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COMMISSION STAFF WORKING DOCUMENT

IMPACT ASSESSMENT

Accompanying the document

COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN 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

{COM(2020) 562 final} - {SEC(2020) 301 final} - {SWD(2020) 177 final} - {SWD(2020) 178 final}

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9 ANNEXES

9.1 Procedural information

9.1.1 Lead DG, Decide Planning/CWP references

The Directorate-General (DG) for Climate Action was leading the preparation of this initiative and the work on the Impact Assessment in the European Commission, with the DG for Energy being co-responsible. The planning entry was approved in Decide Planning under the reference PLAN/2020/6960. It is included in the 2020 Commission Work Programme under the policy objective "Commission contribution to COP26 in Glasgow ".

9.1.2 *Organisation and timing*

The planned adoption date (Q3 2020) included in the Commission Work Programme adopted on 29 January 2020, was unchanged in the revised version adopted on 27 May 2020 following the COVID-19 crisis.

An inter-service steering group (ISG), was established for preparing this initiative. The ISG met five times in the period from February until adoption in September 2020.

9.1.3 Consultation of the RSB

A draft Impact Assessment was submitted to the Regulatory Scrutiny Board (RSB) on 9 July 2020. Following the Board meeting on 22 July 2020, it issued a negative opinion on 24 July 2020. After consideration of the Board's recommendations in the first opinion, a new version of the draft Impact Assessment submission was submitted on 18 August 2020, to which the Board issued a positive opinion with reservations on 27 August 2020.

The Board's recommendations have been addressed as presented below.

RSB 1st Opinion of 24 July 2020

Recommended improvements and how they were addressed

(1) The impact assessment should develop a stronger and more easily accessible narrative that can support a broad public debate. It should be clearer on which (major) decisions it supports and which not. It should explain what margin of manoeuvre and scope will be left for the follow-up sectoral impact assessments, and set out how a coherent approach will be ensured. The link between the impact assessment and the proposed chapeau communication should be explained.

- Sections 1 to 5 where fully reviewed and shortened, improving the logic of how problem definition, objectives and policy options relate to each other, including the introduction of an intervention logic.

(2) The report should further develop the problem analysis. It should acknowledge the role of EU action for global climate policies. It should describe how local environmental and other public policy problems link to a greater short-term climate policy ambition. It should elaborate on why a higher ambition for 2030 is needed (e.g. earlier availability of cheaper low-carbon technologies and co-benefits, greater costs of reaching carbon neutrality in 2050, reducing the post-2030 mitigation burden, etc.).

- The problem definition section 2 has been adapted, focusing on the lack of ambition of the current EU climate 2030 target and on the need to update the climate and energy policy framework in the perspective of reaching climate neutrality by 2050.

(3) The objectives section should go beyond the more ambitious target for the next decade and show how it connects to higher-level objectives of climate policy. The intervention logic should show clearly the logical chain between the identified problems, what the initiative aims to achieve and the solutions considered.

- The objectives section 4 has been adapted to reflect better how objectives relate to addressing the problems, notably in the perspective of the higher-level objective of reaching climate neutrality by 2050. An intervention logic scheme (see section 4.4) has been added to map problems and problem drivers (the existing climate target is insufficient and the policy framework is not adequate) with general and specific objectives (raising the climate target and updating the policy framework). The intervention logic then relates to the policy options described in section 5 (see Table 2 and Table 3).

(4) The impact analysis should include the missing scenarios (EU-NECP, 50% MIX, COVID-19). It should include a summary of the main characteristics of the modelling (e.g. how the partial-equilibrium sectorial modules are combined) and report on headline results. Large parts of the (quantitative) assessment could be moved into dedicated annexes.

- All the missing scenarios have been added to the analysis (see section 5.4 for the description of scenarios) and a summary of headline results has been included in the conclusions (section 8, Table 28). Large parts of the quantitative assessment have been moved to dedicated annexes (Annexes 9.4 and 9.5), with only the main impacts being discussed in the main body of the report (section 6).

(5) The analysis of the extensive public consultation should be completed and integrated into the report. This should include an assessment of which groups support which option, giving due attention to minority views.

- The findings of the public consultation have been introduced in relevant places of the report, including in sections discussing sectoral impacts. See also below the reply to recommendation (2) of the second Opinion of the RSB.

(6) The rich assessment should lead to conclusions. These should include a clear overview of the different impacts of the options and their advantages and disadvantages. They should highlight trade-offs and distributional effects. They should also reflect stakeholder views.

- A conclusion section has been added (section 8).

RSB 2nd Opinion (Positive with reservations) of 27 August 2020

Recommended improvements and how they were addressed

(1) The problem description should show more convincingly that the current pathway towards climate neutrality by 2050 would not be 'balanced'. It should present evidence why a more uniform CO_2 reduction rate over time is preferable, also in terms of cost-efficiency for different stakeholder groups. It should be more explicit on its assumptions on the evolution of the cost of CO_2 reduction.

- The problem definition was further adapted, recognising that a 55% greenhouse gas target actually sees limitedly higher emission reductions up to 2030 than afterwards. The impact assessment compares GHG pathways towards climate neutrality that achieve 50% or 55% GHG reductions by 2030. This allows to assess how these different pathways impacts costs, including for the different sectors and thus stakeholder groups, and how they prepare the energy system and economy towards deep decarbonisation after 2030.

(2) The main text should present a more disaggregated view of stakeholder opinions across the different groups of respondents (e.g. businesses, NGOs, Member State authorities, extra EU bodies and citizens). The report should distinguish between views of individuals and those of organised interest groups. The stakeholder consultation annex should clarify how the analysis has taken account of campaign replies. The graphs and tables in the stakeholder annex would also benefit from a more granular representation of stakeholder groups.

- Annex 9.2 was added with detailed tables with information per group of respondents on the main outcomes of the public consultation regarding GHG, RES and EE ambition. Moreover, the text now clarifies what campaigns have been identified and how this impacts the robustness of the conclusions. A limited amount of additional insights were added to the main text. A synopsis report as well as an in-depth report on the results of the open public consultation were prepared, which includes a summary of position papers received and detailed tables for the remaining questions raised in the public consultation.

(3) The conclusions and executive summary should be more explicit on costs and benefits and on the distributional effects of the various scenarios across sectors and groups of the population. They should better explain how the different ambition levels would impact on the various sectors and what the main related policy choices are (to be addressed now or in subsequent steps).

- The main finding regarding the distributional effects of the proposed options have been summarised in the conclusions and executive summary. The cost and benefits across the various scenarios have been systematically compared (including in terms of system costs, investments, carbon revenues, household expenditure and main macroeconomic aggregates).

(4) The report should be clearer on how far the expected revenues from new carbon revenues will compensate the distributional effects and support sectoral restructuring.

- The Impact Assessment clearly shows that carbon pricing can lead to a better macro-economic outcome. It assesses the impact of lump sum transfers to household, labour tax reduction and investments in to greening of the economy, and discusses how addressing the investment gap is of importance with respect to the COVID-19 crisis. The report recognises clearer that choices will have to be made between these different options of recycling, and this involves a trade-off between redistributional and economic restructuring objectives.

(5) The report should explain why there is no preferred option. It should be clearer that the purpose of this impact assessment is to stimulate public discussion on the 2030 emission reduction level and on the choices that will need to be made across different sectors in order to achieve the selected target.

- The concluding section has to be seen as a multi criteria assessment that is dense in information. While it does not explicitly endorse one option, the conclusion has been further refined pointing out that the 55% GHG reduction option has a number of co-benefits compared to the 50% GHG option, while not leading to significant different costs. This together with the policy architecture assessment in sections 6.6 to 6.10 and the sectoral assessments in annex should indeed allow for informed decision making and stimulate a wider public discussion on adopting an increased 2030 climate ambition.

(6) The report does not include the standard quantification table with estimated costs and benefits. The summary table in the conclusions represents a useful alternative. The report should briefly explain the differences in scenario outcomes reported in that table.

- The differences in scenario outcomes reported in the table are systematically discussed in the conclusions. The conclusions make reference to the summary table.

(7) The report needs further editing and consistent formatting. It needs to complete the integration of changes to the first submission throughout the report. The annex section on procedural information should explain how it incorporated the Board's recommendations.

- Further editing and formatting have been introduced in finalisation of the report. The integration of changes compared to the first submission has been completed and a placement error was corrected. This annex explains how the Board's recommendations have been incorporated.

9.2 Stakeholder consultation: views disaggregated by stakeholder category for ambition, challenges and opportunities

This section adds further detail on views received from various stakeholder types in the open public consultation which was conducted through an online survey. The survey was open for 12 weeks (from March 31st to June 23rd, 2020) and received a total of 3915 replies. A synopsis report as well as an in-depth report on the results of the open public consultation was also prepared, which includes a summary of position papers received.

This section shows the disaggregated views of these stakeholders types on key questions of interest to this impact assessment related to ambition, i.e. the overall climate ambition in terms of the GHG reduction target by 2030, the accompanying 2030 ambitions for renewable energy and for energy efficiency, as well as the opportunities and challenges associated with these options.

Moreover, a number of campaigns were identified in the open replies and survey attachments. The largest campaign (8%; 329 respondents), constituting of mostly private individuals, advocated mainly for a higher climate ambition, and a common carbon price. The second campaign (<1%; 40 respondents), also mostly private individuals, pushed for a revision of the methodology to calculate the GHG emissions of the agriculture sector. The third campaign (<1%; 35 respondents), supported mainly by NGOs, requested coherence with the Paris Agreement and a bigger focus on the costs of inaction. The fourth campaign (<1%; 20 respondents) of private individuals, proposed a climate dividend for citizens as a carbon pricing mechanism. Overall, these campaigns are thus part of the views of private individuals as listed in the tables in this section. The overall conclusions of the stakeholder views are not materially affected even without the campaign contributions: an increase in the GHG emissions target to at least 55% remains clearly the preferred option when looking at professional and organised stakeholder replies. The same is true for ambition in renewables and in energy efficiency, though views of the business sector are distributed more evenly across the options.

Table 29: Desired 2030 ambition on the climate target

Type of information	It should remain unchanged at 40%	It should be increased to at least 50%.	It should be increased to at least 55%
As an individual in a personal capacity	220	380	2 584
Of which:			
EU citizen	217	372	2 556
Non-EU citizen	3	8	28
In a professional capacity or on behalf of an organisation	126	135	320
Of which:			
Academic/research institution	6	14	21
Business association	40	42	54
Company/business organisation	38	46	75
Consumer organisation	4	0	3
Environmental organisation	3	3	25
Non-governmental organisation (NGO)	17	9	86

Trade union	1	2	3
Other	7	5	28
Public authority	10	14	25

Table 30: Desired 2030 ambition on the renewable energy target

Stakeholder Type	Achieve at least a share of 32% renewable energy in the final energy consumption in the EU by 2030, i.e. unchanged from the level already agreed	Achieve at least a share of 35% renewable energy in the final energy consumption in the EU by 2030	Achieve at least a share of 40% renewable energy in the final energy consumption in the EU by 2030	Achieve even higher level of ambition than at least a share of 40% renewable energy in the final energy consumption in the EU by 2030	Do not know/Do not have an opinion
As an individual in a personal capacity	150	134	399	2 378	140
Of which:					
EU citizen	148	129	396	2 357	136
Non-EU citizen	2	5	3	21	4
In a professional capacity or on behalf of an organisation	97	79	114	235	73
Of which:					
Academic/research institution	4	8	12	15	4
Business association	32	22	28	31	33
Company/business organisation	38	31	37	44	15
Consumer organisation	1	1	0	4	1
Environmental organisation	1	1	3	25	2
Non-governmental organisation (NGO)	7	6	13	73	8
Trade union	2	1	0	1	3
Other	4	5	5	23	6
Public authority	8	4	16	19	1

Table 31: Desired 2030 ambition on the energy efficiency target

Stakeholder Type	Achieve at least 32.5% energy efficiency (in both primary and final energy consumption) by 2030, i.e. unchanged from the level already agreed	Achieve at least 35% energy efficiency (in both primary and final energy consumption) by 2030	Achieve at least 40% energy efficiency (in both primary and final energy consumption) by 2030	Achieve even higher level of ambition than at least 40% energy efficiency (in both primary and final energy consumption) by 2030	Do not know/Do not have an opinion
As an individual in a personal capacity	172	193	448	2 135	250
Of which:					
EU citizen	170	188	446	2 113	246
Non-EU citizen	2	5	2	22	4
In a professional capacity or on behalf of an organisation	112	82	101	210	81
Of which:					
Academic/research institution	1	7	13	12	5
Business association	42	25	22	28	29
Company/business organisation	42	29	25	40	24
Consumer organisation	1	1	1	4	0
Environmental organisation	2	1	5	22	2
Non-governmental organisation (NGO)	9	5	16	67	9
Trade union	2	2	0	0	2
Other	5	4	5	22	7
Public authority	8	8	14	15	3

Table 32: Opportunities related to a higher 2030 climate ambition

Type of information	It will be a chance to do our part in saving the planet and thus fulfilling our duty towards the future generations.	It will allow a more gradual pathway to reaching a climate neutral EU by 2050	It will help mitigate costs associated with climate change to the society (from e.g. extreme weather events, droughts, loss of ecosystems etc.)	It will ensure a growing EU economy based on new production and consumption models (e.g. circular economy approach)	It will reinforce EU leadership and inspire action to battle climate change globally	It will create new (green) jobs, including those that are difficult to outsource outside the EU (e.g. maintenance of renewable energy installations, construction)	It will lower pollution, improve health, make cities and buildings more liveable and thus increase the well-being of citizens.	It will give the EU industry a first-mover advantage on global markets	It will improve energy security and reduce the EU dependency on imported fossil fuels	Other
As an individual in a personal capacity	2 607	1 322	2 298	1 762	1 905	2 001	2 642	1 345	2 047	362
Of which:										
EU citizen	2 575	1 304	2 269	1 741	1 875	1 973	2 609	1 327	2 021	358
Non-EU citizen	32	18	29	21	30	28	33	18	26	4
In a professional capacity or on behalf of an organisation	350	378	357	381	301	389	439	273	361	203
Of which:										
Academic/research institution	30	26	30	23	19	26	36	17	30	4
Business association	51	105	61	88	54	88	88	64	87	55
Company/business organisation	89	103	82	104	83	112	111	77	83	58
Consumer organisation	4	3	4	2	3	2	4	3	2	3
Environmental organisation	26	16	25	22	24	24	29	17	20	13
Non-governmental organisation (NGO)	88	67	89	80	72	83	100	60	80	53
Trade union	6	8	6	6	5	5	7	5	6	4
Other	27	23	30	24	18	20	30	10	21	7
Public authority	29	27	30	32	23	29	34	20	32	6

Table 33: Challenges related to a higher 2030 climate ambition

Type of information	It will represent a significant investment challenge for EU industry, services, transport, and energy sectors. The costs of investments are likely to be passed on to consumers via higher prices or taxes	It will likely lead to a structural shift and changing skill requirements in the economy, in particular leading to a decline of sectors and jobs linked to fossil fuels extraction and carbon-intensive manufacturing	It will change the existing policy and will confront us with reduced lead-time for devising and implementing additional measures and for the economic actors to adjust.	The simultaneous transition to climate neutral, circular, and digital economy and society may lead to significant labour reallocation across sectors, occupations and regions. Businesses, especially SMEs could face challenges in re-skilling and ensuring sufficient workforce	It may lead to societal inequalities due to an initially higher cost of green products, sustainable food and transport and renewable energy, which may negatively impact the lower income people/regions and contribute to energy poverty	Even with a more ambitious 2030 target, it is difficult to ensure sufficient action to reduce greenhouse gas emissions on the ground	The EU, if acting alone, will lose out in terms of international competitiveness	Other
As an individual in a personal capacity	1 084	1 708	1 284	1 292	1 112	1 271	350	341
Of which:								
EU citizen	1 065	1 686	1 273	1 272	1 099	1 257	344	332
Non-EU citizen	19	22	11	20	13	14	6	9
In a professional capacity or on behalf of an organisation	362	376	274	314	246	228	219	199
Of which:								
Academic/research institution	26	31	17	31	18	18	12	4
Business association	119	80	78	68	69	59	87	69
Company/business organisation	109	103	81	77	60	71	78	56
Consumer organisation	6	3	3	4	4	1	1	1
Environmental organisation	8	19	15	13	8	11	1	10
Non-governmental organisation (NGO)	37	82	43	71	33	26	14	43
Trade union	5	7	4	5	6	3	6	4
Other	23	21	15	20	21	16	9	8
Public authority	29	30	18	25	27	23	11	4

9.3 Analytical methods

9.3.1 Description modelling tools used

9.3.1.1 Main modelling suite

The main model suite used to produce the scenarios presented in this impact assessment has a successful record of use in the Commission's energy and climate policy assessments. In particular, it has been used for the Commission's proposal for Long Term Strategy[1] as well as for the 2020 and 2030 EU's climate and energy policy framework.

