied in the modelling using the FTT:Power submodule in E3ME. Feed-in-premiums improve the business case for these technologies. Premium rates are set depending on the levelised cost of electricity for the technology considered [126]. Different technologies require different levels of support to encourage greater rates of take up.

Some renewable technologies like wind and solar have already experienced strong cost reductions and have a significant market share across many EU Member States; as a result, they will likely

[125] Coal fired electricity generation without abatement technologies like carbon capture storage.

[126] The levelised cost of electricity within E3ME is calculated using the FTT:Power submodule. It takes into account the price of natural resource inputs, policy costs and investment and operations and maintenance costs for each technology.

receive a lower premium than bioenergy or CCS-complemented electricity generation, which requires further support to compete.

As the technologies gain increasing market shares, and costs are reduced because of learning effects, these premiums are phased out from approximately 2040 to 2050.

Home Heating

Investment subsidies are also applied in the modelling for low-carbon home heating solutions to lower the cost of these technologies relative to fossil intensive options. Investment subsidies are modelled in E3ME via the FTT:Heat submodule as 15 % subsidies to capital costs for renewable technologies (e.g. heat pumps and solar thermal).

Steel sector[127]

Current ambitions focus on reducing blast furnace produced steel and increasing the use of recycled steel. However, under a low-carbon transition, substantial investment in equipment is necessary to deploy low carbon energy technologies. Using recycled steel may not be sufficient to meet future steel demand, and hence also low-carbon production of new steel is needed.

In order to reach net zero GHG emissions by 2050, additional investment in equipment to produce carbon-neutral steel is necessary. This is achieved via investment subsidies for various technologies (e.g. CCUS, recycling and electric arc furnace). Investment subsidies start at 30 % of investment costs in 2021, as estimated using the FTT:Steel E3ME submodule for technology diffusion. This investment subsidy might increase to as much as 60 % of investment costs depending on how this effective policy, in addition to ETS prices, is at decarbonising the sector.

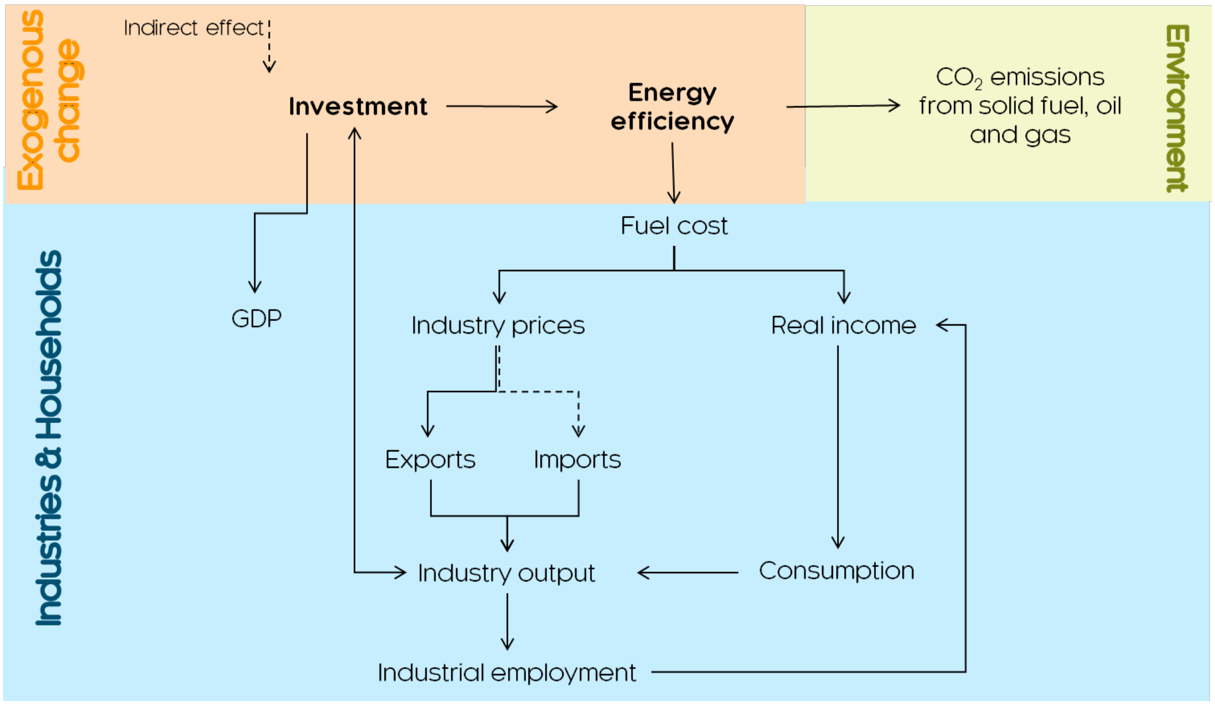
Energy efficiency investment

Figure 3-2 shows how an increase in investment in energy efficiency impacts the wider economy within the E3ME framework. On the environment side, increased energy efficiency will lead to lower CO_2 emissions from fossil fuels.

An increase in investment has on the one hand direct positive impact on GDP, and on the other hand creates multiplier impacts through the output-investment loop. The reduction in fuel cost resulting from energy efficiency investment may lead to a reduction in industry price resulting in increased competitiveness for EU industries. The increase in investment in energy efficiency technologies will also lead to a lower share of energy in households' costs which in turn has a positive impact on disposable income. The increase in consumer spending leads to an increase in both domestic and intra-EU demand for output. The increase in aggregate demand leads to more employment in industry and services, which in turn leads to more disposable income.

[127] The E3ME model includes a detailed bottom-up technology model for the steel sector, which provides greater levels of policy detail. Other industrial sectors are covered by the efficiency measures described in the next section.

Figure 3-2: Macroeconomic effect of increased investment in energy efficiency



Source: E3ME, Cambridge Econometrics.

Estimates for the cost of energy efficiency investments are informed by assumptions from the 55 % scenario of the Climate Target Plan, see PRIMES model data provided in Table 12 [128].

The estimates of the level of investment from the 55 % scenario of the Climate Target Plan are increased by an additional 20 % to reflect the greater level of EU ambition for 2030 towards net-zero GHG emissions.

Fossil fuel boiler regulations for buildings

- From 2022 to 2030: The assumptions are consistent with announced national policies.
- From 2031 to 2050: Ban on installation of fossil fuel boilers, and additional policies in place to support their phase out by 2050. The modelling allows renewable gas (hydrogen, biogas, biomethane) and oil (bioliquids)-fuelled boilers but the modelling does not include specific subsidies for these technologies.

The energy efficiency investments described above are also applied to all buildings to support the phase out of fossil fuel use.

Ban on fossil fuelled internal combustion engines for transport sector

- From 2022 to 2030: The ban on selling new fossil fuel vehicles is consistent with announced national policies. For example, the following announced national phase-out dates are considered:
  - By 2030: Denmark; Ireland; Germany (*only diesel*); Netherlands; Sweden.
- From 2031 to 2050: Policy ambition increases to ensure that the net-zero commitment is met by 2050. We hence assume in our modelling that all other EU Member States

128 2030 Climate Target Plan | Climate Action (europa.eu), Part 1, page 71.

ban new fossil fuelled cars from 2030. In the case of France, we use the announced phase out date of 2040.

Other scenario assumptions that support decarbonisation of road transport include electric vehicle subsidies and public procurement programmes to jumpstart demand for the technology and reduce future costs. These policies reduce the costs of electrification (see below).

Electric passenger vehicle subsidies

The uptake of electrical vehicles is modelled in E3ME using the FTT:Transport submodule. Subsidies for the purchase of electric vehicles are assumed to be available from 2022. Subsidies are introduced at €2 000 per vehicle and could increase to as much as €4 000 per vehicle to encourage greater electrification of the passenger vehicle fleet and to reduce the cost of electric vehicles relative to conventional cars.

Public Procurement

Public procurement of zero-carbon technologies across a range of sectors is implemented. This policy aims to kick-start demand for these technologies by creating sustained demand for them across the EU and will encourage the development and diffusion of these technologies.

Road Transport

Public procurement of electric vehicles.

Heating

Public procurement of renewable and electric heating technologies including heat pumps and solar thermal heating.

Biofuels

Modest biofuel blending mandates for road passenger and freight transport are pursued that are consistent with announced and currently implemented policy. Biofuel blending mandates in the EU reach at most 9 % in middle distillate or diesel blends.

Over time, the volume of biofuels used in road passenger and freight transport declines because of electrification, and existing biofuel capacity will be redirected to aviation. Total bioenergy consumption does not increase in absolute terms.

Scaling up battery storage

The cost of battery storage is calculated off-model and informed by the latest data available from the FTT: Power sub-module for electricity demand and infrastructure deployment. Additional government-funded investment for battery storage deployment has been included in the modelling.

Scaling up low-carbon hydrogen production and power-to-x

Hydrogen is assumed to be produced with low-carbon electricity. This simplifying assumption enables representation of the scale-up of hydrogen use and the effects of the deployment of hydrogen on total fuel and electricity demand.

Hydrogen may be used as a fuel or feedstock for decarbonising industry alongside energy efficiency improvements. Hydrogen is also be used to decarbonise market segments that are challenging to electrify, such as freight transport and aviation.

Carbon Capture Utilisation and Storage (CCUS) for GHG Emissions from Industrial Processes

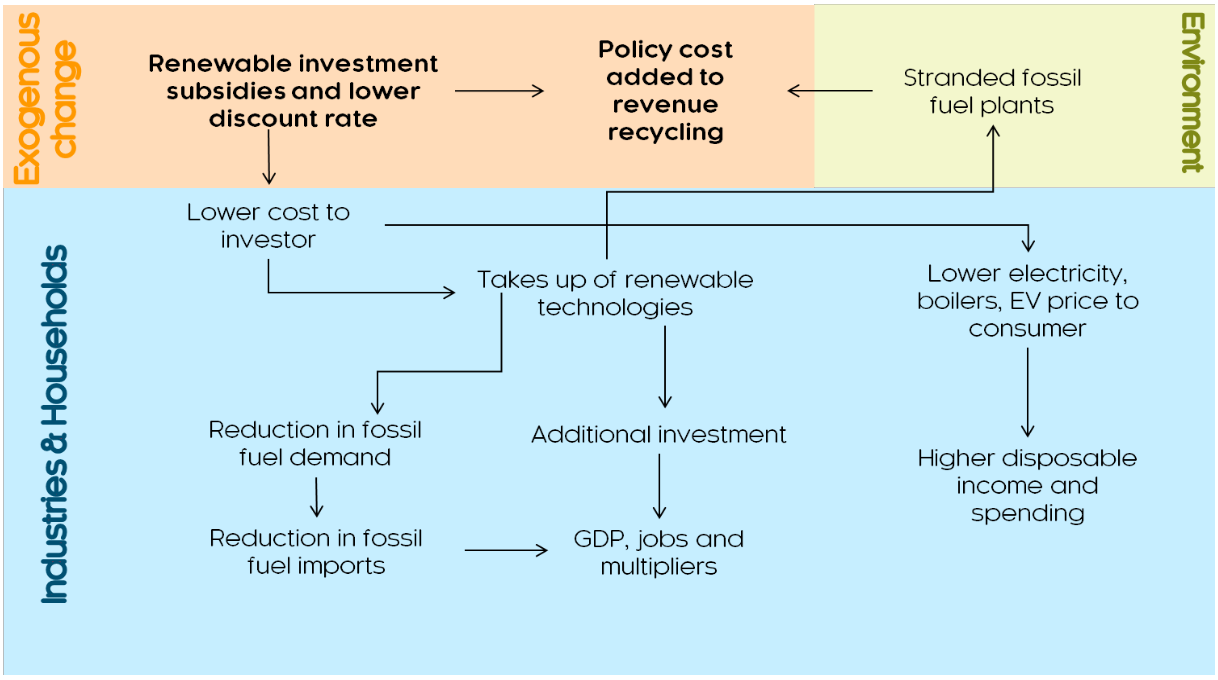
Publicly funded investment in CCUS for industrial processes is pursued. Investment levels are based on costs of approximately 200€/tonne CO_2 abated[129].