The PRIMES and PRIMES-TREMOVE models are the core elements of the modelling framework for energy, transport and CO_2 emission projections. The GAINS model is used for non-CO_2 emission projections and the GLOBIOM-G4M models for projections of LULUCF emissions and removals and the CAPRI model is used for agricultural activity projections.

The model suite thus covers:

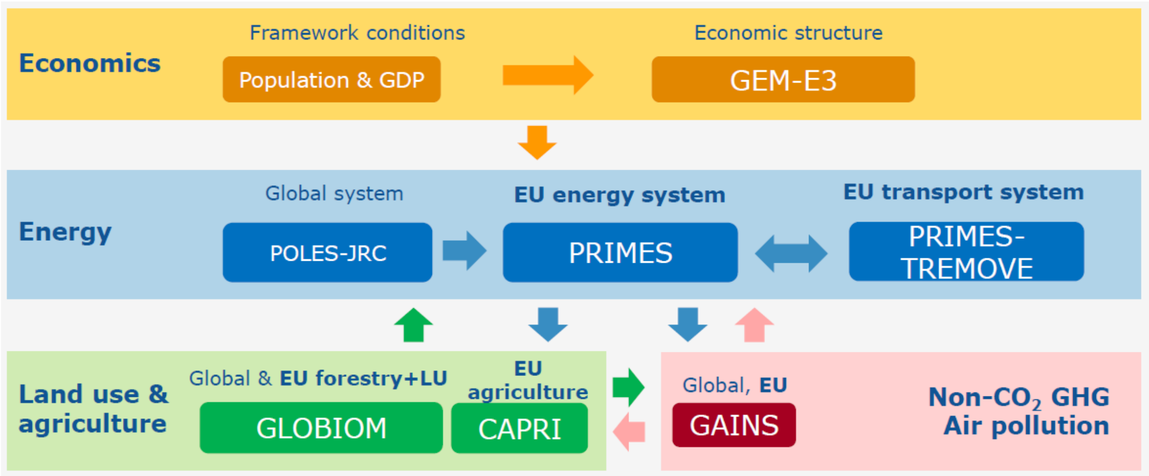
- **The entire energy system** (energy demand, supply, prices and investments to the future) and **all GHG emissions and removals** from the EU economy.
- **Time horizon:** 1990 to 2070 (5-year time steps).
- **Geography:** individually all EU Member States, EU candidate countries and, where relevant Norway, Switzerland and Bosnia and Herzegovina.
- **Impacts:** on the energy system (PRIMES and its satellite model on biomass), transport (PRIMES-TREMOVE), agriculture (CAPRI), forestry and land use (GLOBIOM-G4M), atmospheric dispersion, health and ecosystems (acidification, eutrophication) (GAINS); macro-economy with multiple sectors, employment and social welfare (GEM-E3).

The modelling suite was recently updated in the context of the in-depth analysis of the proposal for an EU Long Term Strategy, with addition of a new buildings module, improved representation of electricity sector, more granular representation of hydrogen and synthetic fuels produced with electricity ("e-fuels"), as well updated interlinkages of the models to improve land use and non-CO_2 modelling.

The models are linked with each other in such a way to ensure consistency in the building of scenarios (Figure 21). These inter-linkages are necessary to provide the core of the analysis, which are interdependent energy, transport and GHG emissions trends.

[1] https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf

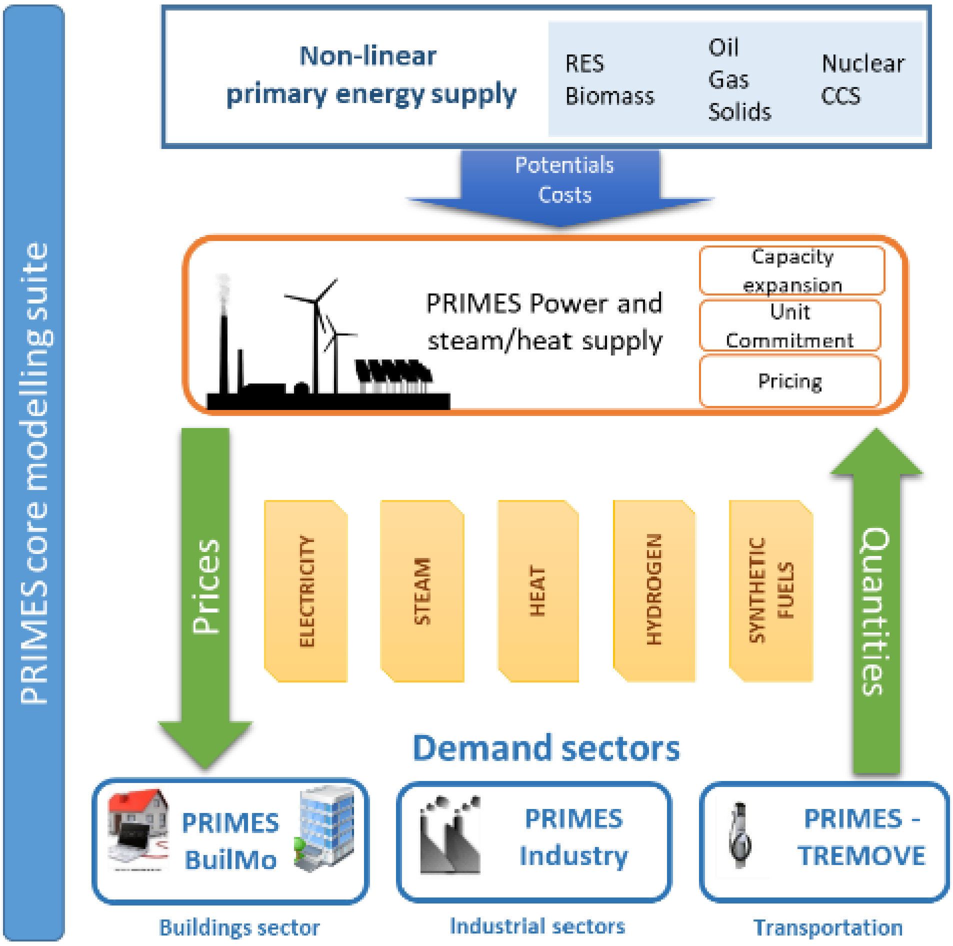
Figure 21: Interlinkages between models



9.3.1.1.1 Energy: the PRIMES model

The PRIMES model (Price-Induced Market Equilibrium System)[2] is a large scale applied energy system model that provides detailed projections of energy demand, supply, prices and investment to the future, covering the entire energy system including emissions. The distinctive feature of PRIMES is the combination of behavioural modelling (following a micro-economic foundation) with engineering aspects, covering all energy sectors and markets. The model has a detailed representation of instruments policy impact assessment related to energy markets and climate, including market drivers, standards, and targets by sector or overall. It simulates the EU Emissions Trading System in its current form. It handles multiple policy objectives, such as GHG emissions reductions, energy efficiency, and renewable energy targets, and provides pan-European simulation of internal markets for electricity and gas.

Figure 22: Schematic representation of the PRIMES model



PRIMES offer the possibility of handling market distortions, barriers to rational decisions, behaviours and market coordination issues and it has full accounting of costs (CAPEX and OPEX) and investment on infrastructure needs. The model covers the horizon up to 2070 in 5-

[2] More information and model documentation: https://e3modelling.com/modelling-tools/primes/

year interval periods and includes all Member States of the EU individually, as well as neighbouring and candidate countries. PRIMES is designed to analyse complex interactions within the energy system in a multiple agent – multiple markets framework.

Decisions by agents are formulated based on microeconomic foundation (utility maximization, cost minimization and market equilibrium) embedding engineering constraints and explicit representation of technologies and vintages; optionally perfect or imperfect foresight for the modelling of investment in all sectors.

PRIMES allows simulating long-term transformations/transitions and includes non-linear formulation of potentials by type (resources, sites, acceptability etc.) and technology learning. Figure 22 shows a schematic representation of the PRIMES model.

It includes a detailed numerical model on biomass supply, namely PRIMES-Biomass, which simulates the economics of supply of biomass and waste for energy purposes through a network of current and future processes. The model transforms biomass (or waste) feedstock, thus primary feedstock or residues, into bio-energy commodities which undergo further transformation in the energy system e.g. as input into power plants, heating boilers or fuels for transportation. The model calculates the inputs in terms of primary feedstock of biomass and waste to satisfy a given demand for bio-energy commodities and provides quantification of the required production capacity (for plants transforming feedstock into bioenergy commodities). Furthermore, all the costs resulting from the production of bioenergy commodities and the resulting prices are quantified. The PRIMES-Biomass model is a key link of communication between the energy system projections obtained by the core PRIMES energy system model and the projections on agriculture, forestry and non-CO_2 emissions provided by other modelling tools participating in the scenario modelling suite (CAPRI, GLOBIOM/G4M, GAINS).

PRIMES is a private model maintained by E3Modelling[3], originally developed in the context of a series of research programmes co-financed by the European Commission. The model has been successfully peer-reviewed, most recently in 2011[4]; team members regularly participate in international conferences and publish in scientific peer-reviewed journals.

Sources for data inputs

A summary of database sources, in the current version of PRIMES, is provided below:

- Eurostat and EEA: Energy Balance sheets, Energy prices (complemented by other sources, such IEA), macroeconomic and sectoral activity data (PRIMES sectors correspond to NACE 3-digit classification), population data and projections, physical activity data (complemented by other sources), CHP surveys, CO_2 emission factors (sectoral and reference approaches) and EU ETS registry for allocating emissions between ETS and non ETS
- Technology databases: ODYSSEE-MURE[5], ICARUS, Eco-design, VGB (power technology costs), TECHPOL – supply sector technologies, NEMS model database[6], IPPC BAT Technologies[7]

[3] E3Modelling (https://e3modelling.com/) is a private consulting, established as a spin-off inheriting staff, knowledge and software-modelling innovation of the laboratory E3MLab from the National Technical University of Athens (NTUA).

[4] SEC(2011)1569 : https://ec.europa.eu/energy/sites/ener/files/documents/sec_2011_1569_2.pdf

[5] https://www.odyssee-mure.eu/

- Power Plant Inventory: ESAP SA and PLATTS
- RES capacities, potential and availability: JRC ENSPRESO[8], JRC EMHIRES[9], RES ninja[10], ECN, DLR and Observer, IRENA
- Network infrastructure: ENTSOE, GIE, other operators
- Other databases: District heating surveys (e.g. from COGEN), buildings and houses statistics and surveys (various sources, including ENTRANZE project[11], INSPIRE archive, BPIE[12]), JRC-IDEES[13], update to the EU Building stock Observatory[14]

9.3.1.1.2 Transport: the PRIMES-TREMOVE model

The PRIMES-TREMOVE transport model projects the evolution of demand for passengers and freight transport, by transport mode, and transport vehicle/technology, following a formulation based on microeconomic foundation of decisions of multiple actors. Operation, investment and emission costs, various policy measures, utility factors and congestion are among the drivers that influence the projections of the model. The projections of activity, equipment (fleet), usage of equipment, energy consumption and emissions (and other externalities) constitute the set of model outputs.

The PRIMES-TREMOVE transport model can therefore provide the quantitative analysis for the transport sector in the EU, candidate and neighbouring countries covering activity, equipment, energy and emissions. The model accounts for each country separately which means that the detailed long-term outlooks are available both for each country and in aggregate forms (e.g. EU level).

In the transport field, PRIMES-TREMOVE is suitable for modelling *soft measures* (e.g. eco-driving, labelling); *economic measures* (e.g. subsidies and taxes on fuels, vehicles, emissions; ETS for transport when linked with PRIMES; pricing of congestion and other externalities such as air pollution; accidents and noise; measures supporting R&D); *regulatory measures* (e.g. CO_2 emission performance standards for new passenger and heavy duty vehicles; EURO standards on road transport vehicles; technology standards for non-road transport technologies, deployment of Intelligent Transport Systems) and *infrastructure policies for alternative fuels* (e.g. deployment of refuelling/recharging infrastructure for electricity, hydrogen, LNG, CNG). Used as a module that contributes to the PRIMES model energy system model, PRIMES-TREMOVE can show how policies and trends in the field of transport contribute to economy-wide trends in energy use and emissions. Using data disaggregated per Member State, the model can show differentiated trends across Member States.

The PRIMES-TREMOVE has been developed and is maintained by E3Modelling, based on, but extending features of, the open source TREMOVE model developed by the TREMOVE[15]

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[6] Source: https://www.eia.gov/outlooks/aeo/info_nems_archive.php
[7] Source: https://eippcb.jrc.ec.europa.eu/reference/
[8] Source: https://data.jrc.ec.europa.eu/collection/id-00138
[9] Source: https://data.jrc.ec.europa.eu/dataset/jrc-emhires-wind-generation-time-series
[10] Source: https://www.renewables.ninja/
[11] Source: https://www.entranze.eu/
[12] Source: http://bpie.eu/
[13] Source: https://ec.europa.eu/jrc/en/potencia/jrc-idees
[14] Source: https://ec.europa.eu/energy/en/eubuildings
[15] Source: https://www.tmleuven.be/en/navigation/TREMOVE

modelling community. Part of the model (e.g. the utility nested tree) was built following the TREMOVE model.[16] Other parts, like the component on fuel consumption and emissions, follow the COPERT model.

Data inputs

The main data sources for inputs to the PRIMES-TREMOVE model, such as for activity and energy consumption, comes from EUROSTAT database and from the Statistical Pocketbook "EU transport in figures[17]. Excise taxes are derived from DG TAXUD excise duty tables. Other data comes from different sources such as research projects (e.g. TRACCS project) and reports.

In the context of this exercise, the PRIMES-TREMOVE transport model is calibrated to 2005, 2010 and 2015 historical data.

9.3.1.1.3 Non-CO_2 GHG emissions and air pollution: GAINS

The GAINS (Greenhouse gas and Air Pollution Information and Simulation) model is an integrated assessment model of air pollutant and greenhouse gas emissions and their interactions. GAINS brings together data on economic development, the structure, control potential and costs of emission sources and the formation and dispersion of pollutants in the atmosphere.

In addition to the projection and mitigation of greenhouse gas emissions at detailed sub-sectorial level, GAINS assesses air pollution impacts on human health from fine particulate matter and ground-level ozone, vegetation damage caused by ground-level ozone, the acidification of terrestrial and aquatic ecosystems and excess nitrogen deposition of soils.

Model uses include the projection of non-CO_2 GHG emissions and air pollutant emissions for EU Reference scenario and policy scenarios, calibrated to UNFCCC emission data as historical data source. This allows for an assessment, per Member State, of the (technical) options and emission potential for non-CO_2 emissions. Health and environmental co-benefits of climate and energy policies such as energy efficiency can also be assessed.

The GAINS model is accessible for expert users through a model interface[18] and has been developed and is maintained by the International Institute of Applied Systems Analysis[19]. The underlying algorithms are described in publicly available literature. GAINS and its predecessor RAINS have been peer reviewed multiple times, in 2004, 2009 and 2011.

Sources for data inputs

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[16] Several model enhancements were made compared to the standard TREMOVE model, as for example: for the number of vintages (allowing representation of the choice of second-hand cars); for the technology categories which include vehicle types using electricity from the grid and fuel cells. The model also incorporates additional fuel types, such as biofuels (when they differ from standard fossil fuel technologies), LPG, LNG, hydrogen and e-fuels. In addition, representation of infrastructure for refuelling and recharging are among the model refinements, influencing fuel choices. A major model enhancement concerns the inclusion of heterogeneity in the distance of stylised trips; the model considers that the trip distances follow a distribution function with different distances and frequencies. The inclusion of heterogeneity was found to be of significant influence in the choice of vehicle-fuels especially for vehicles-fuels with range limitations.

[17] Source: https://ec.europa.eu/transport/facts-fundings/statistics_en

[18] Source: http://gains.iiasa.ac.at/models/

[19] Source: http://www.iiasa.ac.at/

The GAINS model assess emissions to air for given externally produced activity data scenarios. For Europe, GAINS uses macroeconomic and energy sector scenarios from the PRIMES model, for agricultural sector activity data GAINS adopts historical data from EUROSTAT and aligns these with future projections from the CAPRI model. Projections for waste generation, organic content of wastewater and consumption of F-gases are projected in GAINS in consistency with macroeconomic and population scenarios from PRIMES. For global scenarios, GAINS uses macroeconomic and energy sector projections from IEA World Energy Outlook scenarios and agricultural sector projections from FAO. All other input data to GAINS, i.e., sector- and technology- specific emission factors and cost parameters, are taken from literature and referenced in the documentation.