Loans and guarantees to finance investments in energy assets

To incorporate the impacts of loans and guarantees on repayment and the cost of lending, the borrowing rate applied to investment in various low-carbon energy infrastructure projects is reduced to reflect the effects of government-backed loans and guarantees.

Figure 3-3 shows the effect of lower capital costs on the wider economy within the E3ME framework. Lower costs to investors in low-carbon energy assets lead to higher take-up rates of renewable technologies. This has a twofold positive effect on GDP and employment: once through lower fossil fuel demand and imports; and once through an increase in investment. On the consumer side, the policy may lead to lower prices, which in turn lead to higher consumer spending (another GDP component).

Figure 3-3: Macroeconomic effect of lower capital costs



Source: E3ME, Cambridge Econometrics.

Balancing public revenue

The policies that are required to achieve the net zero target can be split into three groups:

1. Policies that generate revenues for Member States, such as ETS auctioning and carbon prices.
2. Policies that incur additional public spending, such as public sector energy efficiency spending, renewable investment subsidies and compensation for power plant assets that become stranded due to regulation.

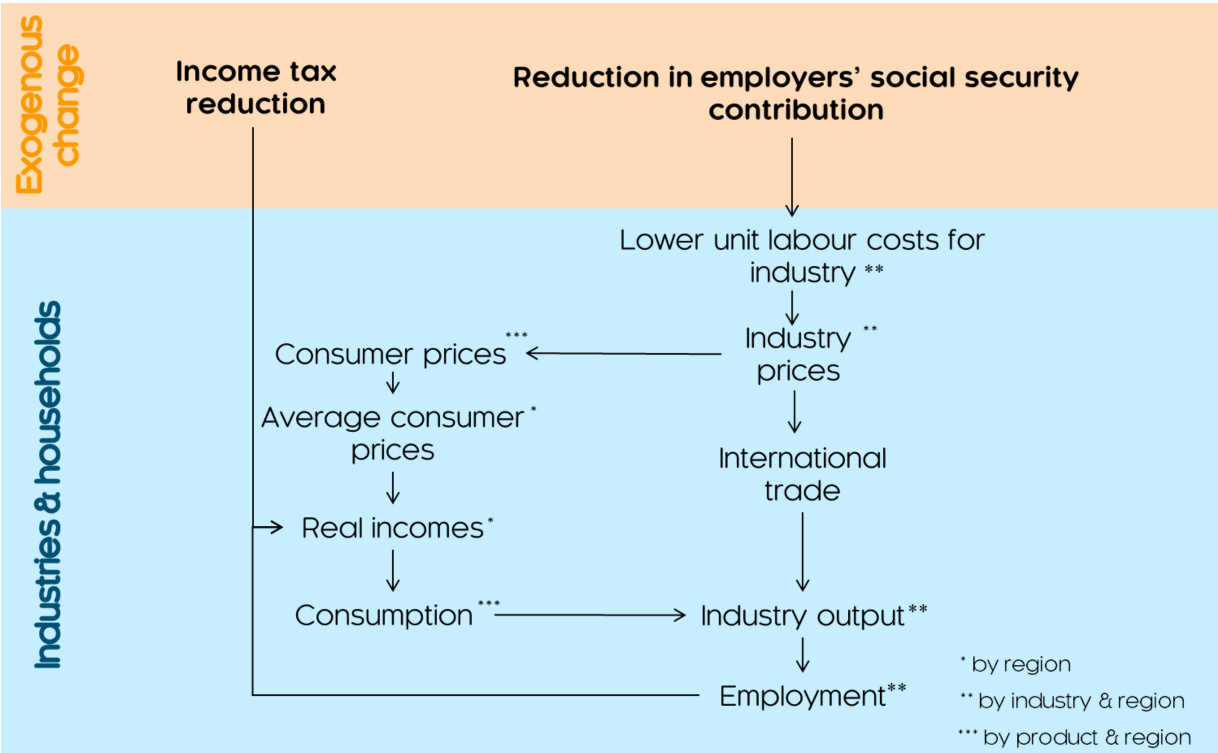
[129] Costs are based on the breakeven cost in 2015 US$ per tonne of CO_2, for a range of carbon capture pathways. See Hepburn, Adlen, Beddington et al. The technological and economic prospects for CO_2 utilization and removal. Nature 575, 87–97 (2019). https://doi.org/10.1038/s41586-019-1681-6.

3. Policies that have small administrative or no costs such as regulations.

The standard treatment in E3ME is to assume revenue neutrality in the scenario, meaning that government balances remain unchanged from the baseline. The net revenues, if positive, are assumed to be used to reduce income tax rates and employers' social security contributions, split equally, so that households and businesses share the benefits. Similarly, if revenues are less than spending, especially during the initial period where policy costs are high, then income tax and employers' social security rates are increased to ensure revenue neutrality.

Figure 3-4 shows the positive effect on the economy when the surplus revenues are used to decrease income tax rates and social security contributions.

Figure 3-4: Macroeconomic effect of revenue recycling



Source: E3ME, Cambridge Econometrics.

3.3.3. Variants of the Net Zero scenario

Two variants of the net zero scenario described above were also modelled. The net zero scenario is based on a combination of climate and energy policies used to achieve climate neutrality by 2050. The variants exclude some of the polices that are included in the net zero scenario.

The two variants are:

- Removing extended/intensified ETS: In this scenario we exclude the extended and intensified ETS and the lower cost of capital for renewable/green technologies;
- Removing EU extra funding for green investment: in this scenario, we exclude €70 billion of annual public investment in green technologies in the EU over 2021-27, and €38 billion annual public investment over 2028-50. These amounts correspond to the additional spending on green technologies due to climate mainstreaming of the MFF (for both periods) and the announced Next Generation EU budget linked to Green recovery (for the 2021-27 period only).

3.3.4. Expected results based on other studies

Table 3-15 below shows results from recent studies that explored the impacts of different decarbonisation pathways in the EU. The scenarios are based on the implementation of ambitious policy measures expected to achieve greater reductions in GHG emissions. These measures are also expected to have an overall impact on GDP. In general, the impact of the introduction of carbon pricing schemes for non-ETS sectors on GDP ranges from -0.27 % to +1.8 % compared to the baseline. The impacts on GDP are found to be more positive when carbon pricing (e.g. ETS) is combined with other regulatory measures.[130] The impacts of enhanced green investments were also found to have a small positive effect on GDP. Employment impacts typically reflect the growth in GDP. However, in all the studies, employment impacts are ranging from 0.02 % to 0.6 %, compared to the baseline. This is because part of the GDP increase is realised through higher productivity rates, leading to higher wages and profits.

Economy-wide impacts were also found to be dependent on the use of revenues from carbon pricing schemes. In particular, the impact on GDP and employment is greater when revenues are used to finance green investments and lower distortionary taxes[131].

The combination of regulatory measures and carbon prices may also have a positive impact on private consumption, which is also reflected in higher GDP impacts. The impact on investment is positive when subsidies and enhanced green investments are implemented.[132] Conversely, when GDP impacts are found to be negative, consumption patterns are also affected negatively, while investment is found to reach a higher level than in the baseline.[133]

Caution is needed when comparing these results, because they are based on different models, and different assumptions. For instance, the JRC-GEM-E3 model assumes that the economy operates in equilibrium without spare capacity, whereas the E3ME model allows for some unused resources, meaning that production of green products can increase without 'crowding out' other activities.

Table 3-15: Results comparison from previous studies (2030 differences form baseline, %)

Study/Model	Assumptions	Emissions	GDP	Employ-ment	Consump-tion	Invest-ments
European Commission, 2020 JRC-GEM-E3	• Carbon pricing non-ETS • Free allocation ETS • Tax recycling • Imperfect labour market	55 % GHG reduction from 2005	-0.27 %	0.05 %	-0.79 %	0.86 %
European Commission, 2020 E3ME	• Carbon pricing non-ETS sectors • Tax recycling • Auctioning ETS	55 % GHG reduction from 2005	0.50 %	0.20 %	-	-

130 Cambridge Econometrics. (2021). Achieving 60 % emission reduction by 2030, Achieving 60% emission reductions by 2030 | Greens/EFA (greens-efa.eu).

131 European Commission. (2020). Stepping up Europe's 2030 climate ambition. Investing in a climate-neutral future for the benefit of our people, EUR-Lex - 52020SC0176 - EN - EUR-Lex (europa.eu).

132 Cambridge Econometrics, (2020). Decarbonising European transport and heating fuels - Is the EU ETS the right tool?, Decarbonising European transport and heating fuels - Is the EU ETS the right tool? (camecon.com).

133 European Commission. (2020). Stepping up Europe's 2030 climate ambition. Investing in a climate-neutral future for the benefit of our people, EUR-Lex - 52020SC0176 - EN - EUR-Lex (europa.eu).

European Commission, 2020 E-QUEST	Higher green investments	55 % GHG reduction from 2005	0.13 %	0.02 %	-	-
Cambridge Econometrics 2021	• Carbon pricing non-ETS sectors • Coal phase out • Nuclear phase out in some MS • Renewable subsidies • EV subsidies & ban on dirty vehicles • Energy efficiency investment • Switch to recycled steel	60 % GHG reduction from 2005	1.8 %	0.60 %	1.4 %	3.1 %
Cambridge Econometrics 2020	Extended ETS to building and transport	43 % GHG reduction from 2005	0.4 %	0.3 %	-	-

Source: Cambridge Econometrics.

3.3.5. Limitations of the approach

All models represent simplifications of a complex reality and are therefore subject to assumptions and limitations. The aim of the current modelling exercise is to capture as accurately as possible the most important mechanisms of decarbonising the EU's energy system. Where there is uncertainty in the adoption of the policy measure, a cautious approach was adopted with assumptions that favour the status quo.

Like any macroeconomic model, the E3ME model is subject to its own limitations, some of which are described in the model manual (see Cambridge Econometrics, 2019). For example, as an econometric model, it depends on historical data with which to estimate behavioural parameters. It is assumed that these behavioural responses do not change over time or in response to policy changes. The model therefore assumes that the demand responses to changes in the carbon prices are similar to the responses observed in the past. An exception to this is in the key energy sectors (power, road transport, heating and steel) where the bottom-up Future Technology Transformation (FTT) sub-models are used instead of an econometric approach. FTT is based on innovation theory and evolutionary dynamics and is linked to the E3ME model with two-way linkages between the technology dynamics and wider economy.

In relation to the current study, one important limitation within the E3ME model is the absence of assumptions in relation to climate change impacts such as extreme weather conditions that might impact industrial and/or agricultural output. These are not included due to the large uncertainty related to such outcomes. Some influence of the impact of climate change is captured through historical data on output and productivity.

There are potential large benefits from reduced air pollution in the Net Zero scenario. These could easily outweigh the economic impacts. Negative externalities related to air pollution and their impact on health and life expectancy are captured partially through historical data on health expenditure and labour productivity. We have not made additional assumptions on the positive impact that emission reductions would have on human health and productivity, since megatrends such as ageing of the population might offset these positive externalities on health expenditure and labour productivity.

The carbon price is set exogenously and is based on the 55 % scenario in the Climate Target Plan. Thus, it does not change when other policies to decrease emissions are also implemented. Early in the projection period, the carbon price works as a price signal leading to more innovation and investment in green technologies, but is also a way of generating revenues to fund for other low carbon policies. Once the carbon emissions in the economy have reached a certain (low) level, then other complementary policies (e.g. energy efficiency, EVs subsidies) drive the overall results.

Further integration of EU energy markets cannot be assessed using the model due to data availability that would allow the estimation of efficiency gains and energy price reductions. Finally, the scenarios are carried out under an assumption that non-EU regions carry on as business as usual. A more comprehensive scenario is required to investigate how climate actions in the rest of the world could affect EU competitiveness, technology spillovers, trade in renewables, and global energy prices.

4. Assessing the cost of non-Europe

In this chapter we present our analysis to estimate the cost of non-Europe in the area of energy. We first discuss the results of the quantitative macroeconomic assessment which is the primary input for estimating the cost of non-Europe. Next, we present the results of a literature review to estimate the cost of non-Europe for specific areas that cannot be evaluated in sufficient detail through the macroeconomic assessment.

4.1. Quantitative macroeconomic assessment

4.1.1. Baseline

Table 4-1 summarises GDP, employment, consumer expenditure, investment, emissions and imports of fossil fuels levels in the EU over the projection period. Population growth is expected to slow to near-zero and working age population will start to decline after 2020. This means that the potential for GDP growth is also reduced. Total employment in the EU is also expected to start falling by 2050 because of the ageing population and automation. Total investment and consumption increase, however, and drive an increase in GDP. CO_2 emissions are reduced, based on the policies already implemented to meet the 2030 targets.

Table 4-1: Summary of the baseline

	2021	2030	2050	Average annual growth (%) (2020-50)
GDP (Million Euro)	12 189 649	13 865 720	18 232 015	1.56
Total employment (000s)	200 335	201 444	185 784	-0.17
Consumers' expenditure (Million Euro)	6 136 277	7 397 373	9 798 737	1.57
Investment spending (Million Euro)	3 174 395	3 602 662	4 652 015	1.55
Imports in fossil fuels (Million Euro)	224 195	223 892	208 775	-0.02
CO_2 emissions (000s tonnes carbon)	747 278	581 494	380 341	-2.26

Source: Cambridge Econometrics.

The rest of the world follows the announced policies in the baseline and no further assumptions are made for them to reach net zero by 2050 in the scenarios.

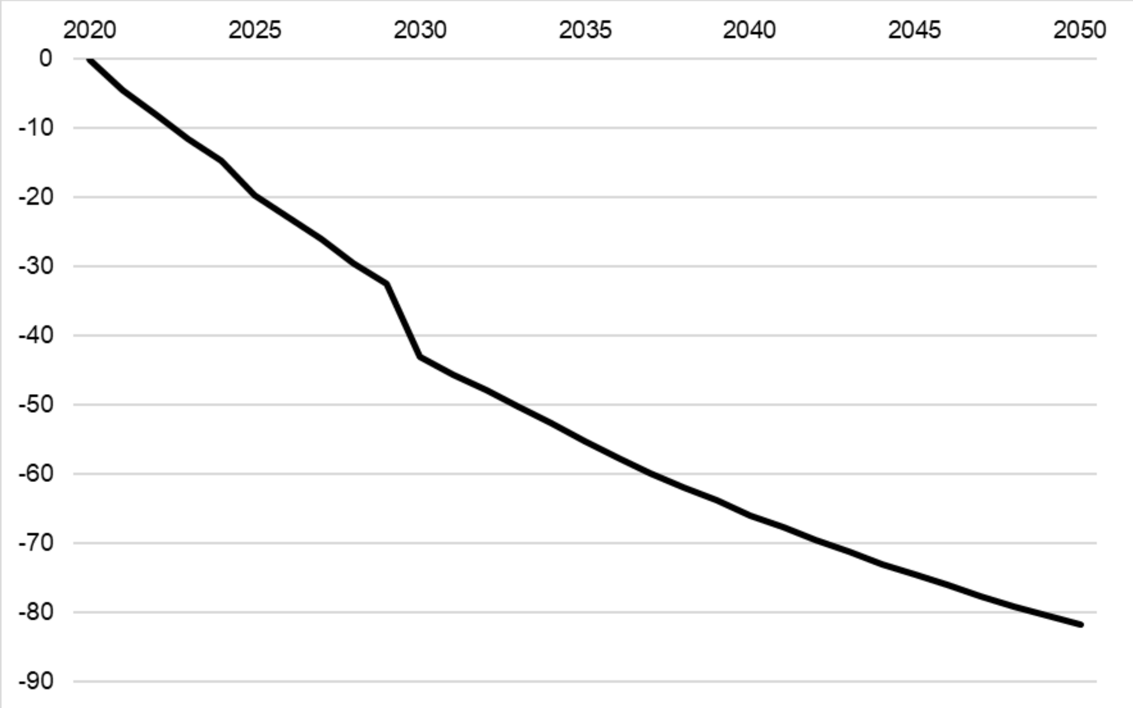
4.1.2. Net Zero scenario

This section presents the results from the net zero scenario, which involves implementing the policy package described in the previous chapter. The scenario results are compared to those from the baseline.

Figure 4-1 shows the impact of the policies on CO_2 emissions. At EU level, CO_2 emissions decline by almost 43 % by 2030 compared to the baseline. This emission reduction is consistent with achieving by 2030 a reduction of 62 % GHG emission below 1990 levels. By 2050, CO_2 emissions are reduced by 82 % compared to the baseline, and by 94% compared to 1990 levels. In 2050, remaining CO_2 emissions (~250 $MtCO_2$) are expected to be absorbed by land use, land use change and forestry

(LULUCF); this is a similar amount to that assumed by the European Commission's analysis under the scenarios consistent with net-zero GHG emissions by 2050[134].

Figure 4-1: Energy and process CO_2 emissions in the EU (% difference from baseline)



Source: Cambridge Econometrics.

Table 4-2 shows the contribution of each broad sector to the total CO_2 emission reduction. Based on the scenario design, the key driver of CO_2 emission reduction by 2030 is the power sector. By including bioenergy and CCS (BECCS) in the technology mix for electricity, it is possible to make total net power sector emissions negative.

In the industry sector, the 65 % emission reduction by 2050 is driven by energy savings and electrification. In transport, the uptake of EVs in road transport and the use of biofuels leads to a reduction in emissions of 41 % by 2030 and 85 % by 2050 compared to the baseline. Air transport is not expected to become fully carbon neutral by 2050.

The reduction in emissions in buildings is driven by investment in energy efficiency technologies and a shift to renewables-based boilers. The residual emissions from energy consumption and industrial processes in 2050 is around 250 $MtCO_2$, which, as noted above, should be compensated by land sinks and LULUCF.

The results in Table 4-2 are consistent with other studies. In particular, the power sector is consistently found to play a major role in reducing CO_2 emissions, through the deployment of renewable energy. In other studies, emission reductions in the power sector are estimated to range between 23 % to 62 %, compared to the baseline, depending on the level of ambition of policy

[134] European Commission, Clean Planet for All, In-depth analysis in support of the Commission Communication COM (2018) 713 , [com_2018_733_analysis_in_support_en_0.pdf (europa.eu)](com_2018_733_analysis_in_support_en_0.pdf).

options considered in the models[135]. Coal regulation and phase-out of petrol and diesel vehicles contribute to reduce emissions in the industry and transport sectors between 5 % and 13 % compared to the baseline. The emissions reduction in the buildings sector is in some studies[136] found to achieve large reductions, in other studies[137] is found to have a small contribution.

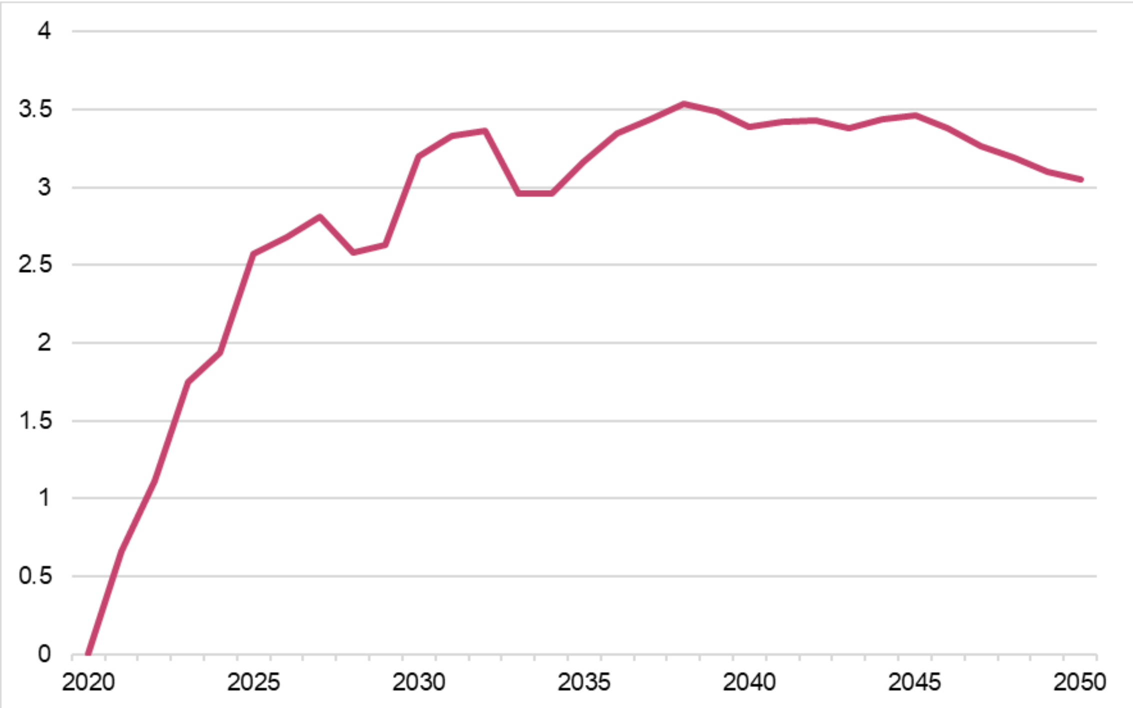
Table 4-2: CO_2 emission reduction by broad sector (% difference from baseline)

	2021	2030	2050
Power generation	-8.9	-88.5	-107.1
Industry	-2.2	-20.0	-64.8
Transport	-4.1	-41.0	-85.3
Buildings	-1.8	-10.5	-75.0
Total	-4.5	-43.1	-81.9

Source: Cambridge Econometrics.

Figure 4-2 shows the impact on GDP (compared to the baseline) of implementing the full set of policies. The GDP increase already in 2021 shows the benefit of such policies in the post-Covid recovery. The steep rise in GDP by 2030, compared to the baseline, is driven by the investment in technologies that allows the phase-out of coal in power generation, and in energy efficiency.

Figure 4-2: EU GDP impact in the net zero scenario (% difference from the baseline)



Source: Cambridge Econometrics.

135 Cambridge Econometrics. (2021). Achieving 60% emission reduction by 2030, Achieving 60% emission reductions by 2030 | Greens/EFA (greens-efa.eu); European Commission. (2020). Stepping up Europe's 2030 climate ambition. Investing in a climate-neutral future for the benefit of our people, EUR-Lex - 52020SC0176 - EN - EUR-Lex (europa.eu).

136 European Commission. (2020). Stepping up Europe's 2030 climate ambition. Investing in a climate-neutral future for the benefit of our people, EUR-Lex - 52020SC0176 - EN - EUR-Lex (europa.eu).

137 Cambridge Econometrics. (2021). Achieving 60% emission reduction by 2030, Achieving 60% emission reductions by 2030 | Greens/EFA (greens-efa.eu).

In the period up to 2030, the increase in GDP is driven by investment, while in the period 2030-50, consumer spending is the main driver of GDP growth (above that in the baseline). The GDP results in Table 4-1 for 2030 are larger than the ones in the literature summarised in Table 3-15.

The results reveal that revenues generated from the ETS and carbon tax can cover more or less of the public policy costs and the requirement for the changes in tax rates are minimal (on average +/-1pp). This means, for example, if an average income tax rate is 20%, it will change either to 19% (revenue surplus will reduce tax) or 21% (revenue gap will lead to increase in tax). Over 60% of the time over the period 2021-50, there are small revenue surpluses that lead to reductions in tax rates in all Member States.

Table 4-3 shows that the impacts on employment follow the evolution of GDP over time, but at a lower magnitude than in the baseline. Consumer prices decline because lower energy bills lead to a lower rate of overall inflation. On the consumer side, the savings from energy efficiency lead in the long run to higher disposable incomes. In turn, higher incomes lead to higher consumer spending on goods and services (either domestically produced or imported).

The decrease in imports of 0.3 % in 2030 and 0.9 % in 2050 compared to the baseline is driven by lower imports of fossil fuels, which were already on a decreasing trend in the baseline (see Table 4-1). Exports are expected to increase slightly compared to the baseline in the period up to 2030 because of gains in energy efficiency boosting competitiveness. However, in the period up to 2050, EU exports are negatively impacted because high carbon costs reduce competitiveness, given the assumption that the rest of the world does not take similar action.