9.3.1.1.4 Forestry and land-use: GLOBIOM-G4M

The Global Biosphere Management Model (GLOBIOM) is a global recursive dynamic partial equilibrium model integrating the agricultural, bioenergy and forestry sectors with the aim to provide policy analysis on global issues concerning land use competition between the major land-based production sectors. Agricultural and forestry production as well as bioenergy production are modelled in a detailed way accounting for about 20 globally most important crops, a range of livestock production activities, forestry commodities as well as different energy transformation pathways.

GLOBIOM covers 50 world regions / countries, including the EU27 Member States.

Model uses include the projection of emissions from land use, land use change and forestry (LULUCF) for EU Reference scenario and policy scenarios. For the forestry sector, emissions and removals are projected by the Global Forestry Model (G4M), a geographically explicit agent-based model that assesses afforestation, deforestation and forest management decisions. GLOBIOM-G4M is also used in the LULUCF impact assessment to assess the options (afforestation, deforestation, forest management, and cropland and grassland management) and costs of enhancing the LULUCF sink for each Member State.

The GLOBIOM-G4M has been developed and is maintained by the International Institute of Applied Systems Analysis[20].

<u>Sources for data inputs</u>

The main market data sources for GLOBIOM-EU are EUROSTAT and FAOSTAT, which provide data at the national level and which are spatially allocated using data from the SPAM model[21]. Crop management systems are parameterised based on simulations from the biophysical process-based crop model EPIC. The livestock production system parameterization relies on the dataset by Herrero et al[22]. Further datasets are incorporated, coming from the scientific literature and other research projects.

GLOBIOM is calibrated to FAOSTAT data for the year 2000 (average 1998 - 2002) and runs recursively dynamic in 10-year time-steps. In the context of this exercise, baseline trends of

[20] Source : http://www.iiasa.ac.at/

[21] See You, L., Wood, S. (2006). An Entropy Approach to Spatial Disaggregation of Agricultural Production, Agricultural Systems 90, 329–47 and http://mapspam.info/ .

[22] Herrero, M., Havlík, P., et al. (2013). Biomass Use, Production, Feed Efficiencies, and Greenhouse Gas Emissions from Global Livestock Systems, Proceedings of the National Academy of Sciences 110, 20888–93.

agricultural commodities are aligned with FAOSTAT data for 2010/2020 and broadly with AGLINK-COSIMO trends for main agricultural commodities in the EU until 2030.

The main data sources for G4M are CORINE, Forest Europe (MCPFE, 2015)[23], countries' submissions to UNFCCC and KP, FAO Forest Resource Assessments, and national forest inventory reports. Afforestation and deforestation trends in G4M are calibrated to historical data for the period 2000-2013.

9.3.1.1.5 Agriculture: CAPRI

CAPRI is a global multi-country agricultural sector model, supporting decision making related to the Common Agricultural Policy and environmental policy and therefore with far greater detail for Europe than for other world regions. It is maintained and developed in a network of public and private agencies including the European Commission (JRC), Universities (Bonn University, Swedish University of Agricultural Sciences, Universidad Politécnica de Madrid), research agencies (Thünen Institute), and private agencies (EuroCARE, in charge for use in this modelling cluster); the model takes inputs from GEM-E3, PRIMES and PRIMES Biomass model, provides outputs to GAINS, and exchanges information with GLOBIOM on livestock, crops, and forestry as well as LULUCF effects.

The CAPRI model provides the agricultural outlook for the Reference Scenario, in particular on livestock and fertilisers use, further it provides the impacts on the agricultural sector from changed biofuel demand. Depending on need it may also be used to run climate mitigation scenarios, diet shift scenarios or CAP scenarios.

Cross checks are undertaken ex-ante and ex-post to ensure consistency with GLOBIOM on overlapping variables, in particular for the crop sector.

Sources for data inputs

The main data source for CAPRI is EUROSTAT. This concerns data on production, market balances, land use, animal herds, prices, and sectoral income. EUROSTAT data are complemented with sources for specific topics (like CAP payments or biofuel production). For Western Balkan regions a database matching with the EUROSTAT inputs for CAPRI has been compiled based on national data. For non-European regions the key data source is FAOSTAT, which also serves as a fall back option in case of missing EUROSTAT data. The database compilation is a modelling exercise on its own because usually several sources are available for the same or related items and their reconciliation involves the optimisation to reproduce the hard data as good as possible while maintaining all technical constraints like adding up conditions.

In the context of this exercise, the CAPRI model uses historical data series at least up to 2017, and the first simulation years (2010 and 2015) are calibrated to reproduce the historical data as good as possible.

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[23] MCPFE (2015). Forest Europe, 2015: State of Europe's Forests 2015. Madrid, Ministerial Conference on the Protection of Forests in Europe: 314.

9.3.1.1.6 Global climate and energy policy context: POLES-JRC

The POLES-JRC model used to provide the global energy and climate policy context is operated by the JRC[24].

POLES is a global energy model that covers the entire energy balance, from final energy demand, transformation and power production to primary supply and trade of energy commodities across countries and regions. It allows assessing the contribution to future energy needs of the various energy types (fossil fuels, nuclear, renewables) and energy vectors.

In addition, it calculates the evolution of GHG emissions: endogenously for the energy-industry sectors and through linkage with specialist models for GHG emissions from land-use and agriculture (GLOBIOM-G4M), and air pollution (GAINS).

The model includes a detailed geographical representation, with a total of 39 non-EU27 regions and countries covering the world; that includes all G20 countries, detailed OECD and the main non-OECD economies. It operates on a yearly time step, allowing integrating recent developments.

The POLES model is well suited to evaluate the evolution of energy demand in the main world economies and international markets as well as to assess international climate and energy policies. The POLES model has participated in numerous research projects, and has contributed to peer-reviewed analyses published widely[25].

Sources for data inputs[26]

Data on socio-economic activity come from the UN and IIASA (population), the World Bank, IMF and OECD (GDP and economic activity), sectoral databases on industrial and mobility activity.

The main energy data sources of the POLES-JRC model are IEA, Enerdata, BGR, USGS, Platts, BP, NEA.

Fossil energy production costs are based on Rystad, complemented by information from the literature. Renewables potentials are based on NREL, DLR, and GLOBIOM, complemented by information from the literature. The technology costs and learning curves are based on extensive literature review, including but not limited to IEA and the SETIS database.

Emissions data are for UNFCCC, EDGAR, National inventories, FAO.

POLES-JRC work developed for this exercise is based on JRC work for the Global Energy and Climate Outlook (GECO) report series[27]. The POLES-JRC model was updated with historical data up to 2018 (population, GDP, energy balances) and 2019 (international energy prices, GDP projections). It includes country policies that have been legislated as of June 2019 or correspond to objectives found in the UNFCCC's Nationally Determined Contributions.

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24 https://ec.europa.eu/jrc/en/poles

25 https://ec.europa.eu/jrc/en/poles/publications

26 For non-EU. Sources for the EU are consistent with those of the PRIMES energy model.

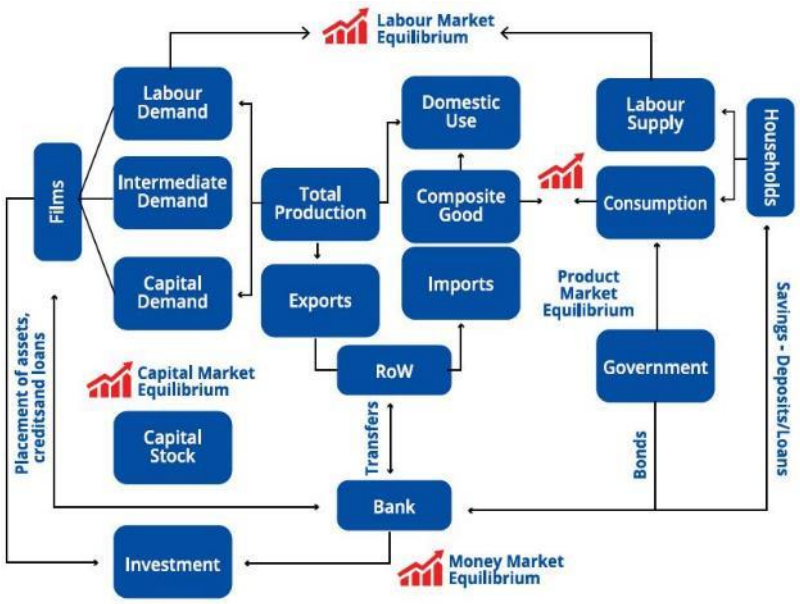
27 https://ec.europa.eu/jrc/en/geco

9.3.1.2 Economic analysis

9.3.1.2.1 GEM-E3

GEM-E3 is a large scale multi-sectoral CGE model that features a series of modelling innovations that enables its departure from the constraining framework of standard/textbook CGE models (where all resources are assumed to be fully used) to a modelling system that features a more realistic representation of the complex economic system. The key innovations of the model relate to the explicit representation of the financial sector, semi-endogenous dynamics based on R&D induced technical progress and knowledge spillovers, the representation of multiple households, unemployment in the labour market and endogenous formation of labour skills. The model has detailed sectoral and geographical coverage, with 51 products and 46 countries/regions (global coverage) and it is calibrated to a wide range of datasets comprising of IO tables, financial accounting matrices, institutional transactions, energy balances, GHG inventories, bilateral trade matrices, investment matrices and household budget surveys. All countries in the model are linked through endogenous bilateral trade transactions identifying origin and destination. Particular focus is placed on the representation of the energy system where specialised bottom-up modules of the power generation, buildings and transport sectors have been developed. The model is recursive dynamic coupled with a forward-looking expectations mechanism and produces projections of the economic and energy systems until 2100 in increasing time steps: annual from 2015 to 2030 and then five-year period until 2100. Figure 23 shows a schematic representation of the GEM-E3 model.

Figure 23: Schematic representation of the GEM-E3 model



The model has been used to provide the sectoral economic assumptions as input for this Impact Assessment. GEM-E3 produces consistent sectorial value added and trade projections matching GDP and population projections by country taken from other sources such as the ECFIN t+10 projections for economic activity, the Europop and the Ageing Report. The model can also be used to assess the impacts of the energy and climate targets on macroeconomic aggregates such as GDP and employment.

The most important results, provided by GEM-E3 are: Full Input-Output tables for each country/region identified in the model, dynamic projections in constant values and deflators of national accounts by country, employment by economic activity and by skill and unemployment rates, capital, interest rates and investment by country and sector, private and public consumption, bilateral trade flows, consumption matrices by product and investment matrix by ownership branch, GHG emissions by country, sector and fuel and detailed energy system projections (energy demand by sector and fuel, power generation mix, deployment of transport technologies, energy efficiency improvements).

This Impact Assessment has used mainly the European Commission's JRC version JRC-GEM-E3[28], complemented by the GEM-E3-FIT version operated by E3Modelling[29]. Detailed documentation is publicly available.

Sources[30] for data inputs

- EUROSTAT, WIOD, EU-KLEMS and GTAP: Input Output tables, National Accounts, Employment, Institutional Transactions, Labour force and Participation rates, Bilateral Trade, GHG emissions, Capital stock, taxes, Household consumption by purpose
- National Statistical Offices: Consumption Matrices
- ECB: Bonds, Treasury bills
- ILO: Employment, Unemployment rate
- World Bank: Infrastructure
- IMF and OECD: Interest rates, Inflation, Bonds, Treasury bills

9.3.1.2.2 E3ME

E3ME[31] [32] is a global, macro-econometric model designed to address major economic and economy-environment policy challenges.

It includes:

- a high level of disaggregation, enabling detailed analysis of sectoral and country-level effects from a wide range of scenarios;
- a capacity to describe social impacts (including unemployment levels and distributional effects).

Its econometric specification provides a strong empirical basis for analysis. It can fully assess both short and long-term impacts.

Integrated treatment of the world's economies, energy systems, emissions and material demands. This enables it to capture two-way linkages and feedbacks between these components.

E3ME covers 61 global regions, with a detailed sectoral disaggregation in each one, and projects forwards annually up to 2050. It is frequently applied at national level, in Europe and beyond, as well as for global policy analysis.

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[28] Source: https://ec.europa.eu/jrc/en/gem-e3/model
[29] Source: https://e3modelling.com/
[30] The data sources of energy statistics are the same as in the PRIMES model.
[31] https://www.camecon.com/how/e3me-model/
[32] https://www.e3me.com/

9.3.1.2.3 QUEST

QUEST[33] is the global macroeconomic model that the Directorate General for Economic and Financial Affairs (DG ECFIN) uses for macroeconomic policy analysis and research. It is a structural macro-model in the New-Keynesian tradition with rigorous microeconomic foundations derived from utility and profit optimisation and including frictions in goods, labour and financial markets.

There are different versions of the QUEST model, estimated and calibrated, each used for specific purposes. Model variants have been estimated using Bayesian methods, jointly with colleagues at the Commission's Joint Research Centre (JRC). These dynamic stochastic general equilibrium (DSGE) models are used for shock analyses and shock decompositions, for example to assess the main drivers of growth and imbalances.

Larger multi-country calibrated model versions are used to address issues for which a deeper level of disaggregation is required, both at the regional and sector level. Many of the main applications deal with fiscal and monetary policy interactions and either use a one-sector model or models that explicitly distinguish tradable and non-tradable sectors.

Other model variants also include housing and collateral constraints, and a banking sector. All calibrated model versions are employed using different country disaggregations, focussing on the euro area or EU as a whole, and other global regions, or on individual member states.

For the analysis of structural reforms an extended version of the QUEST model is used. This model captures both investment in tangibles and intangibles, and disaggregates employment into three skill categories. In this model variant technological change is semi-endogenous.

In this impact assessment we used the E-QUEST model variant which is a two-region, multisector model specifically developed for climate and energy related policy analysis. The main innovation in this model compared to the standard DSGE models is the inclusion of energy-input substitution that allows for a more detailed description of the substitution possibilities between different energy sources. Firms have limited substitution possibilities between "dirty" and "clean" capital-energy bundles. In the "dirty" capital-energy bundle, capital is combined with fossil fuel based energy while in the clean "bundle" electricity is required to use the corresponding capital.

9.3.2 Assumptions on technology, economics and energy prices

In order to reflect the fundamental socio-economic, technological and policy developments, the Commission prepares periodically an EU Reference Scenario on energy, transport and GHG emissions. The latest one dates from 2016[34] and is currently being revised. This update is not yet finalised and work is ongoing on Member States details and the related consultations. Furthermore this work will also be updated to incorporate the impacts of the COVID-19 crisis.

The scenarios assessment as used in this impact assessment incorporate the latest developments in the update of the Reference scenario, notably related to the socio-economic assumptions, energy price projections and technological assumptions.

[33] https://ec.europa.eu/info/business-economy-euro/economic-and-fiscal-policy-coordination/economic-research/macroeconomic-models_en

[34] https://ec.europa.eu/energy/data-analysis/energy-modelling/eu-reference-scenario-2016_en

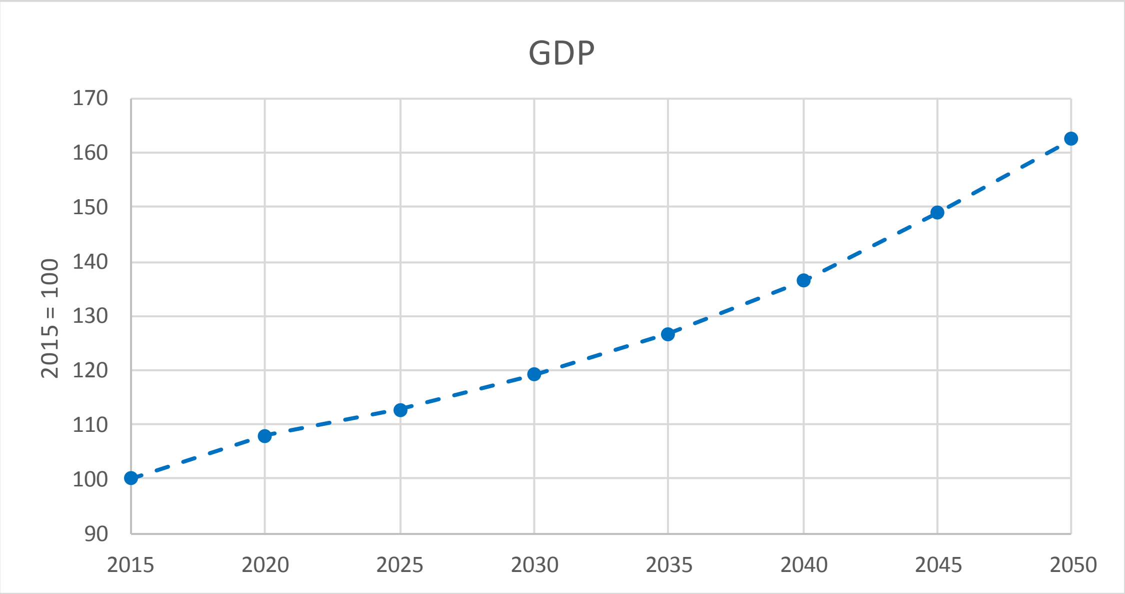
9.3.2.1 Economic assumptions

The modelling work is based on socio-economic assumptions describing the expected evolution of the European society. Long-term projections on population dynamics and economic activity form part of the input to the energy model and are used to estimate final energy demand. Population projections from Eurostat[35] are used to estimate the evolution of the European population that is projected to change very little in total number in the coming decades.

- Pre-COVID economic assumptions

The pre-COVD socio-economic assumptions were prepared before the COVID pandemic unfolded. The long-term evolution of economic activity was estimated from three sources: DG ECFIN's short term economic forecast, t+10 projections and the 2018 Aging Report projections elaborated by the European Commission. For the short-term (2020-2021), the projections are based on actual growth forecast by the Directorate General for Economic and Financial Affairs (Autumn Forecast 2019). Projections up to 2029 use the associated t+10 work from DG ECFIN, which is based on projections of potential output growth and a closure of any output gap in the medium term. The long-term per capita GDP growth projections of the 2018 Ageing Report are used for the period 2030-2070[36]. Figure 24 shows the projected evolution of the EU GDP up to 2050. Assumptions on transport activity complement the socio-economic projections.

Figure 24: Projected EU GDP (2015 = 100)



These pre-COVID socio-economic assumptions were used as modelling inputs for all scenario runs, except COVID-BSL and COVID-MIX.

- Post-COVID assumptions

[35] https://ec.europa.eu/eurostat/web/population-demography-migration-projections/population-projections-data

[36] The 2018 Ageing Report: Economic and Budgetary Projections for the EU Member States (2016-2070): https://ec.europa.eu/info/publications/economy-finance/2018-ageing-report-economic-and-budgetary-projections-eu-member-states-2016-2070_en

As described in section 6.4.3, the COVID-19 health crisis upended economic projections made in preparation of this impact assessment. In particular, the Commission's Spring Economic Forecast 2020 projected that the EU economy would contract by 7.4% in 2020 and pick up in 2021 with growth of 6.1%. Together with the associated revision of DG ECFIN's t+10 projections, this implies that real GDP in 2030 could be approximately 2.3% lower compared to the pre-COVID estimates presented above, based on the Autumn Forecast 2019.

The socio-economic assumptions that will be used for the Reference Scenario update will be fully updated to reflect the impact of the COVID-19 pandemic.

Beyond the update of the population and growth assumptions, an update of the projections on the sectoral composition of GDP was also carried out. This aims to integrate the potential medium- to long-term impacts of the COVID-19 crisis on the structure of the economy, even though this is clouded with uncertainty. Annex 9.10.1.3 provides more background on what such impacts might be.

9.3.2.2 Energy prices assumptions

Alongside socio-economic projections, EU energy modelling requires projections of international fuel prices. The projections of the POLES-JRC model (see annex 9.3.1.1) – elaborated by the Joint Research Centre in the context of the Global Energy and Climate Outlook 2019 (GECO 2019) – are used to obtain long-term estimates of the international fuel prices. The projected evolution of fossil fuel prices is lower than estimates used by the European Commission in the Reference 2016 Scenario. Among other factors, as discussed in annex 9.10.5 the development of unconventional oil and gas resources increased fossil fuel supply estimates for the coming decade.

Table 34 shows the international fuel prices that were used in the different "pre-COVID" scenarios (BSL, MIX-50, REG, MIX, CPRICE, ALLBNK, the MIX-nonCO2 variant, EU-NECP variant).

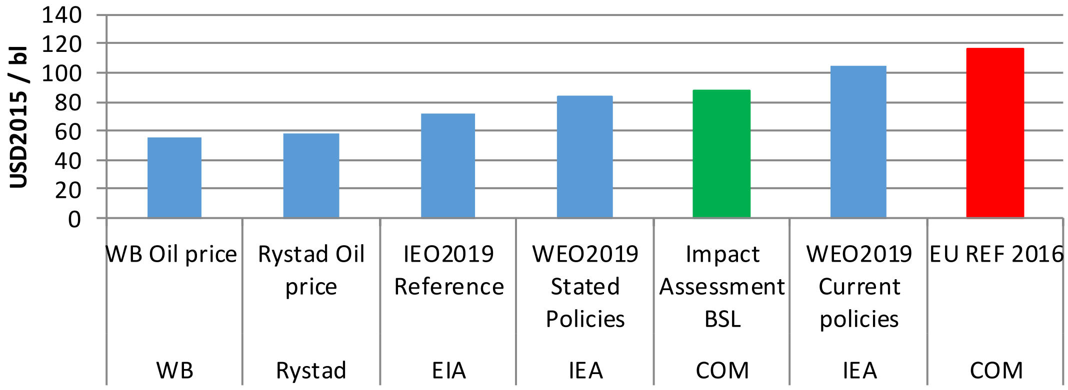
Table 34: International fuel prices assumptions – non-COVID scenarios

in $'15 per boe	**2000**	**'05**	**'10**	**'15**	**'20**	**'25**	**'30**	**'35**	**'40**	**'45**	**'50**
Oil	38.4	65.4	86.7	52.3	58.0	73.2	86.9	93.9	100.8	110.4	125.5
Gas (NCV)	26.5	35.8	45.8	43.7	35.7	39.9	41.8	47.9	57.3	56.7	58.9
Coal	11.2	16.9	23.2	13.1	13.2	16.9	18.4	19.8	20.8	21.8	22.8
in €'15 per boe	**2000**	**'05**	**'10**	**'15**	**'20**	**'25**	**'30**	**'35**	**'40**	**'45**	**'50**
Oil	34.6	58.9	78.2	47.2	52.3	66.0	78.3	84.7	90.9	99.5	113.2
Gas (NCV)	23.4	31.7	40.6	38.7	31.6	35.4	37.0	42.4	50.7	50.2	52.1
Coal	9.9	15.0	20.6	11.6	11.7	14.9	16.3	17.5	18.4	19.3	20.1

Source: JRC, POLES-JRC model, derived from GECO 2019

In order to obtain robust results, international fuel price assumptions were compared to the similar projections from several sources. Figure 25 shows the comparison between projected oil prices in 2030 and estimates from selected studies by international organizations: Rystad, World Bank, Energy Information Administration, International Energy Agency. The price used in the EU Reference Scenario 2016[37] is also reported for comparison.

Figure 25: Oil price projections in 2030 according to various sources



Note: Rystad and World Bank estimates as of 2019

The COVID crisis has had a major impact on international fuel prices (see also annex 9.10.1.3). In the months following the first wave of outbreaks, a majority of countries across the world enacted lockdowns, hence limiting transport of people and goods and changing work pattern. This impacted energy demand with a historic shock only seen worse during the Spanish flu, the Great Depression and World War II.[38] The demand decrease during the 2008 financial crisis came nowhere near the impact of COVID. The lost demand left an oversupply leading to decreasing prices.

This impact hit oil first and foremost, being the main fuel for transport (culminating in negative oil prices in one occurrence). Coal consumption also decreased sharply due to lower electricity demand. In general, fossil fuels were most strongly affected. This effect on prices compared to pre-COVID estimates is expected to be still felt up to 2030, although this will depend on the recovery of global oil demand as well as on the compliance with the OPEC+ existing and possible future deals[39] to adjust supply.

Table 35 shows the alternative assumptions retained to reflect the COVID impact on the fuel prices in the two COVID scenarios analysed in this impact assessment (COVID-BSL and COVID-MIX).

[37] https://ec.europa.eu/energy/data-analysis/energy-modelling/eu-reference-scenario-2016_en
[38] IEA, Global Energy Review 2020, June 2020
[39] IEA, Oil Market Report, June 2020 and US EIA, July 2020.

Table 35: International fuel prices assumptions – COVID scenarios

in $'15 per boe	**2000**	**'05**	**'10**	**'15**	**'20**	**'25**	**'30**	**'35**	**'40**	**'45**	**'50**
Oil	38.4	65.4	86.7	52.3	37.2	58.6	80.1	90.4	97.4	105.6	117.9
Gas (NCV)	26.5	35.8	45.8	43.7	22.2	31.5	40.9	44.9	52.6	57.0	57.8
Coal	11.2	16.9	23.2	13.1	10.1	13.9	17.6	19.1	20.3	21.3	22.3
in €'15 per boe	**2000**	**2005**	**'10**	**'15**	**'20**	**'25**	**'30**	**'35**	**'40**	**'45**	**'50**
Oil	34.6	58.9	78.2	47.2	33.5	52.8	72.2	81.5	87.8	95.2	106.3
Gas (NCV)	23.4	31.7	40.6	38.7	19.7	27.9	36.2	39.7	46.6	50.5	51.2
Coal	9.9	15.0	20.6	11.6	8.9	12.3	15.6	16.9	18.0	18.9	19.7

Source: Estimates, derived from JRC, POLES-JRC model, GECO 2019

9.3.2.3 Technology assumptions

Modelling scenarios on the evolution of the energy system is highly dependent on the assumptions on the development of technologies - both in terms of performance and costs. For the purpose of this impact assessment, these assumptions have been updated based on a rigorous literature review carried out by external consultants in collaboration with the JRC[40].

Continuing the approach adopted in the long-term strategy in 2018, the Commission consulted technology assumption with stakeholders in 2019. In particular, the technology database of the main model suite (PRIMES, PRIMES-TREMOVE, GAINS, GLOBIOM, and CAPRI) benefited from a dedicated consultation workshop held on 16th May 2018 and a more recent one on 11th November 2019. EU Member States representatives had also the opportunity to comment on the costs elements during a workshop held on 25th November 2019. The updated list of technology assumptions will be published together with the upcoming Reference Scenario update.

9.3.3 The existing 2030 framework scenario (BSL) and the EU National Energy and Climate Plans scenario (EU-NECP) variant

9.3.3.1 Policies in the existing policies scenario (BSL)

In order to assess the trajectory that is entailed by the recent policies and objectives adopted at EU level, a Baseline scenario (BSL) was developed.

It assumes that measures are taken either at EU or MS level in order to achieve the energy and climate 2030 targets[41], as adopted by EU leaders on October 2014[42], further refined on May 2018 with the agreement on the Effort Sharing Regulation and enhanced on June 2018 with the agreement on the recast of Renewable Energy Directive and the revised Energy Efficiency Directive.

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[40] JRC118275

[41] The 2030 climate and energy framework did set three key targets for the year 2030: (a) at least 40% cuts in greenhouse gas emissions (from 1990 levels), (b) at least 27% share for renewable energy, and (c) at least 27% improvement in energy efficiency. They built on the 2020 climate and energy package.

[42] Conclusions of the European Council of 23 and 24 October 2014.

In addition to the headline targets, some of the policies included in this baseline are:

- The EU Emissions Trading System[43] (EU ETS) covers 45% of EU greenhouse gas emissions, notably from industry, the power sector and aviation. Emissions for the ensemble of sectors under the system are capped to reduce by 43% by 2030 compared to 2005. The baseline scenario additionally assumes that the Market Stability Reserve will ensure that the ETS contributes to the achievement of the overall target cost-effectively. MSR functioning is set to be reviewed[44] in 2021 and every five years after to ensure its aim of tackling structural supply-demand imbalances.
- Aviation emissions are also covered by the EU ETS. The EU, however, decided in 2014 to limit the scope of the EU ETS to flights within the EEA until 2016 to support the development of a global measure by the International Civil Aviation Organization (ICAO).[45] In light of the adoption of a Resolution by the 2016 ICAO Assembly on the global measure, the EU has decided to maintain the geographic scope of the EU ETS limited to intra-EEA flights from 2017 until the end of 2023.[46] The EU ETS for aviation will be subject to a new review in the light of the international developments related to the operationalisation of CORSIA. The next review should consider how to implement the global measure in Union law through a revision of the EU ETS legislation. In the absence of a new amendment, the EU ETS would revert back to its original full scope from 2024.
- The Effort Sharing Regulation[47] (ESR) sets binding annual reduction targets for member states, with an aim to reduce emissions by 30% compared to 2005 by 2030. The ESR targets are set according to national wealth and cost-effectiveness. The ESR allows for flexibilities such as transfers between member states.
- The Land Use, Land Use Change and Forestry Regulation[48] (LULUCF regulation), whereby accounted emissions should not exceed removals and that includes incentive to improve land use practices, flexibility and trading, flexibility towards ESR.
- CO_2 emission standards for new cars and vans[49] and for new trucks[50] have been defined, and will contribute towards reducing emissions from the road transport sector.
- The Fuel Quality Directive[51] requires a reduction of the greenhouse gas intensity of transport fuels by a minimum of 6% to be achieved by 2020.
- The revised Renewable Energy Directive[52] entered into force in 2018. It establishes a new binding renewable energy target for the EU for 2030 of at least 32%, with a clause for a possible upwards revision by 2023.
- The Energy Efficiency Directive was amended in 2018[53] establishing a target of at least 32.5% for 2030. This means in absolute terms, that EU energy consumption should be no

[43] Directive 2003/87/EC
[44] Decision (EU) 2015/1814
[45] Regulation (EU) 421/2014
[46] Regulation (EU) 2017/2392
[47] Regulation (EU) 2018/842
[48] Regulation (EU) 2018/841
[49] Regulations (EU) 2019/631
[50] Regulation (EU) 2019/1242
[51] Directive 2009/30/EC
[52] Directive 2018/2001/EU
[53] Amendment 2018/2002 of Directive 2012/27/EU

more than 1128 Mtoe of primary energy and no more than 846 Mtoe of final energy.[54] The directive allows for a possible upward revision in the target in 2023.

- The Energy Performance of Buildings Directive and its amendment in 2018[55] aim to achieve a highly energy efficient and decarbonised building stock and to create a stable environment for investment decisions. It established an obligation for Member States to present long-term renovation strategies, aiming at decarbonising the national building stocks by 2050, with indicative milestones for 2030 and 2040.
- The Ecodesign and Energy Labelling Directives establish a framework for a set of regulations to improve the energy efficiency of different product categories. They help eliminate the least performing products from the market, and support competitiveness and harmonised standards throughout the internal market.
- In the field of transport, besides the post-2020 CO_2 standards for new light duty and heavy duty vehicles, the Clean Vehicles Directive and the Directive on the deployment of alternative fuels infrastructure contribute to the roll-out of recharging infrastructure. Furthermore, the uptake of sustainable alternative fuels is supported by the Renewables Energy Directive and Fuel Quality Directive. Improvements in transport system efficiency (by making the most of digital technologies and smart pricing and further encouraging multi-modal integration and shifts towards more sustainable transport modes) are facilitated by e.g. the TEN-T Regulation supported by CEF funding, the fourth Railway Package, the proposed revision of the Eurovignette Directive, the Directive on Intelligent Transport Systems, the European Rail Traffic Management System European deployment plan, the Regulation establishing a framework for the provision of port services, and others.
- For aviation, in addition to implementation of the EU Emission Trading Scheme, Baseline reflects the Union-wide air transport performance targets for the key performance area of environment, Clean Sky, Single European Sky and SESAR, and aeroplane CO_2 emissions standards, as part of the so-called “basket of measures” that aim to reduce emissions from the sector.
- For maritime shipping, in addition to emissions being monitored under the Regulation on Monitoring, Reporting and Verification of Maritime Emissions[56], the Baseline scenario reflects the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP) adopted by the International Maritime Organisation, as well as the Sulphur Directive. The Baseline also accounts for other initiatives addressing air pollution from inland waterways vessels, as well as road safety, and thus reducing the external costs of transport.

In addition, these policies will continue pushing further GHG emissions reduction, and increasing energy savings and renewable energies deployment after 2030, either because they do not have a "sunset clause" (notably ETS, and since recently, Article 7 in revised EED), or because of the technological learning and cost reductions that they are expected to induce. Moreover, most actions in the energy system have long-term impacts (e.g. construction of well-insulated houses,

[54] This takes into account the withdrawal of the United Kingdom and the Commission decision for an equivalent target after EU law no longer applies to the United Kingdom.
[55] Directive 2010/31/EU and amendement 2018/844/EU
[56] Regulation (EU) 2015/757

efficient power plants or other types of infrastructure). The baseline captures these dynamics, but it needs to be emphasised that no intensification of policies post-2030 was assumed and no target for GHG emissions reduction in 2050 was set concerning climate neutrality.

Moreover, BSL has been specifically built for the purpose of the development of long-term decarbonisation scenarios. It does not reflect specific, short-term Member State policies, and, in particular, no consultation with the Member States has taken place to verify that current or updated policies are adequately represented, as currently being included under the NECPs. This is done under the Reference Scenario 2020 exercise, conducted in parallel with the work for this impact assessment.