Table 4-3: Economic impact by components of GDP (% difference from baseline)

% difference from baseline	2021	2030	2050
GDP	0.7	3.2	3.0
Consumer spending	0.3	2.3	4.0
Investment spending	1.9	5.8	2.0
Exports	0.1	0.6	-0.5
Imports	0.2	-0.3	-0.9
Employment	0.2	0.9	1.1
Inflation (consumer price)	-0.4	-2.0	-2.2
Absolute difference from the baseline	**2021**	**2030**	**2050**
GDP (Million Euro)	80 763	443 943	555 564
Consumer spending (Million Euro)	16 493	173 752	391 423
Investment (Million Euro)	59 775	210 305	93 612
Exports (Million Euro)	2 588	15 704	-16 727
Imports (Million Euro)	4 098	-6 892	-28 244
Employment ('000s)	318	1 912	2 135
Inflation (consumer price)	-0.004	-0.028	-0.048

Source: Cambridge Econometrics

The increased investment in green technologies results from the combination of policies mentioned in Section 3.3. For example, feed-in premiums boost the use of relatively new technologies (such as biomass and CCS power plants), while carbon pricing (i.e. the ETS) is more appropriate for technologies that are already well established in the market (and is particularly important for pushing coal out of the power mix). The scenario includes measures to reduce the cost of capital for low-carbon technologies, which are important for increasing investment.

The investment has several different impacts. Within the energy sector, investment in new technologies leads to cost reductions through learning effects (driven by innovation), which in the future increases further the take up of these technologies. Through supply-chain and multiplier effects, the investment boosts production levels in other sectors of the economy; some of these sectors in turn increase their own investment to build new production capacity.

Although investment in fossil fuel sectors falls, this effect is outweighed by the increases in investment elsewhere.

Turning to sectoral impacts, the policies benefit in particular sectors that provide investment goods and services, including advanced manufacturing sectors and construction. Manufacturing and construction see increases in output of 4.2 % and 2.2 %, respectively, compared to the baseline, by 2030. The increase in production in these sectors in turn leads to an increase in the distribution and logistics parts of the transport sector. However, by 2050 some of these impacts are reduced because the focus of growth shifts from investment to higher levels of consumer spending.

The output of the energy extraction sector in the EU falls, but the absolute loss of EU production is limited by the important role of imported fuels in the baseline (see below). Finally, although the EU does not produce much of its own fuels, the lack of climate action in the rest of the world means that there is still some export potential.

Electrification in transport and other sectors boosts output in the electricity utility sector, compared to the baseline. Agriculture benefits from biomass-based technologies that are implemented and (by 2050) higher levels of general consumption that get reflected in food production. Higher levels of consumer spending also increase the demand for personal services.

The evidence from the other studies shows that large losses in output are expected for the mining sectors, due to reduced production of coal estimated at -2.4 % in 2030 and -5.6 % in 2050 compared to the baseline. [138] Small reductions are expected to occur in the utility services, due to the take up of energy efficiency measures. In other studies, output in the sectors of construction and manufacturing is expected to increase up to 2.3 % compared to the baseline. [139]

Table 4-4: Economic impact by broad sector (% difference from the baseline)

	2021	2030	2050
Agriculture	0.2	2.4	5.7
Mining and Utilities	1.3	1.4	-2.1
Manufacturing	1.1	4.2	2.2
Construction	1.1	3.9	1.9
Transport	0.7	2.8	1.8
Services	0.5	2.3	2.4

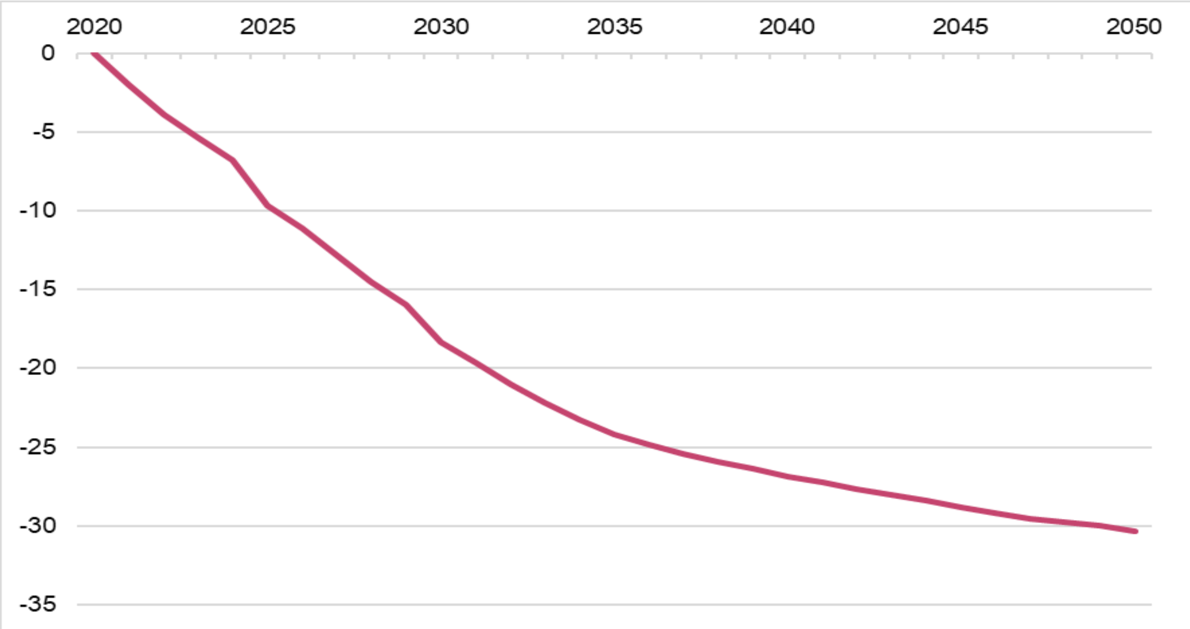
Source: Cambridge Econometrics

138 Cambridge Econometrics. (2021). Achieving 60% emission reduction by 2030, Achieving 60% emission reductions by 2030 | Greens/EFA (greens-efa.eu).

139 Cambridge Econometrics. (2021). Achieving 60% emission reduction by 2030, Achieving 60% emission reductions by 2030 | Greens/EFA (greens-efa.eu) ; European Commission. (2020). Stepping up Europe's 2030 climate ambition. Investing in a climate-neutral future for the benefit of our people, EUR-Lex - 52020SC0176 - EN - EUR-Lex (europa.eu).

Figure 4-3 shows a steep decline (€63 billion by 2050) for fossil fuel imports into the EU, compared to the baseline. In the baseline there is already a slight declining trend in energy imports to the EU (0.02 % pa). In the scenario, by 2050 the remaining demand for fossil fuels imports is for air transport, the chemicals industry (petrochemicals) and the re-export of refined petroleum.

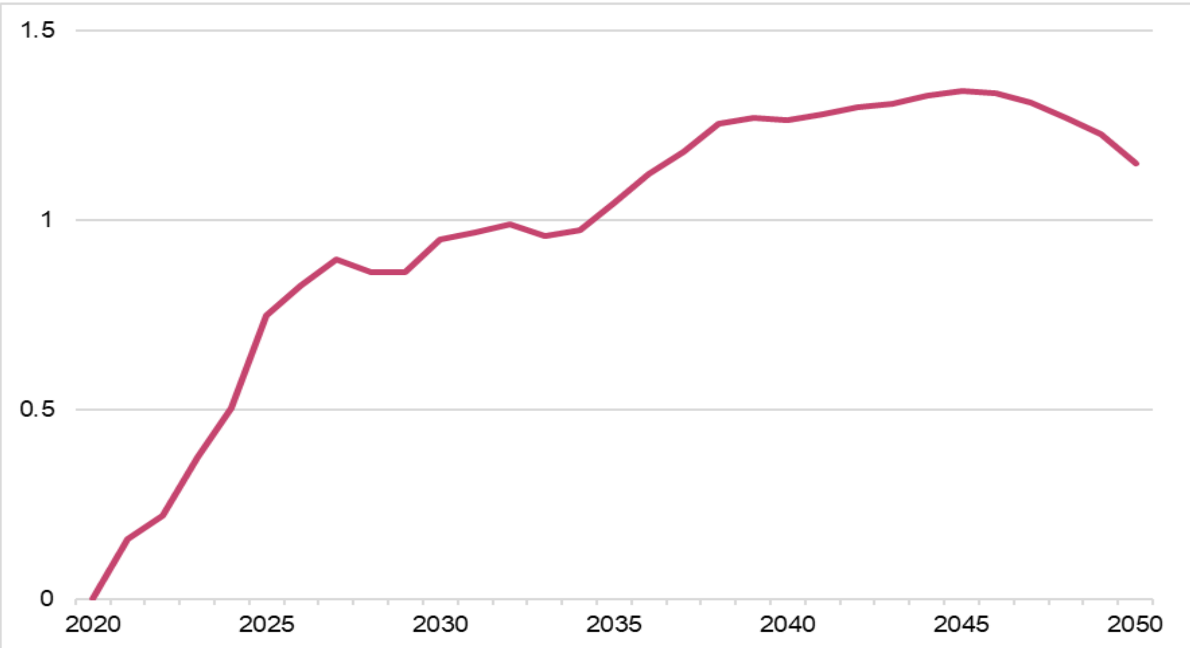
Figure 4-3: Fossil fuel imports in the EU (% difference from baseline)



Source: Cambridge Econometrics

The impacts on EU employment show a similar evolution as those for GDP, but with smaller effects in percentage terms. Increases in productivity, shifting sectoral composition, wage effects, technology improvements and limited labour supply are reasons why employment does not increase by as much as GDP.

Figure 4-4: EU employment (% difference from baseline)



Source: Cambridge Econometrics

Employment in the construction sector increases because of the additional investment, especially energy efficiency in buildings. There is a 2.8 % increase in construction employment by 2030, compared to the baseline. Although current employment is smaller in absolute terms, there is a large increase in employment in the utilities sector (19 % by 2050). This reflects the increase in electricity consumption because of electrification (which balances efficiency measures) and the higher labour intensity of low-carbon generation technologies.

Table 4-5: Employment impact by broad sector

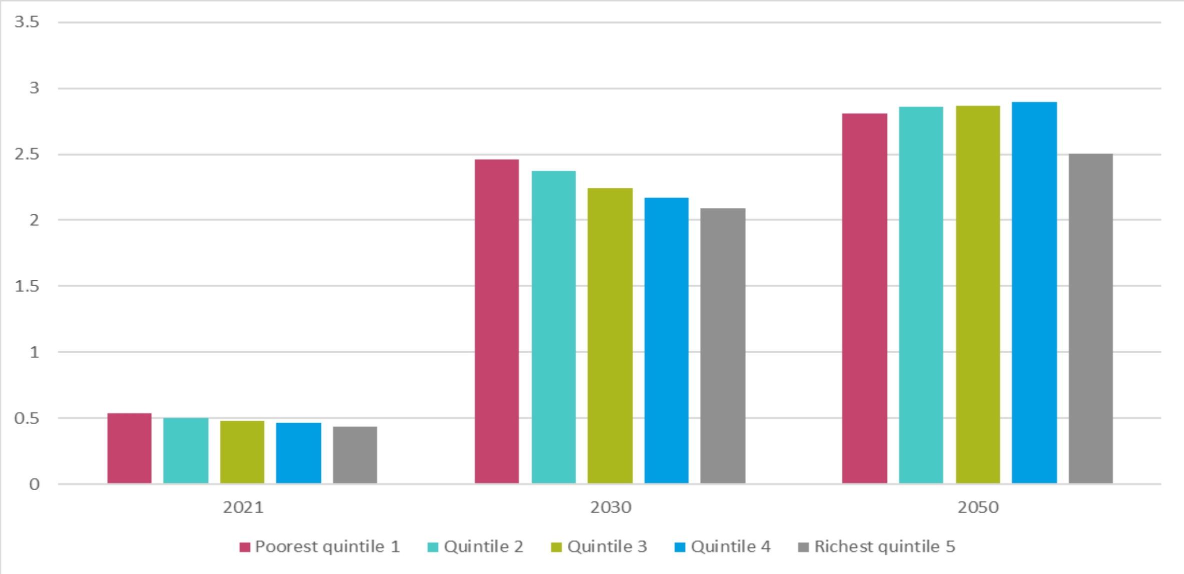
% difference from baseline	2021	2030	2050
Agriculture	0.0	0.4	0.4
Mining and Utilities	0.3	8.5	18.8
Manufacturing	0.2	0.8	1.2
Construction	0.4	2.8	1.4
Transport	0.0	0.4	0.3
Services	0.1	0.7	0.8
absolute difference from baseline ('000)	2021	2030	2050
Agriculture	4.4	36.5	22.4
Mining and Utilities	10. 1	263	658.8
Manufacturing	53.8	214	270.3
Construction	57.1	376.5	142.5
Transport	1.5	38.6	25.5
Services	191	983.1	1 015.6

Source: Cambridge Econometrics

Figure 4-5 shows that households in all five income quintile groups enjoy a higher disposable income than in the baseline. The income effects are estimated for each income quintile based on their share of spending and the source of income. These shares are fixed but linked to E3ME consumer prices for different products (including energy) and income components (including adjustment to income taxes) to estimate distributional impacts.