Beyond specific climate and energy policies, a range of other policies will definitely play an important role in achieving reductions of greenhouse gas emissions of the EU economy.

First of all, some sectoral policies will affect directly the dynamics of GHG emission. This is the case of transport and industrial policies for instance, which will affect notably the way and the forms in which energy is consumed, and thus will modify associated GHG emissions. Agricultural policy and waste policy will play an important role on sectoral methane and nitrous oxide emissions, two powerful greenhouse gases, and will also contribute to the supply of renewable fuels to the energy sector, and thus to its capacity to mitigate GHG (and notably CO_2) emissions.

Second, other, more "horizontal", policies are to play an indirect, but crucial, role in shaping the capacity of the EU economy to deliver GHG reductions. Such policies are often referred to as "enabling policies" and aim at ensuring a favourable environment for the transformation. They relate to the steering of investments, technological development, economic adaptation, and are critical to guarantee social inclusiveness.

This Commission has launched in 2020 a number of key initiatives that are relevant for this assessment:

- the European Green Deal Investment Plan[57]
- the European Industrial Strategy[58]
- the Circular Economy Action Plan[59]
- the Farm to Fork Strategy[60]
- the EU Biodiversity Strategy for 2030[61]

These policies have not be considered in the baseline, but they will contribute to achieving a higher climate target, and are thus reflected in the policy analysis.

A key element to play a role on the evolution by 2030 of GHG emissions in the EU is the MFF[62] for 2021-2027, which is being negotiated. A number of policies and funding tools under this framework matter for the GHG profile, notably to steer investments towards the climate

[57] https://ec.europa.eu/commission/presscorner/detail/en/qanda_20_24
[58] COM(2020) 102 final,
[59] COM(2020) 98 final
[60] COM(2020) 381 final
[61] COM(2020) 380 final
[62] In May 2020, the Commission has proposed a powerful, modern and revamped long-term EU budget boosted by Next Generation EU - see COM(2020) 442 final

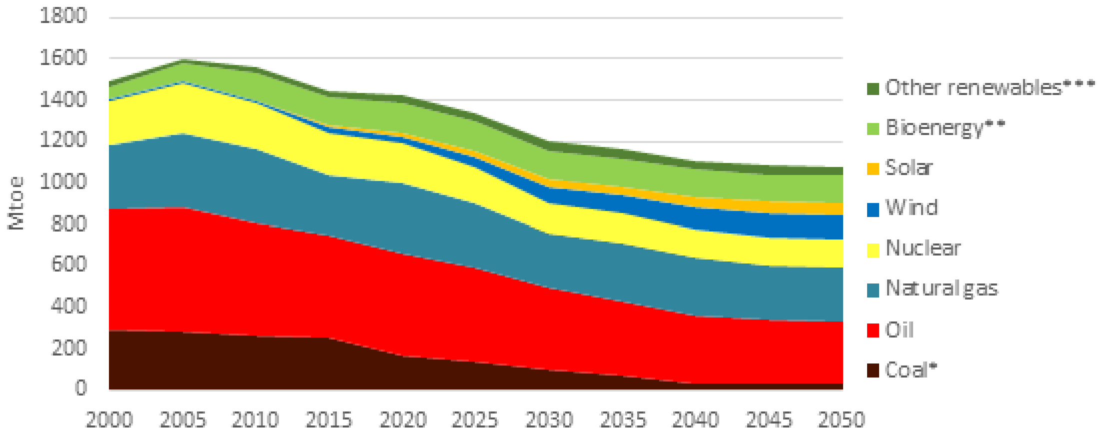
objective, to accelerate research and development on clean solutions with Horizon Europe[63] or through the ambitious CAP strategic plans[64].

Finally, BSL considers key national policies that are existing or reflected in the national NECPs.

9.3.3.2 Existing policies scenario (BSL) and COVID-BSL scenario

In BSL, gross inland consumption[65] is projected to be 1225 Mtoe in 2030 (Figure 26), a 15% decrease compared to 2015. Until 2050, this decrease will grow to 23%. This changes the energy mix profoundly. Solar and wind triple their share in gross inland consumption from respectively 1% and 2% in 2015 to 3% and 6% in 2030. Coal decreases its share from 18% in 2015 to 8% in 2030.

Figure 26: Gross Inland Consumption in the Baseline



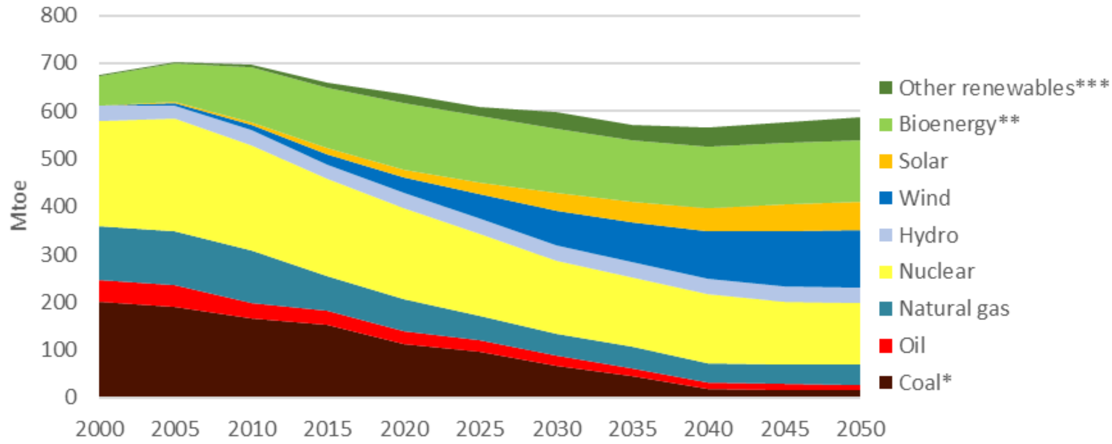
*Note: * includes peat and oil shale; ** includes waste, *** hydro, geothermal, ocean and ambient heat*

Source: 2000-2015: Eurostat, 2020-2050: PRIMES model

Primary energy production (Figure 27) reduces by 10% in 2030, compared to 2015. Fossil fuels reduce their share in energy production from 38% in 2015 to 23% in 2030 (further declining towards 2050), mainly driven by the reduction of solid fossil fuels replaced by renewable energy sources, chiefly wind and solar.

[63] https://ec.europa.eu/info/horizon-europe-next-research-and-innovation-framework-programme_en
[64] https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/future-cap_en
[65] Including peat and oil shale, waste, and ambient heat.

Figure 27: Primary energy production in the Baseline



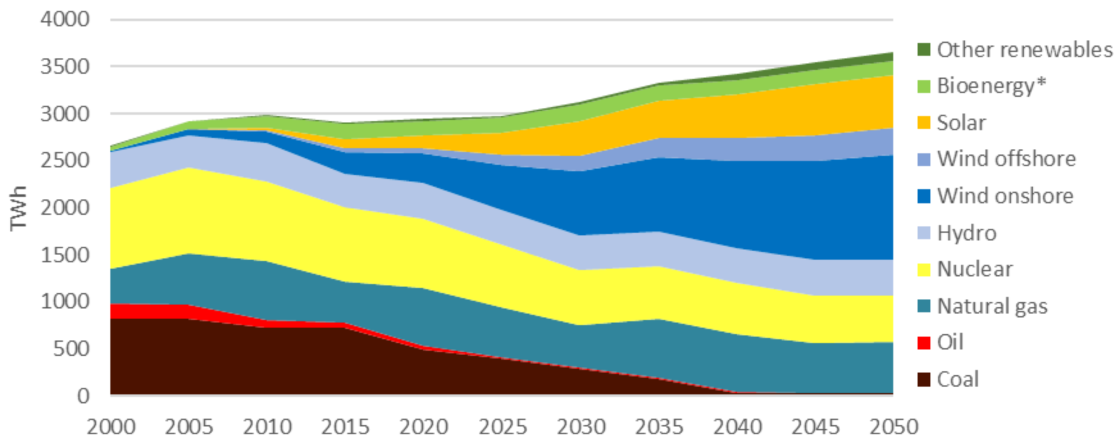
*Note: * includes peat and oil shale; ** includes waste, *** hydro, geothermal, ocean and ambient heat*

Source: 2000-2015: Eurostat, 2020-2050: PRIMES model

Net imports will decrease by 18% until 2030 and another 14% thereafter until 2050. Over time, natural gas increases its share in imports at the expense of coal and oil.

Power generation (Figure 28) is growing throughout the projection period. Gross electricity generation in the BSL increases from 2,902 TWh in 2015 to 3,116 TWh in 2030 (7%) and by another 17% between 2030 and 2050 due to electrification of demand, notably, in transport. While in 2015, 2% of power demand came from the transport sector, this share is 5% in 2030 and 10% in 2050.

Figure 28: Gross electricity generation in the Baseline

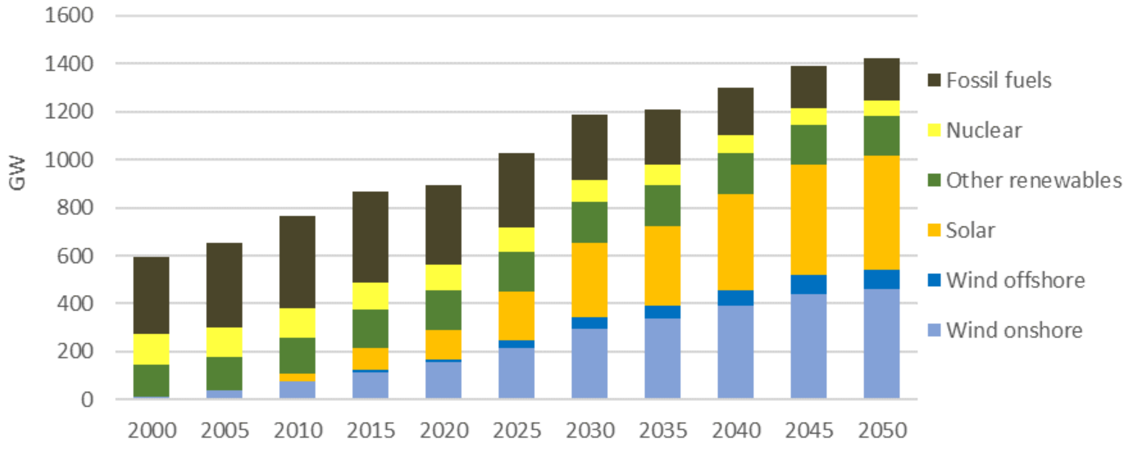


*Note: * includes waste*

Source: 2000-2015: Eurostat, Wind Europe, 2020-2050: PRIMES model

By 2030, more than half of generation comes from renewable sources (57%) which will increase by 2050 to 71%. The biggest increase in the EU power generation mix comes from wind which more than triples in gross electricity generation by 2030 (compared to 2015) to 840 TWh. It increases another 67% between 2030 and 2050. Coal-based generation decreases substantially (to 288 TWh) by 2030 and is marginal in 2050. Natural gas continues to play a role in power generation throughout the period, being responsible for 15% of the electricity generated in 2030 and in 2050.

Figure 29: Net installed capacity in the Baseline

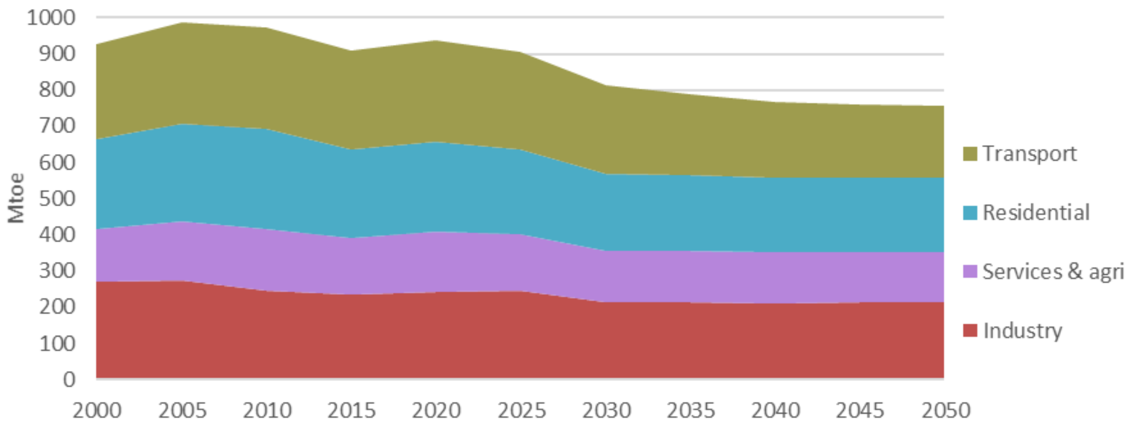


Source: 2000-2015: Eurostat, Wind Europe, 2020-2050: PRIMES model

The significant increase in wind power is also visible in the installed capacity which increases from 127 GW in 2015 to 343 GW in 2030 and 543 GW in 2050 (Figure 29). Solar power also expands enormously from 88 GW in 2015 to 313 GW in 2030 and 475 GW in 2050. Between 2015 and 2030, every year, on average 15 GW of new solar capacity will be installed.

The final energy demand in BSL (Figure 30) decreases by 17% between 2015 and 2050 (already by 2030 it decreases by 10%). The strongest decrease in the period between 2015 and 2030 comes from the residential sector (-12%). After 2030 and towards 2050, by far the biggest decrease is going to come from the transport sector (-20%). It is also the sector with the single biggest effort over the entire period of 2015-2050 (28% decrease).[66]

Figure 30: Final energy consumption by sector in the Baseline

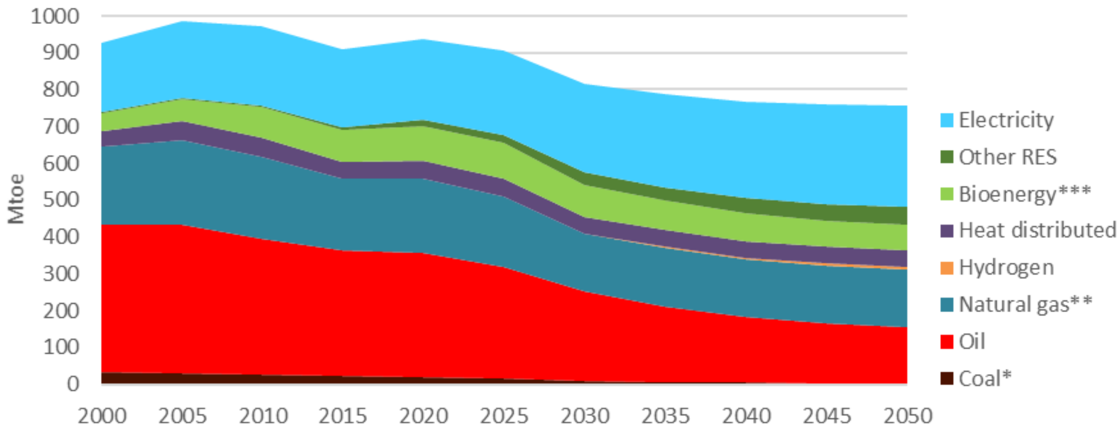


Source: 2000-2015: Eurostat, 2020-2050: PRIMES model

Final energy demand for coal drops by 88% over the entire period 2015-2050 (-62% by 2030 and another -67% thereafter by 2050). Also demand for oil sees a significant decrease of 55% over the entire period– the most important in absolute terms. Electricity as an energy carrier grows by 30% by 2050 (Figure 31).

[66] Final energy demand in the transport sector excludes international aviation and international maritime navigation.

Figure 31: Final energy consumption by fuel in the Baseline

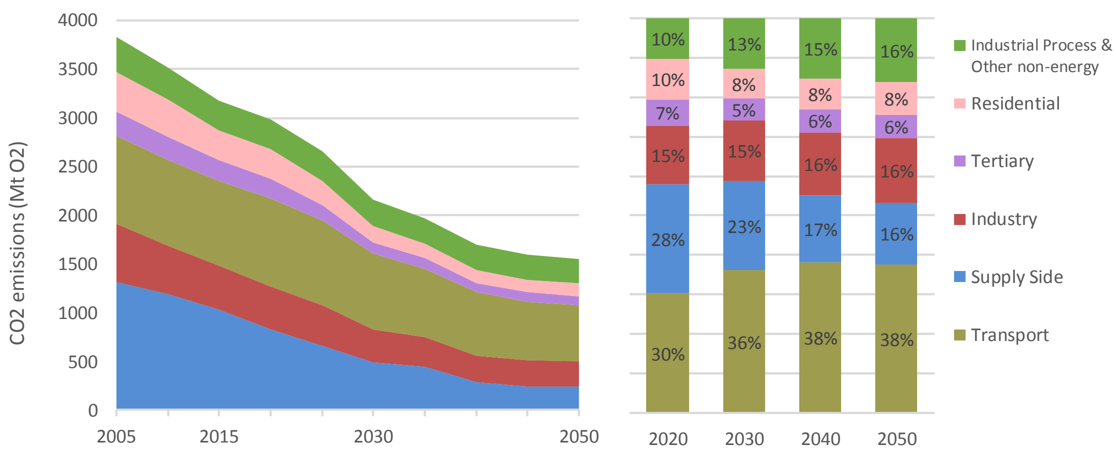


*Note: * includes peat and oil shale; ** includes manufactured gases, *** includes waste*

Source: 2000-2015: Eurostat, 2020-2050: PRIMES model

The energy projections described above, result in both reduced energy intensity and carbon intensity of the energy system. This in turn leads to steadily decreasing energy related CO_2 emissions across the economy (Figure 32).

Figure 32: Evolution of CO_2 emissions by sector (left) and their shares (right) in BSL[67]



Source: PRIMES model

CO_2 emissions reduce compared to 1990 by 46% in 2030 and 59% in 2050. Emissions of Power Generation experience the biggest reductions in 2030 compared to 2015 (52%), followed by the residential (49%) and the services (47%) sectors. Industrial energy emissions reduce by 18%. Finally the transport sector, despite the implementation of the CO_2 standards for vehicles, achieves only 12.54% reductions by2030.[68]

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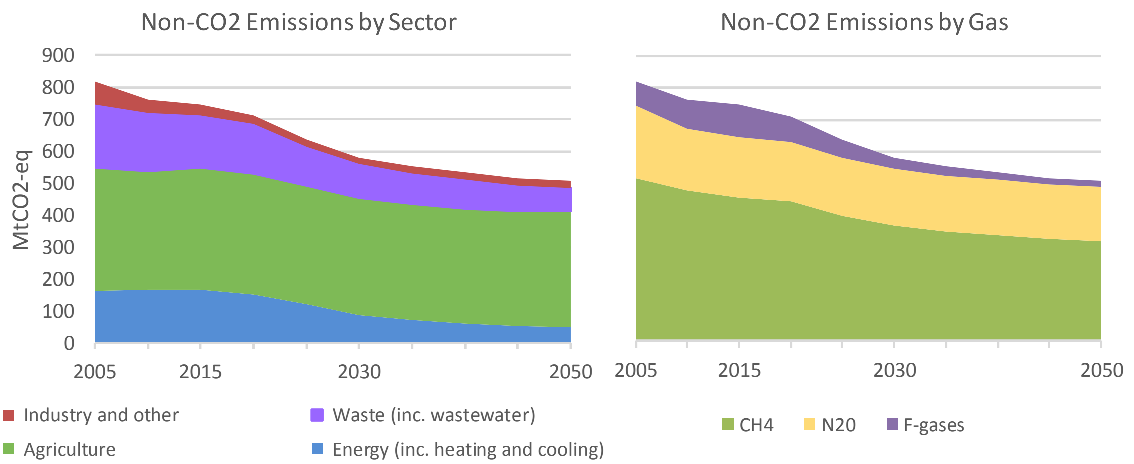
[67] Refinery CO_2 emissions are included under industry, consistent with annex 9.4.2.7. Supply side includes power generation, district heating and the energy branch excluding refineries. Transport emissions include total aviation (intra and extra EU) but only inland navigation (covering inland waterways and national maritime navigation).

[68] Transport emissions include total aviation (intra and extra EU) but not the international maritime sector.

As shown in Figure 33 reduction of non-CO_2 emissions reductions are more limited than for CO_2. Total reductions in 2030 reach 32% compared to 2005 and 26% compared to 2015. CH_4 emissions, which are close to two thirds of total non-CO_2 emissions, are only reduced by 26% between 2015 and 2030, while N_2O emissions reduce by 5%. Only F-gases are reduced drastically by 65%. From a sectoral perspective, agriculture not only remains the biggest emitter, but as its emissions reduce very slightly over the projection period, its share in total non-CO_2 emissions gradually increases from 54% in 2015 to 68% in 2030 and 73% in 2050. The sectors showing the biggest emissions reductions are AC & refrigeration, waste and energy, with reductions in 2030 compared to 2015 being 68%, 53% and 36% respectively. On the contrary, non-CO_2 emissions in agriculture reduces only by 7%, emissions in industry by 6% and emissions in wastewater remains stable.

Figure 33: Non-CO_2 emissions by sector and by gas in the Baseline



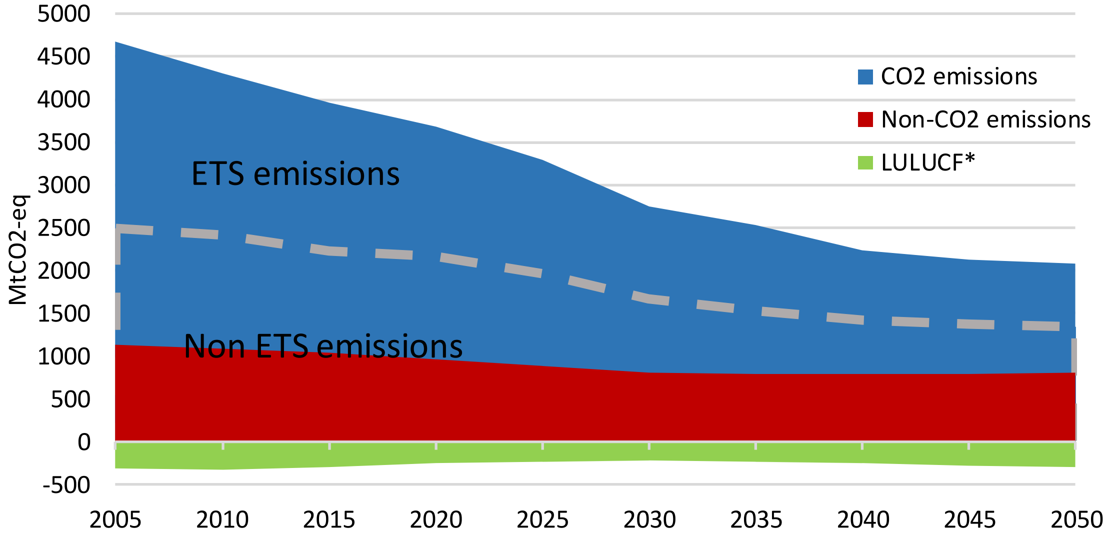
Source: GAINS model

The LULUCF sector has seen an increase in sink in the period up to 2013 but since, with increasing harvesting rates and natural disturbances like forest fires, this has reduced. This is projected to continue. BSL assumes a deterioration of the EU emissions and removals from forest management and harvested wood products in line with increasing harvesting foreseen as under the Forest Reference Levels[69].

Figure 34 shows overall GHG emissions for the EU in the BSL.

[69] Annex of the draft delegated act 22 June 2020 - Commission expert group on Land Use, Land Use Change and Forestry (LULUCF)

Figure 34: GHG emissions profile in the Baseline



*Note: Includes domestic and international (intra and extra EU) aviation; GHG global warming as of IPCC AR5 report; * LULUCF 2030 projection based on "No Debit" projections (see also section 6.2.3)*

Source: PRIMES, GAINS and GLOBIOM models

The profile of overall GHG emissions in BSL shows emissions reduce well below the legislated climate target of -40% GHG reductions by 2030 compared to 1990 (Figure 35). This is the case both for the ETS and ESR sectors.

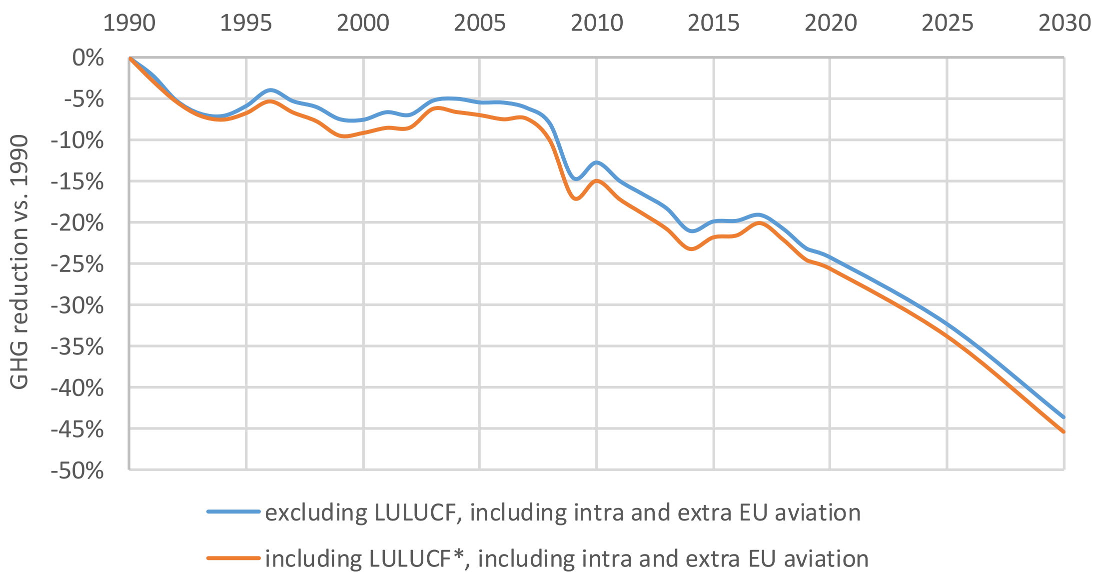
It is assumed that emission reductions in BSL are also driven by a meaningful carbon price across the whole period. Early on in the period, this is provided for with the Market Stability Reserve rebalancing demand and supply. This has led to a re-establishment of a meaningful carbon price since 2018, which was maintained also after the COVID-19 crisis significantly impacting emissions from early 2020 onwards[70].

In summary, GHG emissions for the scope that includes intra and extra EU aviation and maritime navigation but excludes net LULUCF[71] reduce by 44.5% compared to 1990 by 2030. Including net LULUCF, this adds up to a reduction of 46.3%.

[70] Assuming such a meaningful carbon price, as well as assuming the achievement of the RES and EE targets in BSL would likely require a review of the MSR, as is foreseen in 2021 to keep the surplus from increasing again.

[71] Excluding LULUCF and including intra EU navigation and aviation

Figure 35: GHG reductions in the Baseline



*Note: * LULUCF 2030 projection based on "No Debit" projections (see also section 6.2.3)*

Source: EEA GHG data viewer, PRIMES, GAINS and GLOBIOM models

The absence of additional energy and climate policies though post-2030 do not allow the continuation of the strong GHG emissions reduction trend, with emissions almost stabilising post 2040. The BSL scenario projects that in 2050 GHG emissions reduce by around 60% compared to 1990.

In addition, a variant of the BSL, called COVID-BSL, was developed to factor in the COVID-19 crisis (see section 6.4.3).

The key energy indicators for BSL and COVID-BSL are shown in the Table 36.

Table 36: Key energy indicators for BSL and COVID-BSL

Key energy indicators	BSL		COVID-BSL	
	2030	2050	2030	2050
GIC (Mtoe)	1 202	1 078	1 188	1 049
Gross Inland Energy Consumption Shares (%) of:				
- Solid fuels	8%	3%	9%	3%
- Oil	33%	28%	33%	28%
- Natural gas	22%	25%	22%	25%
- Nuclear	13%	12%	12%	11%
- Renewables	24%	33%	25%	33%
Final Energy Demand (Mtoe)	795	725	803	721
Final Energy Demand in industrial sector (Mtoe)	217	217	220	212
Final Energy Demand in residential sector (Mtoe)	201	186	206	192

Final Energy Demand in tertiary sector (Mtoe)	133	127	130	119
Final Energy Demand in transport (Mtoe)*	245	196	248	199
Fuel used in FEC (% share)				
- solid fossil fuels	1%	0%	1%	0%
- liquids	31%	21%	31%	22%
- gas	20%	21%	20%	22%
- electricity	30%	38%	29%	37%
- RES and biofuels	12%	11%	12%	12%
- heat distributed	6%	6%	6%	6%
Greenhouse gas emissions reductions excluding LULUCF vs 1990**	-45.6%	-59.1%	-45.7%	-59.5%
Industry (compared to 2015)	-18.2%	-31.0%	-16.3%	-32.8%
Power (compared to 2015)	-53.0%	-76.5%	-53.9%	-76.4%
Residential (compared to 2015)	-47.2%	-58.6%	-45.8%	-57.1%
Services (compared to 2015)	-48.7%	-62.5%	-47.5%	-62.1%
Transport (compared to 2015)	-12.5%	-36.3%	-14.0%	-37.8%
non CO_2 (compared to 2015)	-25.8%	-32.3%	-25.8%	-32.3%

Note: * Not including international aviation and navigation; ***including intra EU aviation and navigation*

Source: PRIMES and GAINS models

The COVID-BSL scenario shows similar overall reductions than BSL in 2030 and 2050, with a slightly different sectoral profile: emissions reduce more in the transport sector and in power production in COVID-BSL than in BSL, but less in industry, residential and services.

9.3.3.3 The EU-NECP variant

Finally, as stated in section 5.1 and mentioned section 5.4, an EU-NECP variant was developed next to the BSL, which reflects in a stylised manner and to the extent possible the aggregate level the ambition of final NECPs submitted by the Member States. Due to time constraints this reflection is simplified at this stage, hence detailed results of this scenario are not discussed in this impact assessment.

The Commission will continue the work on the modelling of its scenario toolkit with a view of future impact assessments supporting the future implementation of the 2030 Climate Target Plan.

9.3.4 Policy scenarios

The following overview provides the scenario description used in the modelling suite.

Table 37: Scenario assumptions description (scenarios produced with the PRIMES-GAINS-GLOBIOM modelling suite)

Scenario	**BSL***	**REG**	**MIX**/ MIX-50**	**CPRICE**	**ALLBNK**
Brief description	Achieving the current 2030 EU targets	No extension of ETS scope to buildings and road transport, but extension of ETS to intra-EU maritime navigation	Extension of ETS scope to buildings, road transport and intra-EU maritime navigation but also keeping road transport and buildings in ESR	Extension of ETS scope to buildings, road transport and intra-EU maritime navigation; buildings and road transport are taken out of the ESR	Most ambitious scenario for GHG reductions
	Achievement of EE 32.5% target; Achievement of 32% RES target	High ambition increase of EE and RES policies. There is no carbon price applied in buildings and road transport	Medium/low ambition increase of EE and RES policies in non-ETS because RES and EE legislation is revised to contribute to higher GHG target. Additionally, a carbon price is also applied in buildings and road transport	Carbon pricing as the principal instrument to reduce CO_2 emissions, no intensification of EE or RES policies, some intensification of policies related to transport CO_2	Applies the GHG target on a broader scope including all international aviation and international maritime navigation
Target scope	EU27				
Aviation	Intra + Extra EU aviation is included	Intra EU aviation and navigation included			Intra + Extra EU aviation and navigation included
Maritime navigation	International Intra + Extra EU maritime navigation not included				

Scenario	BSL*	REG	MIX**/ MIX-50	CPRICE	ALLBNK
Achieved reduction (including net LULUCF sink)		Around 55%	At least 50% and Around 55%	Around 55%	Around 55%
ASSUMED POLICIES					
Carbon pricing (stylised, for international aviation and maritime navigation may represent also other instruments than EU ETS such as taxation or CORSIA for aviation)					
Stationary ETS	Yes				
Aviation - Intra EU	Yes				
Aviation - Extra EU	Yes	Yes: mixture 50/50 carbon pricing (reflecting inclusion in the ETS, or taxation, or CORSIA) and carbon value (reflecting operational and technical measures); total equal to EU ETS carbon price			Yes
Maritime navigation - Intra EU	International Intra EU maritime navigation not included	Yes, carbon pricing, equal to the EU ETS carbon price			Yes
Maritime navigation - Extra EU	No	Yes: mixture of 50/50 carbon pricing (reflecting inclusion in the ETS or taxation) and a carbon value (reflecting operational and technical measures); total equal to the EU ETS carbon price			Yes
Buildings and road transport	No		Yes		
Coal phase out	Yes				
CO_2 standards for LDVs and HDVs	Yes as currently legislated	CO_2 standards for LDVs and HDVs + Charging and refuelling infrastructure development (review of the AFID and TEN-T Regulation & funding), including strengthened role of buildings			
		High ambition increase	Medium/low ambition increase	Low ambition increase	Medium Ambition increase

Scenario	BSL*	REG	MIX**/ MIX-50	CPRICE	ALLBNK
EE policies overall ambition	Stylised (32.5% EE)	High Ambition increase	Medium/low Ambition increase	As in BSL	Medium Ambition increase
EE in Buildings + Industry	Stylised (32.5% EE)	High Ambition increase (increase in renovation rate, support for heat pumps uptake)	Medium/low Ambition increase (increase in renovation rate, support for heat pumps uptake)	As in BSL	As in MIX
EE in Transport (see details in the section below)	As currently legislated + proposed revision of the Eurovignette Directive	High Ambition increase	Medium/low Ambition increase	Low Ambition increase	As in MIX
RES policies overall ambition	Stylised (32% RES)	High Ambition increase	Medium/low Ambition increase	High Ambition increase	Medium Ambition increase
RES in buildings + Industry	Stylised (32.5% EE)	High Ambition increase (incentives for uptake of RES in heating and cooling)	Medium/low Ambition increase (incentives for uptake of RES in heating and cooling)	As in BSL	As in MIX
RES policies in ETS	Stylised (32% RES)	Implications of the new offshore strategy			

Scenario	BSL*	REG	MIX**/ MIX-50	CPRICE	ALLBNK
RES in transport and policies impacting transport fuel content	Stylised (32% RES)	High ambition increase of fuel policies (Renewable and low carbon fuels mandate, including ReFuelEU aviation and FuelEU maritime initiatives)	Medium/low ambition increase of fuel policies (Renewable and low carbon fuels mandate, including ReFuelEU aviation and FuelEU maritime initiatives)	Low ambition increase of fuel policies (reflecting ReFuelEU aviation and FuelEU maritime initiatives)	Very high ambition increase of fuel policies (reflecting ReFuelEU aviation and FuelEU maritime initiatives)
Additional non-CO_2 policies (represented by carbon value)	No	Medium Ambition increase			High Ambition increase
LULUCF policies	No	No (Separate scenarios assessment of impact of policies that enhance the LULULCF sink)			

* A variant of BSL scenario: EU-NECP was also modelled to reflect the aggregate ambition of final NECPs achieved on the EU level.