In 2021 and 2030, the poorest households benefit by the most from the green transition while the richest households benefit by the least. This result can be explained by the assumption that the gap in policy revenues is partly funded through higher income tax rates, which affect richer households relatively more. The impact of real income on the spending side is driven by the share of energy consumption in households' total spending (which is typically higher for poorer households, at least for heating). Energy savings technologies reduce energy bills and therefore can be progressive overall, but the carbon tax applied to households may have regressive effects. On the income side, households' incomes are affected by changes in employment and wages, as well as the redistribution of revenue surplus in the form of income support and higher social contributions.

Figure 4-5: Households impact by income quantile (% difference from baseline)



Source: Cambridge Econometrics

4.1.3. Variants of the Net Zero scenario

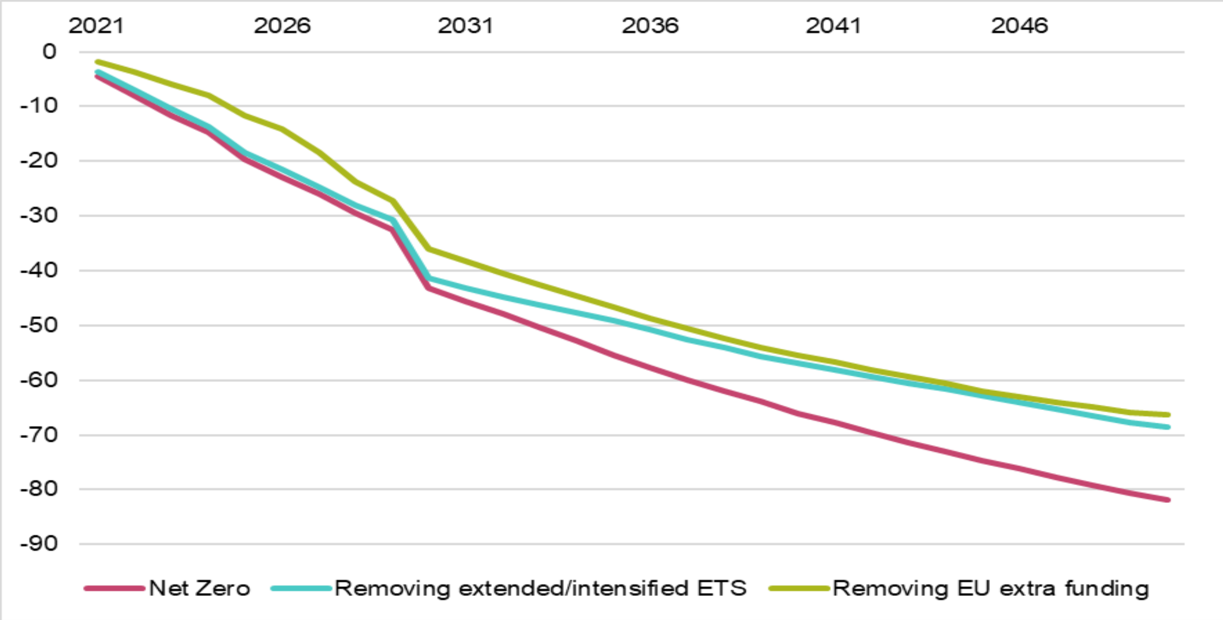
In addition to the Net Zero scenario, two variants were also modelled. The first variant does not include some of the policies in which the EU has direct mandate, such as the extended and intensified ETS and the lower cost of capital for renewable/green technologies. The second variant scenario does not include some of the public green investment that is financed through the MFF and Next Generation EU.

Figure 4-6 shows the CO_2 emission reductions in the variants compared to the baseline.

Carbon pricing is a key policy to achieving the net zero target, so removal of higher ETS prices and carbon tax rates means a lower level of emission reduction than in the net zero scenario. Up to 2030, CO_2 emissions in this variant follow the same path as in the Net Zero scenario, but they diverge once the carbon prices follow different paths. Other policies remain effective in reducing emissions (renewable subsidies, phase-out of coal for electricity generation and fossil fuelled vehicles, procurement policies for renewable/ green technology, and energy efficiency mandates), but the interaction effects with carbon pricing are lost and on their own they are not enough to reach net zero by 2050.

Removing part of public green investment financed by the EU also leads to missing the net zero 2050 target. In this variant, the transition takes longer because it relies mainly on carbon pricing policies and regulations to bring down emissions. Alternative renewable technologies remain expensive and have slower take-up rates because of the removal of public sector investment, procurement, and subsidies.

Figure 4-6: CO_2 emission reduction by scenario (% difference from baseline)



Source: Cambridge Econometrics

In Table 4-6, the emission levels in all scenarios and variants are compared to 1990 levels and presented as a relative reduction. In the absence of additional policies to decarbonise the energy system (i.e. the baseline), 64 % reduction compared to 1990 is achieved. The Net Zero scenario leads to a 94 % emission reduction, while the two variants achieve around 88 % emission reduction compared to 1990. Figures for non-energy related emissions are not available for 1990, so 1995 non-energy emissions were used as a proxy.

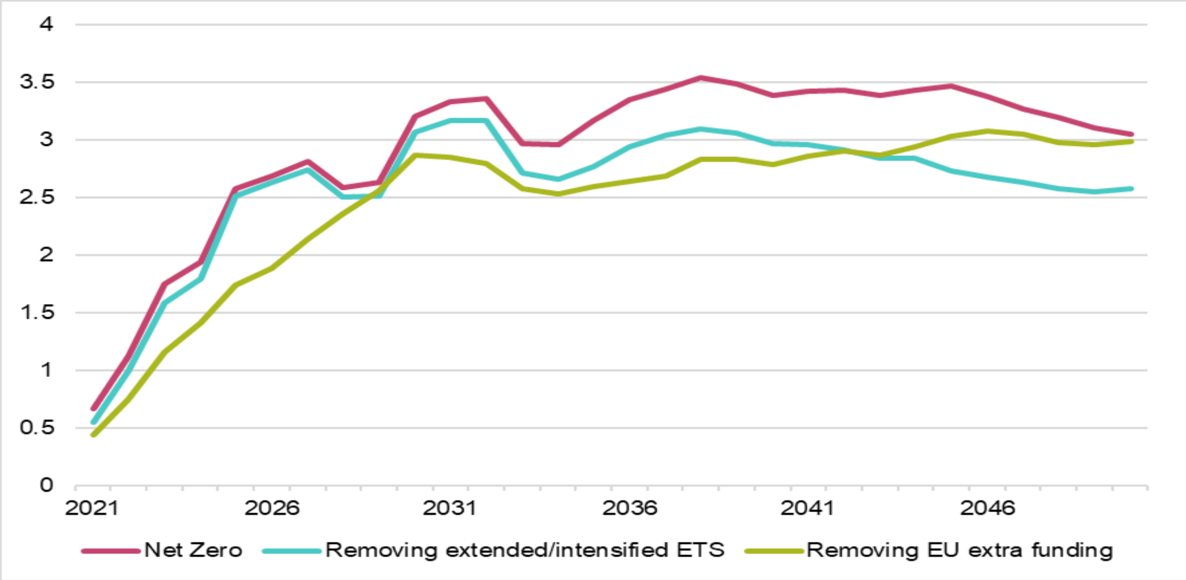
Table 4-6: CO_2 emission reduction by scenario (% difference from 1990 emissions)

	2021	2030	2050
Baseline scenario	-29.6	-43.2	-64.2
EU Net Zero scenario	-32.8	-61.6	-93.5
Removing extended/intensified ETS	-32.1	-60.6	-88.8
Removing EU extra funding scenario	-30.9	-58.6	-87.9

Source: Cambridge Econometrics

Figure 4-7 shows the positive effects on EU GDP in the Net Zero scenario and the two variants.

Figure 4-7: EU GDP impact by scenario (% difference from baseline)



Source: Cambridge Econometrics

Table 4-7: Economic impact by scenario and components of GDP (% difference from baseline)

Scenario	Variable name	2021	2030	2050
Net Zero	GDP	0.7	3.2	3.0
	Employment	0.2	0.9	1.1
	Consumer spending	0.3	2.3	4.0
	Investment	1.9	5.8	2.0
	Imports	0.2	-0.3	-0.9
	Exports	0.1	0.6	-0.5
	Inflation (consumer price)	-0.4	-2.0	-2.2
Removing extended/intensified ETS	GDP	0.5	3.1	2.6
	Employment	0.1	0.9	0.8
	Consumer spending	0.1	2.2	2.8
	Investment	1.8	5.7	2.0
	Imports	0.2	-0.2	-0.8
	Exports	0.1	0.6	0.8
	Inflation (consumer price)	-0.4	-2.2	-2.6
Removing EU extra funding	GDP	0.4	2.9	3.0
	Employment	0.2	0.9	1.1
	Consumer spending	0.4	2.3	4.3
	Investment	0.7	4.6	1.4
	Imports	0.1	-0.4	-0.9
	Exports	0.1	0.5	-0.6
	Inflation (consumer price)	-0.2	-1.9	-1.6

Source: Cambridge Econometrics

The first variant (removing extended/intensified ETS) shows smaller positive GDP impacts than the Net Zero scenario does. The removal of the carbon price and higher ETS price means that as the environmental target is not achieved, industry and households face lower costs, resulting in an improvement to EU exports and real income (consumption). This does not take into account the potential costs from climate change resulting from the non-respect of the net zero target (e.g. losses due to extreme weather events). This also assumes that all businesses face costs due to carbon prices and higher ETS, while in reality some would benefit from it, potentially triggering a structural move towards higher levels of productivity. Increases in exports and consumption have a positive effect on GDP. However, the reduced revenues from the carbon tax and ETS mean that other policy costs must be financed through alternative means. One way is through an increase in income tax and social security rates, which has a negative impact on GDP through lowering disposable incomes and increasing labour costs, which lead to lower consumer and employment demand.

Not providing loan guarantees means that borrowing costs and renewable investments are more expensive than in the Net Zero scenario. Overall, these impacts are relatively limited and investment will remain high (albeit lower than the Net Zero scenario) since it is driven by other policies such as regulations, phase out of fossil fuels, public procurement and energy efficiency.

Compared to the Net Zero scenario, there are more energy imports, which have a negative impact on GDP.

The second variant (removing EU extra funding for green investment) also shows that the environmental target is not achieved and that there is a less positive GDP impact than the Net Zero scenario. In the Net Zero scenario, green public investment leads to a reduction in renewable costs through learning and economies of scale, and consequently leads to additional private sector investments. The removal of this public green investment means that overall there is less investment in this variant, which is one of the main drivers of GDP growth in the Net Zero scenario.

Publicly funded energy efficiency investment in the Net Zero scenario helps to reduce energy bills for business and consumers, so removing the investment means that companies and households face higher energy bills than in the Net Zero scenario. Higher emissions in this scenario from lower uptake of green technologies means that higher ETS and carbon tax rates are applied to sectors and households. This in turn reduces aggregate demand.

Furthermore, because the demand for fossil fuels is not reduced as much as in the Net Zero scenario, there are more energy imports as well as higher imports of other goods and services (from using revenues to reduce general taxes instead), resulting in a negative impact on GDP compared to the Net Zero scenario. Some of the EU funding in this variant is redirected to reduce taxes that lead to higher consumer demand in the long run. The modelling results suggests that EU funding can still be used for non-green policies to stimulate the EU economy. However, using the fund to promote green investment not only produces better GDP results throughout the period, but also helps reduce emissions and to achieve the EU net zero target.