** A variant of MIX: MIXnonCO2 showing more reductions coming from non-CO_2 emissions and less reductions from CO_2 (mostly in the energy system) compared to MIX.

These policies are presented in the PRIMES modelling tool where some take the form of explicit policies such as for instance improved product energy performance standards, vehicle CO_2 standards and fuel mandates and others are induced by Energy Efficiency, Renewable Energy and non-CO_2 values, which reflect generic incentives altering investment decisions towards increased energy efficiency and renewable energy options (including removal of non-market barriers and consumer behaviour in favour of energy efficiency) and abatement of non-CO_2 emissions. Table 38 shows that these values for the different scenarios typically are higher in policy scenarios that are based on regulatory approaches than in scenarios that are more based on carbon pricing. The values in BSL reflect the existing policy framework required to meet the current climate and energy targets.

Table 38: Key modelling variables reflecting underlying policy assumptions

Scenarios	Carbon price ETS sectors (€'15/ t of CO_2)	Non CO_2 carbon values (€'15/ t of CO_2) [72]	Average renewables value (€'15/ MWh)	Average energy efficiency value (€'15/ toe)
BSL	32	0.0	91	891
MIX-50	36	0.6	94	951
REG	32	10	177	1270
MIX	44	10	112	1194
MIX-nonCO_2	44	55	109	1194
CPRICE	60	10	49	891
ALLBNK	65	55	111	1202

[72] Mitigation potential based on the GAINS model marginal abatement cost curve (see Figure 69) but interpolated to fit PRIMES optimisation.

Specific measures to improve the efficiency of the transport system

Policies that aim at improving the efficiency of the transport system (corresponding to row "EE in Transport" in the table above), and thus reduce energy consumption and CO_2 emissions, are phased-in in scenarios in terms of level of ambition (low, medium, high ambition increase). All scenarios assume an intensification of such policies relative to the baseline. Among these policies, the CO_2 emission standards for vehicles are of particular importance. The existing standards[73], applicable from 2025 and from 2030, set binding targets for automotive manufacturers to reduce emissions and thus fuel consumption.

Low ambition increase

In this case, a review of the following policy initiatives is considered that drive improvements in transport system efficiency and support a shift towards more sustainable transport modes, and lead to energy savings and emissions reductions:

- Incentives for intermodal freight transport;
- Initiatives to increase and better manage the capacity of railways, inland waterways and short sea shipping, supported by the TEN-T infrastructure and CEF funding;
- Gradual internalisation of external costs ("smart" pricing);
- Incentives to improve the performance of air navigation service providers in terms of efficiency and to improve the utilisation of air traffic management capacity;
- Revision of roadworthiness checks;
- Limitedly increase in ambition for CO_2 emission standards for vehicles (passenger cars, vans, trucks and buses) as of 2030 or 2035, supported by the roll-out of recharging and refuelling infrastructure. For cars this corresponds to a reduction of around 40% in 2030 compared to the 2021 target.

Medium ambition increase

Beyond measures included in the low ambition increase case, in the medium ambition increase case policies fostering energy-efficiency in transport are intensified through:

- Additional efforts to improve the functioning of the transport system: support to multimodal mobility and intermodal freight transport by rail, inland waterways and short sea shipping;
- Deployment of the necessary infrastructure, smart traffic management systems, transport digitalisation and fostering connected and automated mobility;
- Further actions on clean airports and ports to drive reductions in energy use and emissions;
- Additional measures to reduce emissions and air pollution in urban areas;
- Pricing measures such as in relation to energy taxation (e.g. alignment of minima on energy content for diesel and petrol), and infrastructure charging;

[73] The existing legislation sets for newly registered passengers cars, an EU fleet-wide average emission target of 95 gCO_2/km from 2021, phased in from 2020. For newly registered vans, the EU fleet-wide average emission target is 147 gCO_2 /km from 2020 onward. Stricter EU fleet-wide CO_2 emission targets, start to apply from 2025 and from 2030. In particular emissions will have to reduce by 15% from 2025 for both cars and vans, and by 37.5% and 31% for cars and vans respectively from 2030, as compared to 2021. From 2025 on, also trucks manufacturers will have to meet CO_2 emission targets. In particular, the EU fleet-wide average CO_2 emissions of newly registered trucks will have to reduce by 15% by 2025 and 30% by 2030, compared to the average emissions in the reference period (1 July 2019–30 June 2020). For cars, vans and trucks, specific incentive systems are also set to incentivise the uptake of zero and low-emission vehicles.

- Revision of roadworthiness checks;
- Other measures incentivising behavioural change;
- Medium intensification of the CO_2 emission standards for cars, vans, trucks and buses (as of 2030) as compared to low ambition increase case, supported by large scale roll-out of recharging and refuelling infrastructure. For cars this corresponds to a reduction of around 50% in 2030 compared to the 2021 target.

High ambition increase

Beyond measures foreseen in the medium ambition increase case, the high ambition increase case includes:

- Further measures related to intelligent transport systems, digitalisation, connectivity and automation of transport - supported by the TEN-T infrastructure;
- Additional measures to improve the efficiency of road freight transport;
- Incentives for low and zero emissions vehicles in vehicle taxation;
- Increasing the accepted load/length for road in case of zero-emission High Capacity Vehicles;
- Additional measures in urban areas to address climate change and air pollution;
- Pricing measures such as in relation to energy taxation (e.g. alignment of minima on energy content for diesel and petrol and mirroring the alignment in terms of energy content at MS level);
- Higher intensification of the CO_2 emission standards for cars, vans, trucks and buses (as of 2030) as compared to the medium ambition increase case, leading to lower CO_2 emissions and fuel consumption and further incentivising the deployment of zero- and low-emission vehicles, supported by the large scale roll-out of recharging and refuelling infrastructure. For cars this corresponds to a reduction of around 60% in 2030 compared to the 2021 target.

9.4 Sectoral transformation to achieve 50% to 55% GHG reduction by 2030 and transition to climate neutrality

This annex gives an overview of the detailed modelling results in the energy system and per specific sectors that allow the EU economy to achieve 50% to 55% GHG reduction by 2030 and put it on a pathway towards climate neutrality.

9.4.1 Greenhouse gas emissions per sector

Table 39 below gives an overview of the emission profile and reductions compared to 2005 for all main sectors for the main scenarios assessed.[74]

[74] In the public consultation, the sectors rated by the respondents as important to increase the 2030 GHG emissions target were energy supply (48%), mobility and transport (16%), industry (13%), and buildings (7%).

Table 39: Sectoral greenhouse gas emissions per scenario

$MtCO_2$-eq	1990	2005	2015	2030						
				BSL	MIX-50	REG	MIX	MIX-non-CO2	CPRICE	ALLBNK
Total GHG incl. LULUCF[75]	**4673.6**	**4320.2**	**3611.2**	**2481.3**	**2289.2**	**2101.3**	**2104.0**	**2099.8**	**2102.0**	**1969.5**
CO_2 excl. LULUCF		**3812.9**	**3156.6**	**2124.8**	**1965.8**	**1810.1**	**1812.7**	**1834.4**	**1810.7**	**1704.2**
ETS Stationary		**2073.1**	**1601.3**	**932.6**	**838.9**	**728.7**	**722.4**	**744.5**	**718.9**	**648.4**
ESR sectors		**2485.9**	**2235.5**	**1687.7**	**1594.5**	**1520.9**	**1528.1**	**1501.8**	**1528.9**	**1471.7**
Supply Side[76]		1405.4	1116.7	555.0	469.0	365.7	362.5	383.5	362.7	300.7
Power generation		1257.1	987.9	464.7	387.2	299.9	288.9	309.2	292.0	236.0
Industry[77]		835.1	635.7	520.2	506.4	502.2	493.4	495.1	487.3	475.8
Residential		404.6	309.5	163.5	134.5	112.5	117.7	117.8	120.8	108.8
Services		166.9	146.6	75.2	63.7	68.1	61.8	61.4	58.0	57.7
Agriculture energy		77.0	60.8	42.2	38.7	38.3	38.1	38.0	37.9	36.9
Transport		874.2	819.2	716.4	697.1	675.4	685.5	685.0	691.2	673.9
Of which Road Transport		770.4	731.8	611.7	597.8	580.1	588.5	588.0	593.8	581.1
Intra EU aviation & navigation		91.3	79.7	98.4	93.0	89.0	90.7	90.7	91.2	86.5
Extra EU Aviation		71.9	82.9	102.1	98.9	93.1	96.3	96.4	97.3	92.7
Non-CO_2		819.9	747.9	581.1	547.9	515.8	515.8	489.9	515.8	489.9
LULUCF	-254.8	-312.6	-293.2	-224.5	-224.5	-224.5	-224.5	-224.5	-224.5	-224.5

Source: PRIMES model, GAINS model

[75] Including domestic and intra EU aviation and navigation
[76] Including power generation, energy branch, refineries and district heating
[77] Including process CO_2 emissions from industry

9.4.2 *Energy sector*

9.4.2.1 Energy mix and demand

The first conclusion that can be drawn from the analysis is that achieving 55% GHG reductions in 2030 would require further lower total energy demand (gross inland consumption), by around 21% compared to 2015 in REG, MIX and CPRICE, i.e. equivalent to around 5% below BSL. Reaching the reduced GHG reduction goal of 50% leads to an energy demand reduction of 19%. After 2030, the uptake of energy intensive new fuels[78] including hydrogen[79], e-gas and e-liquids, leads to slower reductions (see Figure 36)[80].

The energy mix in 2030 remains overall still dominated by fossil fuels, but renewables increase significantly from 15% of the GIC in 2015 to 31-32% in 2030 in scenarios with 55% GHG reduction, i.e. 5-6 percentage points (p.p.) higher than in BSL. The ALLBNK case leads to an uptake of renewables, of 34% of the gross inland consumption, hence 2 p.p. more than REG (382 Mtoe vs. 368 Mtoe). Lowering the GHG ambition to 50% GHG reductions lead to a RES share of 28% in MIX-50 (339 Mtoe). Spurred by decreasing costs and better integration, the increasing contribution of renewables is mostly driven by non-biomass renewables[81], which become larger than biomass by 2030 in all cases. The contribution of nuclear energy remains relatively stable at 11% in the policy scenarios with 55% GHG reduction (13% in 2015 and in MIX-50), resulting from the operation of existing nuclear power plants and the commissioning of new plants. In contrast, coal use is projected to decrease by more than 70% compared to 2015 (15-18 p.p. more than BSL), oil[82] by 30-32% (15-18 p.p. more than BSL) and natural gas by 26-28% (12-14 p.p. more than BSL). These decreases are somewhat less pronounced in MIX-50 with coal reducing by 64%, oil by 29% and natural gas by 24%. The ALLBNK case shows markedly strong reductions, notably for natural gas (-30%), oil (-32%) and then coal (-81%). These projected evolutions are in line with scenarios from third parties[83] though natural gas use in residential buildings decreases faster (-44% between 2015 and 2030 for MIX).

The changes of the energy mix lead to a reduction of CO_2 emissions from the fossil fuel combustion[84] in 2030 of 56% compared to 1990. The MIX-50 scenario leads to 4 p.p. lower (-52%) and the ALLBNK scenario to 3 p.p. higher (-59%) reductions as compared to MIX.

By 2050, the trends observed by 2030 are greatly amplified. The growth of renewables is dramatic, more than tripling compared to 2015[85], while fossil fuels represent in 2050 only 10-11% of the GIC in energy uses, complemented by non-energy uses[86].

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[78] By convention, both the production of e-gas and e-liquids and the inputs for this production are accounted for in gross inland energy consumption.

[79] The policy scenarios considered see a ramp up of the installed electrolyser capacity between 37-66 GW by 2035, responsible for a production of up to ca. 8 Mt of hydrogen in 2035.

[80] The effect is more visible in CPRICE scenario as new fuels are developing stronger in that scenario.

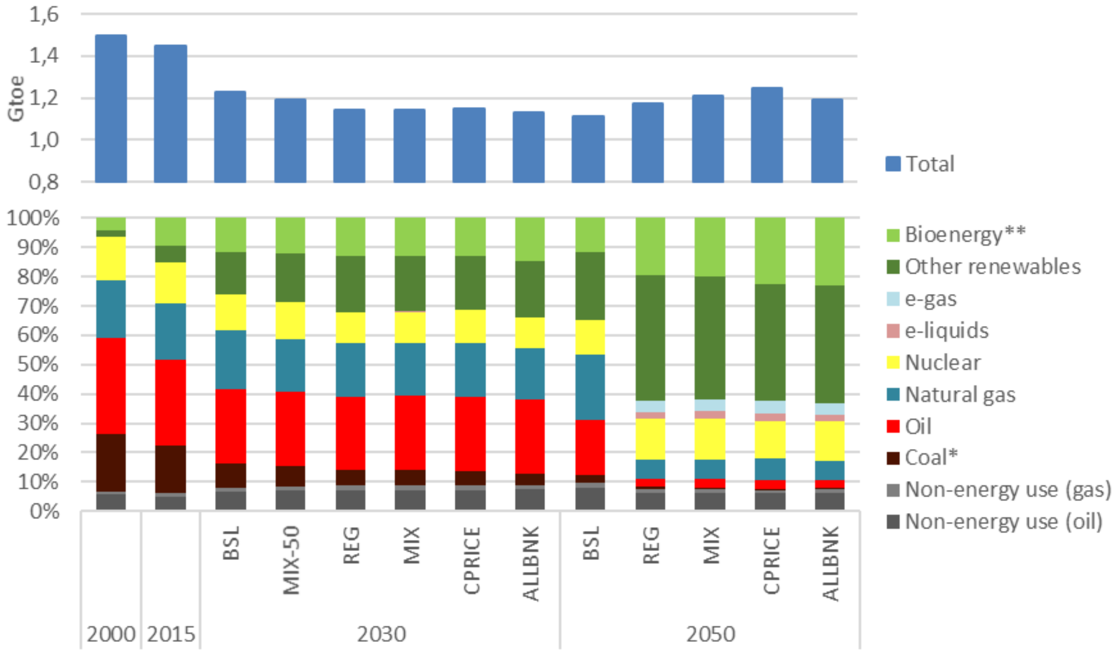
[81] Non-biomass renewables in the total energy demand are hydroelectricity, wind electricity, solar electricity, solar heat, geothermal heat, ambient heat (from heat pumps) and ocean electricity.

[82] Excluding non-energy uses of oil

[83] See: Tsiropoulos I., Nijs W., Tarvydas D., Ruiz Castello P., 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.