In conclusion, using EU funding toward green investment and stimulus produces better outcomes for GDP through positive stimulus effects on private sector investment, cost reductions through learning effects, lower energy bills for consumers and a reduction in fossil fuel imports.

In both variants, the removal of EU level climate policies leads to smaller positive GDP impacts and higher emissions than the net zero scenario. However, the estimated GDP benefits of the EU climate policies are expected to be larger once co-benefits from emissions reduction, such as pollution impacts on human health and mortality, are considered.

4.2. Complementary literature review

4.2.1. Benefits of electricity network interconnection and market coupling

The integration of European electricity markets, where enabled by physically interconnected networks and adequate market design, brings about major system efficiency gains and hence welfare to European consumers and industries. Electricity interconnections and market coupling lead to more competition and higher security of supply on the one hand, and to lower overall system costs on the other hand, as power generation capacity is used more efficiently and balancing and reserve capacity (including demand response resources) can be shared amongst Member States, which reduces the marginal cost and the overall capacity needs.

While the effects of network interconnections and market coupling on competition and security of supply are difficult to quantify, there are estimates on their impacts on system costs, which vary however significantly depending on their time-scale, scope and methodology. Newbery et al (2016)[140] estimated in their study that **further investments in interconnection capacity coupled with day-ahead and intra-day market integration** could lead to gains of over €1 billion per year, while cross-border balancing could provide additional benefits ranging from €1.3 billion to €2.7 billion per year by 2030. Moreover, a properly interconnected electricity system also facilitates the integration of variable RES and reduces curtailment, the cost of which might be €130-160 million per year. The study concluded that the benefits of interconnections and market coupling substantially exceed the costs of the related investments and market design changes.

Another study, undertaken by Baker et al (2018)[141] concluded that the potential benefits of **fully integrating the EU's electricity markets** could be in the range of €16 billion to €43 billion annually by 2030, depending on the extent to which the power generation portfolio is optimised, the development of additional interconnection capacity, and the widespread application of demand response. Most of the benefits in social welfare rely on the **full harmonisation and integration of wholesale markets** (between €12.5 and €32.5 billion potential savings), while a **supra-national approach to resource adequacy** (from €3 to €7.5 billion) **and shared balancing** (€3 billion) could provide lower, but still significant savings.

Other studies[142] focus specifically on the potential benefits arising from short-term market coupling by using the currently available or planned interconnection capacity more efficiently, and from the implementation of harmonised network codes.

There has been significant progress towards implementing **day-ahead market coupling** at EU level, enabling cross-zonal capacity between neighbouring bidding zones to be more efficiently used. By 2020 day-ahead market coupling was implemented at one third of the EU borders[143], leading to a significantly higher efficiency in the use of the electricity interconnectors.[144] The

140 Newbery, D., Strbac, G., and Viehoff, I., (2016) The benefits of integrating European electricity markets. Energy Policy, July 2016. DOI: 10.1016/j.enpol.2016.03.047.

141 Baker, P., Hogan, M., and Kolokathis, C., (2018). Realising the benefits of European market integration. The Regulatory Assistance Project (RAP). Retrieved from: https://www.raponline.org/wp-content/uploads/2018/05/rap-pb-mh-ck-benefits-european-market-integration-2018-may-21.pdf These figures are based on Booz & Co. (2013) Benefits of an integrated European energy market and the European Commission (2016) estimates.

142 ACER/CEER (2020). Annual Report on the Results of Monitoring the Internal Electricity and Natural Gas Markets in 2019 – Electricity Wholesale Markets Volume. October 2020. And ENSTO-E (2019) POWERFACTS EUROPE 2019.

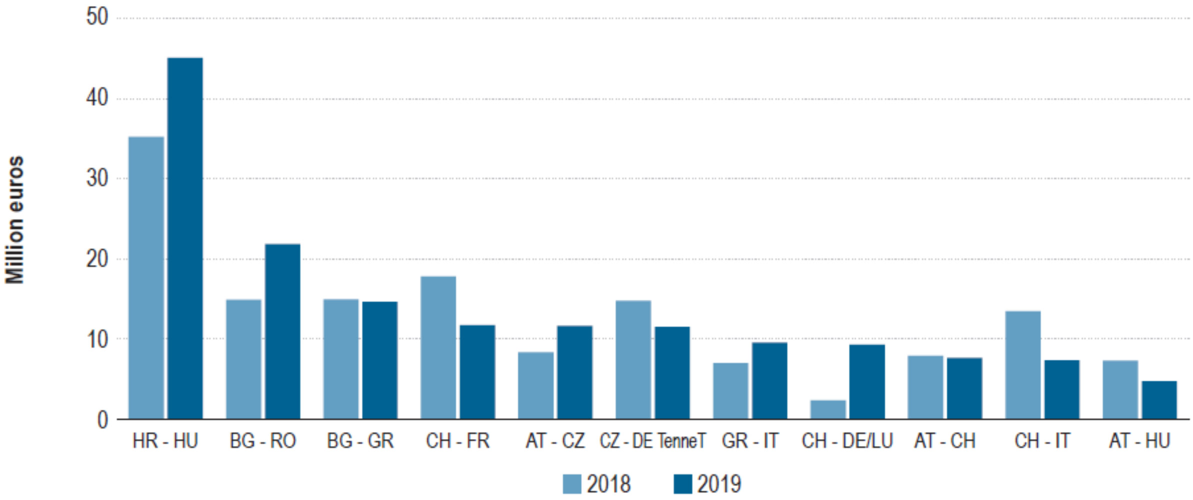
143 By the end of 2019, DA market coupling had been implemented on 32 out of 42 EU borders (excluding the 4 borders with Switzerland).

144 Efficient use is defined as the percentage of the available Net Transfer Capacity used in the 'right economic direction' in the presence of a significant (>1 euro/MWh) price differential between the 2 bidding zones.

economic benefits of this development are reflected in the price differentials between neighbouring bidding zones. Notwithstanding the progress, there is still a large potential for improvements; ACER[145] estimates that the potential welfare gains from extending the day-ahead market coupling to all EU borders (including the 4 borders with Switzerland) will amount to over 150 million euros per year.

Further benefits, but less high than for day-head markets, could be obtained by implementing **intra-day market coupling.** At present the efficient utilisation of cross-zonal capacity remains rather low at only 59 % in 2019[146], which illustrates the large potential for further improvement. The EU level can and does play a major role to increase the available electricity interconnection capacity between EU Member States, and to enhance its efficient use by different measures and instruments.

Figure 4-8: Estimated potential social welfare gains from further extending DA market coupling– 2018–2019 (million euros).



Source: ACER (2020) Annual Report on the Results of Monitoring the Internal Electricity and Natural Gas Markets in 2019 – Electricity Wholesale Markets Volume, based on ENTSO-E, NRAs and Vulcanus data.

Finally, ENTSO-E estimates that €0.7 – 1 billion per year of social welfare gains are realisable from the implementation of **EU harmonised network codes**, while in comparison, ACER suggests that greater progress in the development of the electricity markets could lead to even greater welfare gains estimated at around €5 billion per year.[147]

Taking into account the different estimates, **we conclude that additional benefits ranging between €16 and €43 billion per year could be achieved by 2030, which rely primarily on EU action and is therefore fully considered a cost of on-Europe**. This range is in line with previous

145 ACER/CEER (2020). Annual Report on the Results of Monitoring the Internal Electricity and Natural Gas Markets in 2019 – Electricity Wholesale Markets Volume. October 2020.

146 ACER/CEER (2020). Annual Report on the Results of Monitoring the Internal Electricity and Natural Gas Markets in 2019 – Electricity Wholesale Markets Volume. October 2020.

147 ENTSO-E (2019) POWERFACTS EUROPE 2019.

Cost of Non-Europe estimates[148] of a more integrated energy market (€29 billion per year), although the scope of actions included are different from those from Baker et al (2018).[149]

4.2.2. Benefits of RD&I

Horizon Europe is the main European programme funding research and innovation, with a total available budget of €95.5 billion for the 2021-2027 period, from which €15 billion are assigned for projects under Cluster 5: Climate, Energy and Mobility[150]. Findings from the impact assessment accompanying the proposal for Horizon Europe[151], suggest that the continuation of RD&I funding in 2021-2027 period is expected to provide a clear EU added value. Like its predecessor Horizon 2020, Horizon Europe is expected to have **positive effects on growth, trade and investment flows, and in jobs.**

The potential cost of discontinuing the EU RD&I programme (i.e. the cost of non-Europe) was estimated to be substantial, with a decline of competitiveness and growth of up to €550 billion of GDP over 20 years, and up to €720 billion over 25 years.[152] The macroeconomic models used project that the programme is expected to produce 0.08 % of additional GDP on average over 25 years, with the highest gains (+0.31 % of GDP) expected to occur around 2034. This means that each euro invested can potentially generate a return from 10 to 11 euros in gross domestic product (GDP) gain over 25 years. EU RD&I investments are also expected to generate up to 100 000 jobs in R&I activities during the "investment phase" (2021-2027) and promote an indirect gain of up to 200 000 jobs over 2027-2036, from which 40 % are highly skilled jobs. This would mean more than 15 000 jobs would be generated by EU investments in Climate, Energy and Transport RD&I projects.

Considering that almost 16 % of the Horizon Europe budget is going to Climate, Energy and Transport, the **cost of non-Europe of RD&I area of Climate, Energy and Transport could roughly be estimated to be around €113 billion of GDP growth over 25 years** from EU R&I investment in this cluster (around €4.5 billion per year), together with over 15 000 jobs generated by 2027, and over 30 000 between 2027-2036.

It should be noted that the added value of European RD&I funding goes beyond economic impacts. When compared to national and regional-level RD&I activities only, EU funded RD&I projects produce demonstrable benefits in terms of scale, speed and scope.[153]

EU-wide competition for RD&I funds increases the quality and visibility of the research and innovation output beyond what is possible via national or regional competition, **strengthening the**

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148 Del Monte, M. et al (2019). Europe's two trillion-euro dividend: Mapping the Cost of Non-Europe, 2019-24. European Added Value Unit, European Parliament, April 2019. This estimate is based largely on Booz & Co. (2013) Benefits of an integrated European energy market as well as case studies from Del Monte, M. (2017) and, Mapping the Cost of Non-Europe, 2014-19.vEuropean Parliament Research Service, December 2017.

149 The total benefits assumed by from Del Monte, M. et al (2019) assumed the lower-range of estimate of the benefits of a fully harmonised wholesale market, while it also included estimates for the benefits of smart grids for consumers' demand response and of phasing out regulated prices.

150 Based on the political agreement of December 11 2020, this sum includes €5.4 billion from Next Generation Europe. Source: European Commission (2021). The EU Research& Innovation Programme 2021 – 27. Retrieved from: https://ec.europa.eu/info/sites/default/files/research_and_innovation/funding/presentations/ec_rtd_he-investing-to-shape-our-future.pdf.

151 SWD(2018) 307 final Commission Staff Working Document Impact Assessment Accompanying the document Proposals for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing Horizon Europe – the Framework Programme for Research and Innovation, laying down its rules for participation and dissemination.

152 Calculated for the EU-27, based on the NEMESIS model. Figures in constant prices. Source: SWD(2018) 307 final - Annex V Macroeconomic modelling.

153 SWD(2018) 307 final - Annex 4: Added Value of EU-funded R&I.

EU's scientific excellence. This is evidenced by the fact that EU-funded peer-reviewed research publications are cited more than twice the world average, and are almost four times more represented in the world's top 1 % of cited research when compared to the overall publication output of the 28 EU MS.[154]

EU RD&I funding also stimulates the **creation of cross-border collaboration networks** within the EU through the requirements for cross-country consortia in project calls. Trinomics (2019)[155] studied the impacts of EU RD&I actions on Renewable Energy technologies over the past 20 years, covering from Framework Programme (FP) 5 up until Horizon 2020 (FP8). The study found that in virtually all Renewable Energy sectors, large projects that coordinated research activities across the EU, EU funding stimulated the formation of partnerships in the context of specific R&D challenges.

EU R&I activities also **strengthen the EU's competitive advantage,** for example through the sharing of knowledge, technology transfer and access to new markets.[156] Trinomics (2019)[157] found that EU RD&I funding enabled the development of several specific Renewable Energy technologies and the continuation of research that would not have been possible otherwise with private and/or national funding only. Technologies such as solar CSP and fixed-bottom offshore wind benefited greatly from EU support to accelerate their development and market entry. The stakeholders in these sectors assigned significant importance to the role of EU funding for bringing these technologies to the market.

An assessment of EU Added Value of FP7 and Horizon Europe found that in general, EU-funded RD&I teams were around 40 % more likely to be granted patents or produce patent applications, when compared to receiving national or regional funding only.[158] Similarly, an impact assessment of the FP6-FP7 energy projects[159] provided strong evidence on the commercialisation effects of FPs, concluding that most FP projects that aimed to improve technologies were successful in doing so. A typical project funded by FP6 brought a technology from the validation phase to model/prototype tested in a relevant environment.[160]

EU RD&I also creates new market opportunities through collaborative multi-disciplinary teams and dissemination of results. EU RD&I activities involve key industrial players, SMEs and end-users, which reduces commercial risks, for example, by the development of common standards and interoperable solutions, and by defragmenting existing markets.[161]

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154 Based on Field Weighted Citation Index . Source: SWD(2018) 307 final - Annex 4: Added Value of EU-funded R&I.

155 Trinomics (2019). Study on impacts of EU actions supporting the development of renewable energy technologies. European Commission Directorate-General for Research and Innovation. doi: 10.2777/902810.

156 SWD(2018) 307 final - Annex 4: Added Value of EU-funded R&I.

157 Trinomics (2019). Study on impacts of EU actions supporting the development of renewable energy technologies. European Commission Directorate-General for Research and Innovation. doi: 10.2777/902810.

158 This estimate is not specific to energy projects. Source: PPMI study (2017), Assessment of the Union Added Value and the Economic Impact of the EU Framework Programmes (FP7, Horizon 2020). Available at: https://op.europa.eu/en/publication-detail/-/publication/af103c38-250d-11e9-8d04-01aa75ed71a1/language-en.

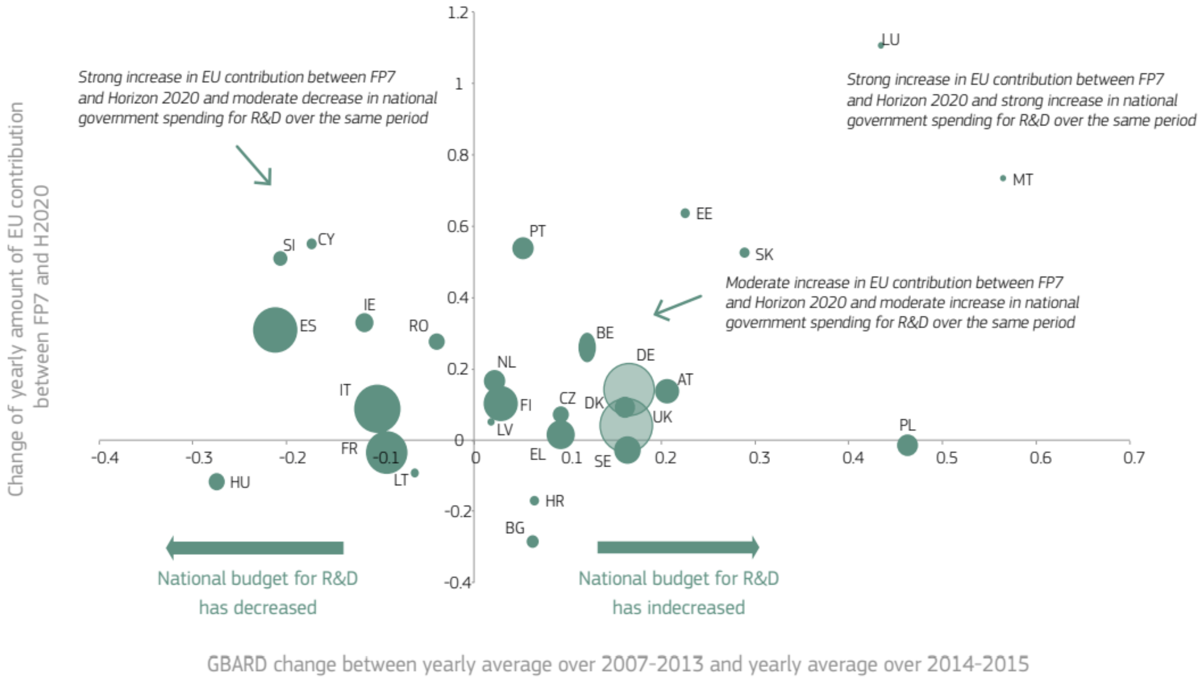
159 Technopolis Group, Hinicio, LBST, FEEM (2014). Evaluation of the impact of projects funded under the 6th and 7th EU Framework Programme for RD&D in the area of non-nuclear energy, Final Report. Available at: https://ec.europa.eu/energy/content/evaluation-impact-projects-funded-under-6th-and-7th-eu-framework-programme-rdd-area-non_mt.

160 The impact assessment used the system of Technology Readiness Levels (TRLs) to measure how far a new technology is from application. The scale starts with TRL1, which is scientific fundamental research, and ends at TRL9, which corresponds to the pre-commercialisation step. The average FP6 and FP7 non-nuclear energy project started at TRL 3.75 (median 3), and finished at 6.12 (median 6).

161 SWD(2018) 307 final - Annex 4: Added Value of EU-funded R&I.

Finally, the EU RD&I support provides **high additionality**, investing in distinctive research and innovation projects that are different from those funded at national or regional level. The EU programmes do not displace or replace national funding[162] (see Figure 4-9 below). On average 83 % of the projects funded by EU programmes would not have gone ahead without Horizon Europe.[163]

Figure 4-9: Change in Government budget allocations for R&D (GBARD) and change in EU contribution between FP7 and Horizon 2020.



Notes: Size of circles represent the number of applications in Horizon 2020.

Source: European Commission DG RTD (2017). LAB-FAB-APP, Investing in the European future we want. Report of the independent High Level Group on maximising the impact of EU Research & Innovation Programmes.

4.2.3. Benefits of a Carbon Border Adjustment Mechanism

A possible option for implementing more ambitious climate policy without risking carbon leakage is to introduce a carbon border adjustment mechanism (CBAM). The European Green Deal referred to the implementation of such a CBAM as one of the measures to consider for reaching climate neutrality by mid-century. Within the context of this study, a CBAM is highly relevant as it is a clear example of additional measures that the EU could take to realise climate neutrality in an efficient manner and could thereby translate into a cost of non-Europe if not pursued. Moreover, it is a measure that would obviously require the EU to take the primary action as it would be highly inefficient and incompatible with the single EU market for Member States to implement such a measure individually.

[162] European Commission DG RTD (2017). LAB-FAB-APP, Investing in the European future we want. Report of the independent High Level Group on maximising the impact of EU Research & Innovation Programmes.

[163] Based on survey data. Source: PPMI study (2017), Assessment of the Union Added Value and the Economic Impact of the EU Framework Programmes (FP7, Horizon 2020). Available at: https://op.europa.eu/en/publication-detail/-/publication/af103c38-250d-11e9-8d04-.

The main objective of a CBAM is to fight climate change by avoiding carbon leakage.[164] Its final shape is still being developed but it would basically consist of a carbon tax on a specific set of imported products from particular third countries, to compensate for the differences between the effective carbon price in the EU and in the country exporting to the EU. This is especially relevant for third countries with no equivalent forms of carbon pricing to those that operate in the EU. This way, a level playing field is created within the EU for imported and domestically produced products. Furthermore, a rebate could be introduced for goods exported from the EU to third countries with no carbon pricing or at a lower level.[165] The mechanism would need to be compatible with World Trade Organization (WTO) rules. Once introduced, it would allow for more ambitious EU climate policies without risking carbon leakage. It could eventually replace current measures to avoid carbon leakage, including the free allowances for EU ETS sectors and the possibility for Member States to compensate electro-intensive industries for ETS costs passed on through electricity prices.

As the CBAM is still under development, a full view on its impacts and benefits is not available yet. However, some indication of its impacts can be found in the Commission's inception impact assessment[166] and the European Parliament's resolution on the topic[167]. The key impacts mentioned in those publications are:

- More effective climate policies in the EU;
- Promotion of more ambitious climate policies in trading partner countries;
- Positive impact for innovation and research through a higher price for carbon-intensive products and consequently a stimulus for developing sustainable products;
- Increased jobs within the EU by avoiding substitution of EU production by third country production;
- Higher consumer prices with potential risk of adverse distributional impacts;
- Some additional administrative burden.

We conclude that, assuming that it stays fully WTO compatible, the CBAM has mostly positive impacts, in particular for enabling more ambitious climate policies without compromising the competitiveness of the EU industry and the associated jobs. The risk of adverse impacts through higher consumer prices is the main drawback which can be mitigated through recycling of the revenues of the instrument in a way that compensates for those impacts.

[164] European Commission (2020) – Carbon Border Adjustment Mechanism – Inception Impact Assessment.

[165] European Parliament (2021) – A WTO-compatible EU carbon border adjustment mechanism.

[166] European Commission (2020) – Carbon Border Adjustment Mechanism – Inception Impact Assessment.

[167] European Parliament (2021) – A WTO-compatible EU carbon border adjustment mechanism.

5. Conclusions

The analyses in this report suggest that there is considerable scope for additional policy measures to realise the energy transition in an efficient way. Thirteen key challenges need to be addressed, including both energy supply and demand side measures and covering many sectors of the economy. The required policy measures to address those challenges are numerous and will require strong and concerted action at both EU and Member State level.

EU leadership is crucial for policy measures related to strategy development and target setting as moving forward in a coordinated and collective manner is key for establishing ambitious and coherent national plans. The targets to reduce GHG emissions, increase renewable energy generation and enhance energy efficiency are pivotal in this regard, as well as specific EU strategies for developing public energy infrastructure and promising key technologies (e.g. batteries, power-to-hydrogen, CCUS, offshore renewable energy). Furthermore, the possibility to support concrete projects as (Important) Projects of Common (European) Interest can lead to an important EU contribution to specific challenges of the energy transition. While the effectiveness of these policies strongly depends on the specific policy measures implemented to achieve the targets, and is therefore hard to isolate, we conclude that not having EU coordinated strategies and targets in place would lead to a significant cost of non-Europe.

EU action is also crucial for effective carbon pricing, technical standardisation and energy markets' integration. Furthermore, the EU can play an important role in co-funding public infrastructure, reducing the cost of capital for sustainable investments, funding RD&I and coordinating tax reform. Key instruments in this context include the EU Emissions Trading System, the Connecting Europe Facility, the EU taxonomy for sustainable activities and Horizon Europe.

Furthermore, EU budgetary actions and in particular the requirement to dedicate a minimum share of the EU budgets to climate-relevant topics in combination with the significant size of the MFF and NextGenerationEU result in a considerable amount of additional EU funding that is directed to sustainable investments in EU Member States.

Our macroeconomic assessment of a consistent package of policies to reach climate neutrality by 2050 (Net Zero Scenario) confirms that there are positive effects on both GDP and employment from realising the energy transition to achieve climate-neutrality by 2050, in line with the ambitions set out by the EU Green Deal (Table 5-1). The Net Zero scenario is the only scenario that leads to climate-neutrality by 2050, through a combination of policies implemented at both EU and MS level.

When we remove some of the key EU-driven policies, in particular carbon pricing and measures that lower the cost of capital from the Net Zero Scenario, the EU fails to reach the net zero target in 2050 and achieves slightly lower GDP and jobs growth than in the net zero scenario.

Hence, the **cost of non-Europe** if those policies would not be implemented is a significant gap in realising climate neutrality by 2050 and slightly lower economic growth.

When we remove the green public investment financed by the MFF and NextGenerationEU from the Net Zero Scenario, the primary impact is that the EU again fails to reach climate neutrality, with a similar GDP and employment impact as in the Net Zero Scenario.

Hence, the **cost of non-Europe** of the additional funding of green investments is a significant gap in realising climate neutrality while having little impact on GDP and employment.

Table 5-1: All scenarios: summary of economic impacts

% difference from the baseline	2021	2030	2050
GDP			
Net Zero	0.7	3.2	3.0
Removing extended/intensified ETS	0.5	3.1	2.6
Removing EU extra funding	0.4	2.9	3.0
Carbon dioxide emission reduction			
Net Zero	-4.5	-43.1	-81.9
Removing extended/intensified ETS	-3.6	-41.3	-68.6
Removing EU extra funding	-1.8	-35.9	-66.4
Total employment			
Net Zero	0.2	0.9	1.1
Removing extended/intensified ETS	0.1	0.9	0.8
Removing EU extra funding	0.2	0.9	1.1
Absolute difference from the baseline	**2021**	**2030**	**2050**
GDP (Million euro)			
Net Zero	80 763	443 943	555 564
Removing extended/intensified ETS	66 421	425 816	468 752
Removing EU extra funding	53 290	396 840	545 008
Carbon dioxide emission reduction (000s tonnes carbon)			
Net Zero	-33 933	-250 735	-311 476
Removing extended/intensified ETS	-26 914	-239 915	-261 064
Removing EU extra funding	-13 808	-208 834	-252 454
Total employment ('000s)			
Net Zero	318	1912	2135
Removing extended/intensified ETS	234	1766	1393
Removing EU extra funding	319	1754	2132

Source: Cambridge Econometrics

A complementary literature review revealed the specific **cost of non-Europe if additional EU action to integrate energy markets and to stimulate RD&I in the energy sector would not be implemented**. Taking into account the different estimates, we conclude that additional benefits **ranging from €16 to €43 billion per year by 2030** could be achieved from further energy markets' integration, which rely primarily on EU action and is therefore fully considered a cost of non-Europe. With regards to **RD&I we estimate that the cost of non-Europe of discontinuing Horizon Europe, the primary EU instrument to stimulate RD&I, would roughly be around €113 billion lower GDP growth over 25 years** from EU R&I investment in this cluster (around €4.5 billion per year), together with over 15 000 less jobs generated by 2027, and over 30 000 between 2027-2036. A **further cost of non-Europe could result from not implementing the proposed carbon border adjustment mechanism**. Such a WTO compliant mechanism is expected to have mostly positive impacts, in particular for enabling more ambitious climate policies without compromising the competitiveness of EU industry.

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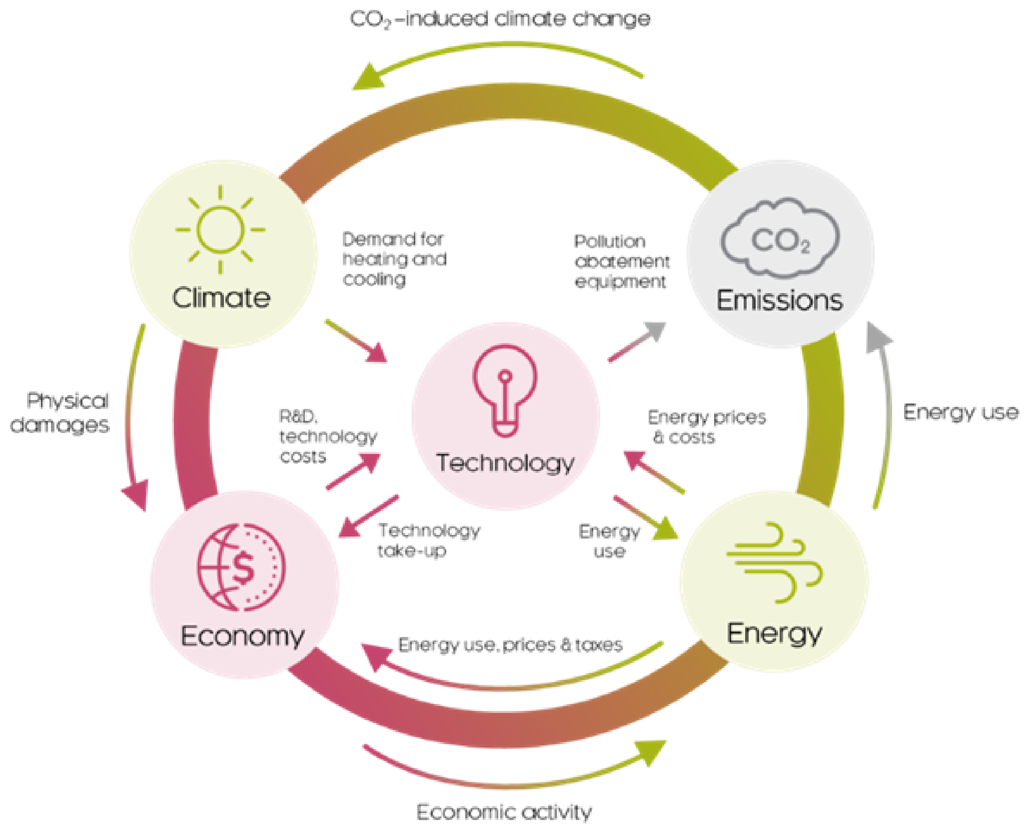
Appendix A: About the E3ME model

Cambridge Econometrics' E3ME model is a computer-based model of the world's economic and energy systems and the environment. It was originally developed through the European Commission's research framework programmes and is now widely used in Europe and beyond for policy assessment. The model manual (Cambridge Econometrics, 2019) is available online at the model website www.e3me.com.

The E3ME model provides an economic accounting framework that can be used to evaluate the effects of economic shocks (in this case the policies required to reduce carbon emissions) on the wider economy. Behavioural relationships in the model are estimated using econometric time-series analysis based on a database that covers the period since 1970 annually. The main source of European data is Eurostat.

Figure 5-1 shows how the three components (modules) of the model - energy, environment (emissions and climate in the diagram) and economy - fit together. Each component is shown separately in the diagram. Each data set has been constructed by statistical offices to conform with accounting conventions. Exogenous factors coming from outside the modelling framework are shown on the outside edge of the chart as inputs into each component.

Figure 5-1: E3 linkages in the E3ME model



Source: Cambridge Econometrics.

A key feature of the E3ME is model is its level of disaggregation. The model is global but breaks the world economy into 61 regions, including all EU Member States individually identified. Within each European country the economy is broken down into 69 sectors. The key sectors in this proposal are the energy-related sectors, but there may be secondary impacts on any other sectors of the economy.

The E3ME baseline is consistent with the economic indicators that are coming from published European Commission forecasts (GDP, population, energy, and emissions) and the World Energy Outlook from IEA. The calibration is made in terms of growth rates and not actual levels and is done at Member State level.

E3ME recognises that the transition to a low-carbon economy depends on the adoption of new technologies. The power, road transport, household heating and steel sectors in E3ME are represented using a novel framework for the dynamic selection and diffusion of innovations, initially developed by J.-F. Mercure, called FTT (Future Technology Transformations). These technology sub-modules are connected to E3ME to provide energy and economic impacts of low carbon technologies. Example of FTT policies include:

- renewable subsidies and feeds-in-tariff
- carbon tax
- car registration tax
- boiler tax
- regulations (e.g. to limit lifetime of power plant, gas boiler regulation, petrol and diesel ban)
- kick-start policies for new technologies.

FTT sub-modules in E3ME

The transition to a low-carbon economy depends on the adoption of new technologies. It is therefore crucial that any modelling of the transition includes a realistic treatment of technology diffusion.

The power, road transport, steel and heating sectors in E3ME are represented using a novel framework for the dynamic selection and diffusion of innovations, called FTT (Future Technology Transformations).

The FTT sub-model is based on a decision-making core for investors who must choose between a list of available technologies. 'Levelised' cost distributions (including capital and running costs) are fed into a set of pairwise comparisons, which are conceptually similar to a binary logit model.

The diffusion of technology follows a set of coupled non-linear differential equations, sometimes called 'Lotka-Volterra' or 'replicator dynamics' equations, which represent the better ability of larger or well-established technologies to capture the market (S-curve). The life expectancy of these technologies is also an important factor in determining the speed of transition.

Due to learning-by-doing and increasing returns to adoption, FTT results in path-dependent technology scenarios that arise from specific sectoral policies.

The following factors affect choice of technologies in FTT:

- Starting point (historical data) where a technology is on the S-curve of technology diffusion and latest costs (e.g. reduction in wind and solar costs in the recent years)
- Levelized costs of technologies which can be affected by learning and spillovers (from other countries), fuel prices, efficiency level.
- Non-market based policies such as regulations (e.g. coal and nuclear phase out, bans on fossil fuel boilers), forcing a switch to other technologies
- Size of market e.g. total electricity demand, heat demand, steel demand or fleet demand. The bigger the market size is for investors, and the more likely that expensive technologies will become viable
- Policies affecting levelized cost of energy (LCOE) including carbon tax, subsidies, feeds-in-tariff etc.

Table 5-2: Technologies in FTTs

Power	Passengers transport	Heating	Steel*
1 Nuclear	1 Petrol Econ	1 Oil	Conv. BF – OHF
2 Oil	2 Petrol Mid	2 Oil condensing	Conv. BF – BOF
3 Coal	3 Petrol Lux	3 Gas	Conv. BF - BOF (BB)
4 Coal + CCS	4 Adv Petrol Econ	4 Gas condensing	Conv. BF - BOF (CCS)
5 IGCC	5 Adv Petrol Mid	5 Wood stove	Conv. BF - BOF (CCS, BB)
6 IGCC + CCS	6 Adv Petrol Lux	6 Wood boiler	BF TGR - BOF (CCS)
7 CCGT	7 Diesel Econ	7 Coal	BF TGR - BOF (CCS, BB)
8 CCGT + CCS	8 Diesel Mid	8 District heating	DR-gas - EAF
9 Solid Biomass	9 Diesel Lux	9 Electric	DR-gas - EAF (BB)
10 S Biomass CCS	10 Adv Diesel Econ	10 Heatpump Ground	DR-gas - EAF (CCS)
11 BIGCC	11 Adv Diesel Mid	11 Heatpump AirWater	DR-gas - EAF (CCS, BB)
12 BIGCC + CCS	12 Adv Diesel Lux	12 Heatpump AirAir	DR-coal - EAF
13 Biogas	13 LPG Econ	13 Solar Thermal	DR-coal - EAF (BB)
14 Biogas + CCS	14 LPG Mid		DR-coal - EAF (CCS)
15 Tidal	15 LPG Lux		DR-coal - EAF (CCS, BB)
16 Large Hydro	16 Hybrid Econ		SR - BOF
17 Onshore	17 Hybrid Mid		SR- BOF (BB)
18 Offshore	18 Hybrid Lux		SR - BOF (CCS)
19 Solar PV	19 Electric Econ		SR - BOF (CCS, BB)
20 CSP	20 Electric Mid		SR + - BOF
21 Geothermal	21 Electric Lux		SR + - BOF (BB)
22 Wave	22 motorcycles Econ		SR + - BOF (CCS)
23 Fuel Cells	23 motorcycles Lux		SR + - BOF (CCS, BB)
24 CHP	24 Adv motorcycles Econ		DR(H2) - EAF
	25 Adv motorcycles Lux		MOE
			Scrap - EAF

* BF = blast furnace, BOF = Basic Oxygen Furnace, EAF = The Electric Arc Furnace, TGR = Top Gas Recycling, DR = Direct Reduction , SR = Smelting Reduction, SR + = Advanced Smelting reduction, CCS = CO2 removal for use and storage, BB = Bio-Based, MOE = Molten Oxide Electrolysis, H2 = Hydrogen

Source: Cambridge Econometrics.

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The European Union's energy system is on a path of transformation that should allow it to achieve a net-zero emissions target by 2050. However, there are many challenges ahead and achieving this target requires making profound structural changes. In this context, the present report, drafted at the request of the European Parliament's Committee on Industry, Research and Energy (ITRE), looks at what the consequences would be if the EU does not take further ambitious and united action in the transformation of its energy system. The **cost of non-Europe in this area is estimated at up to 5.6 % of EU GDP in 2050**, and avoiding this will require EU budgetary, regulatory and coordination action. The benefits would be many, including averted environmental costs and damage, and more sustainable and prosperous societies emerging as a result of a just and fair transition.

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