[84] Including international aviation

Figure 36: Energy gross inland consumption



*Note: * includes peat, oil shale, ** includes waste*

Source: 2000, 2015: Eurostat, 2030-2050: PRIMES model

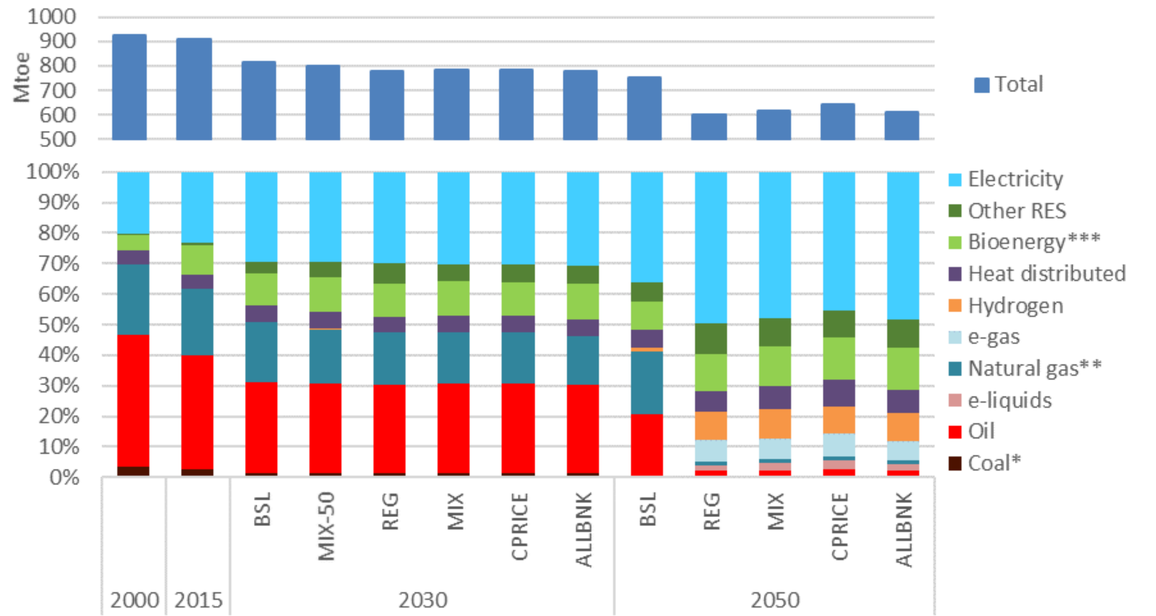
The evolution of the gross inland consumption follows the evolution of final energy consumption (FEC).[87] The FEC declines in all scenarios but slightly more strongly in REG and MIX than in CPRICE as the latter depends less on moderation of energy demand in different sectors but features more of fuel switching. The overall fuel mix for final demand changes progressively and the specific sectoral drivers and dynamics are described in the relevant sections.

[85] While biomass would double by 2050, other renewables would grow sevenfold compared to current level.

[86] Compared to the Baseline, natural gas reduces most (up to 80% lower).

[87] A majority in the public consultation perceived that an increase to greater than 40% for energy efficiency by 2030 was required. This is driven mainly by the opinion of individuals rather than professional respondents.

Figure 37: Final energy demand by energy carrier



*Note: * includes peat, oil shale, ** includes manufactured gases, *** solid biomass, liquid biofuels, biogas, waste*

Source: 2000, 2015: Eurostat, 2030-2050: PRIMES model

The following general trends can be noticed. First of all, coal becomes marginal in final energy demand in 2030 with 12 Mtoe in BSL, driven by reductions in industry and the declared policies in a number of Member States to reduce coal for heating purposes, as well as the required increase in uptake of renewables in BSL to achieve the renewable energy target of 32% by 2030. The coal share further reduces to 9-11 Mtoe in the policy scenarios, and then virtually disappears by 2050. Oil and natural gas remain significant contributors to the final energy demand (reaching 226-235 Mtoe and 123-135 Mtoe respectively in 2030), albeit at lower level compared to today (339 and 197 Mtoe in 2015 for oil and gas respectively). By 2050, the situation changes radically. Oil and natural gas consumptions are reduced to a fraction of current levels in the policy scenarios (12-16 Mtoe and 7-8 Mtoe respectively), while they are still important in BSL (152 and 155 Mtoe respectively). They are partially substituted by new renewable and low-carbon fuels, mainly of gaseous form (39-49 Mtoe in 2050) and to a lower degree of liquid form (11-18 Mtoe). These types of energy vectors would retain an important role in satisfying the energy needs of the economy in the long term, building on an increasingly integrated energy system[88].

Conversely, the contribution of electricity in final demand increases across all scenarios, including in BSL, although electrification is further accelerated in the policy scenarios. From 23% in 2015, the share of electricity in final demand goes up to 29 - 31% in 2030 (234-239 Mtoe, about the same level as BSL with 238 Mtoe) and to 46-50% in 2050 (293- 296 Mtoe). The 2030 electricity demand in MIX-50 and ALLBNK (235 and 237 Mtoe respectively) is within the range of the REG, MIX and CPRICE scenarios. This increase is driven by the uptake of heat pumps in buildings, the electrification of industrial processes as well as the further electrification of

[88] The Energy System Integration Strategy further elaborates on the linking of multiple energy carriers, infrastructures, and consumption sectors as an enabler for a greenhouse gas neutral energy system for the EU.

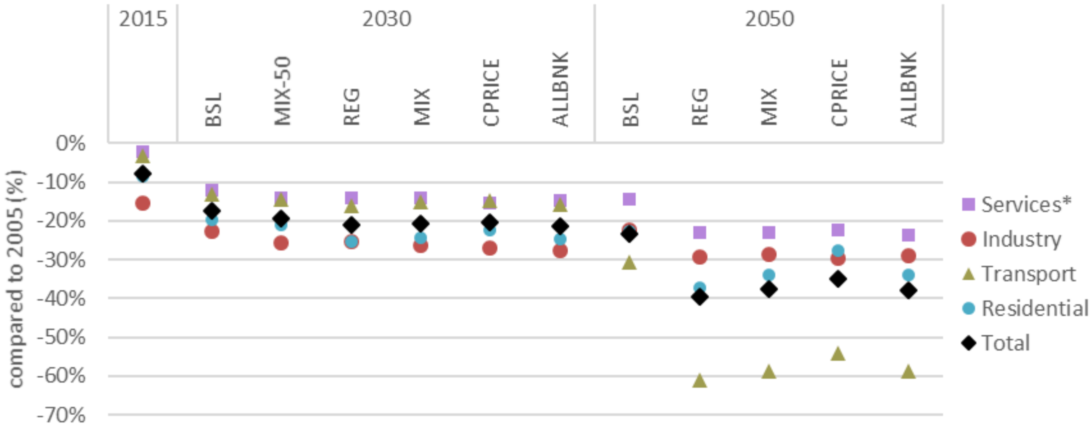
transport. The direct contribution of renewables in final energy demand is also increasing significantly.

Among the different sectors, the residential sector undergoes the highest energy demand reduction by 2030, ranging from CPRICE with -22% compared to 2005 to REG with -25% (2-5 p.p. beyond BSL), triggered notably by the strengthening of dedicated policies and measures (see detailed assumptions in annex 9.3.4). The decline is somewhat lower in MIX-50 (-21%) and at the higher end in ALLBNK (-25%).

Energy demand for transport shows a markedly different profile: the reduction is more limited by 2030 (-14 - 16%, 1-3 p.p. beyond BSL), but then goes through a dramatic evolution over 2031-2050 to reach -54% to -61% compared to 2005. This is driven by the substitution of conventional internal combustion engine vehicles by zero- and low-emission vehicles spurred notably by the further tightening of CO_2 emission standards.

Finally, energy demand in industry is reduced by 25 - 28% in 2030 (2-4 p.p. beyond BSL). Afterwards, industrial activity, driven by future economic growth, tends to have lower energy reductions in energy demand compared to the other sectors.

Figure 38: Evolution of final energy consumption (compared to 2005)

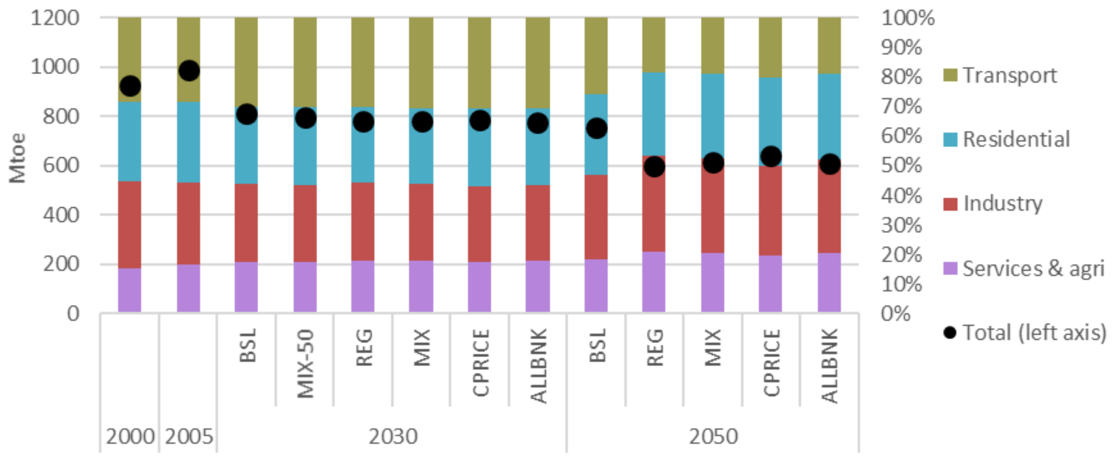


*Note: Final energy sectors as per Eurostat energy balances (transport excludes international aviation), * includes agriculture*

Source: 2005, 2015: Eurostat, 2030-2050: PRIMES model

The relative sectoral evolutions lead to a changing sectoral composition of the final energy demand (Figure 39), with industry and services becoming relatively more important over time, while residential and transport are declining. This effect is stronger in REG than in MIX and CPRICE.

Figure 39: Share of sectors in final energy consumption

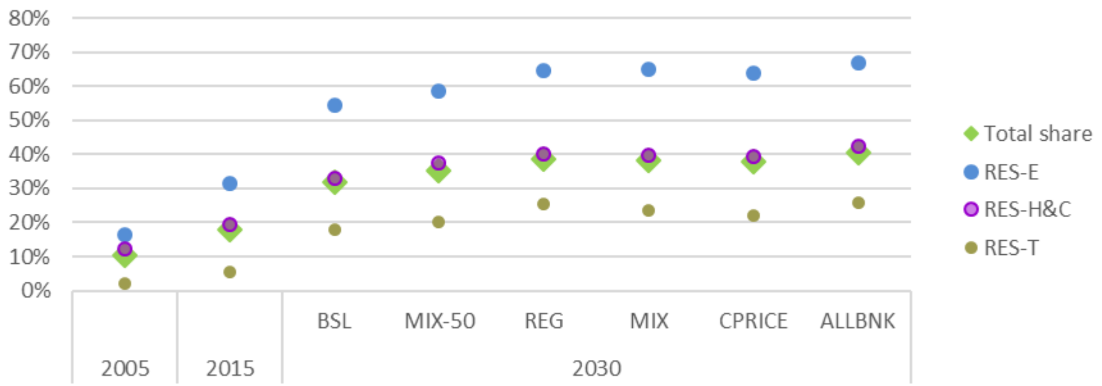


Source: 2000, 2015: Eurostat, 2030-2050: PRIMES model

9.4.2.2 Renewable energy supply and demand

Renewables are increasingly becoming a prerequisite in any decarbonisation strategy (see also section 6.2.1.2). From currently just above 18% in gross final energy consumption, the overall renewables share[89] increases to just above 32% in the BSL scenario, representing the required increase in uptake to achieve the renewable energy target of 32% and to at least 37.9% in the policy scenarios up to 38.7% in REG. Lowering the GHG reduction ambition leads to a RES share of 35.1% in MIX-50. The renewables share increases further to 40.4% in ALLBNK. This dynamic is observed in all major demand sectors over the whole period analysed and compared to BSL (Figure 40).[90]

Figure 40: Renewables shares



Source: PRIMES model

By 2030, the electricity sector will see the highest share of renewables ("RES-E") with 55% in the BSL scenario and 64-65% in the main policy scenarios, driven by a combination of much

[89] Defined as per Directive (EU) 2018/2001 of 11 December 2018 on the promotion of the use of energy from renewable sources (recast).

[90] A majority in the public consultation was in favour of increasing renewable energy shares in final energy consumption by 2030 greater than 40%. This is driven mainly by the opinion of individuals rather than professional respondents.

more ambitious renewables policies and/or a further increase in the ETS carbon price, whether the ETS is expanded to the buildings and road transport sectors or not. Lowering the 2030 GHG reduction ambition leads to a RES-E share of 58% in MIX-50. In the ALLBNK scenario, the RES-E share reaches 67%. By 2050, renewables in power generation are projected to more than 85%. This implies that substantial acceleration, compared to observed trends of renewable electricity growth of 3% per year observed over 2010-2018, will be needed.

During the same time period, the share of renewables in the heating and cooling sector ("RES-H&C") will increase to 33% in BSL in order to achieve the existing 2030 RES target and 39-40-% in the policy scenarios to contribute to the increased GHG ambition. This reduces to 37% in the MIX-50 scenario while the ALLBNK scenario sees a RES-H&C share of 42%. The annexes on buildings (annex 9.4.2.5) and on industry (annex 9.4.2.7) provide more information on the developments in the heating and cooling sector.

Of all sectors, transport has, in 2015, the lowest penetration of renewables with a share ("RES-T") of 6%[91]. By 2030, this increases to 18% in BSL and to 22% (CPRICE) - 26% (REG) in the main policy scenarios. The MIX-50 scenario achieves 20% (2 p.p. less than CPRICE) while in the ALLBNK scenario this share reaches the same level as in REG. Annex 9.4.2.6 provides more detail on the development in the transport sector.

Figure 8 in section 6.2.1.3 shows the breakdown of renewable energy supply by different sources. In 2015, the overall production in the EU was at 204 Mtoe. By 2030, this will increase to 316 Mtoe in the BSL scenario and to 363 (MIX) – 371 (REG) Mtoe in the policy scenarios. Renewable energy supply further increases to 385 Mtoe in the ALLBNK scenario.

Along with the growth, the portfolio of renewable energy supply options is getting more diverse (Figure 41). Biogenic sources, currently responsible for about 124 Mtoe or 61% of all renewable energy supply in 2015, are currently the single largest contributor. By 2030, the production is going to increase modestly to 141 Mtoe in the BSL scenario and to 151 (CPRICE) – 154 (REG) Mtoe in the policy scenarios. This figure reduces to 146 Mtoe in the MIX-50 and increases to 164 Mtoe while in the ALLBNK scenario. Due to the strong growth of other sources, however, the share of biogenic sources (in all renewable energy sources) is going to fall to 42% in the BSL scenario and in the policy scenarios. Likewise, the share of hydropower will decrease from 14% in 2015 to 10% in the BSL scenario and 9% in the policy scenarios, despite growing in absolute terms from 29 Mtoe to 32 Mtoe (across all scenarios)[92].

During the same time, the share of wind energy in total renewable energy production will increase from 13% to 23% in the BSL scenario and to 24% (REG) to 25% (MIX, CPRICE) in the policy scenarios. The share of solar energy will increase from 6% in 2015 to 12% in the BSL scenario and 11% (REG) - 12% (MIX, CPRICE) in the policy scenarios.

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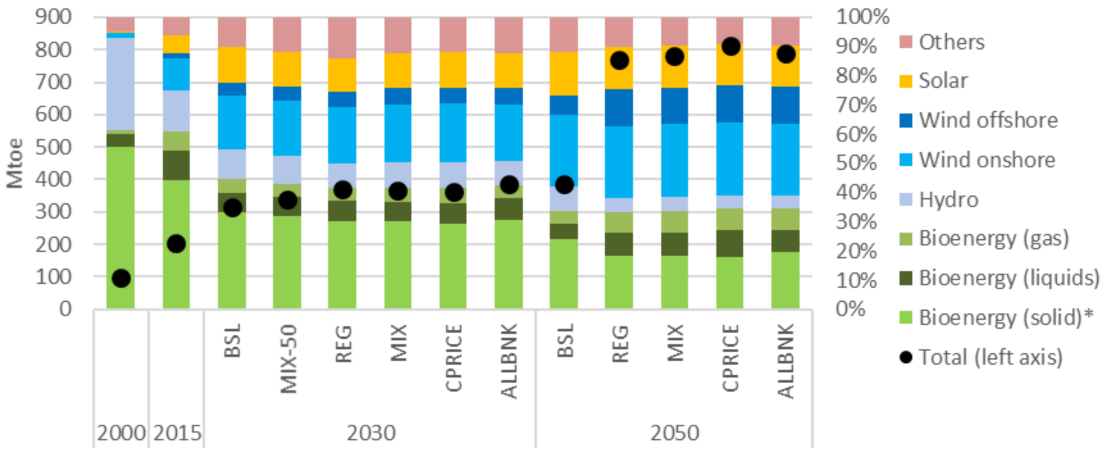
[91] According to Articles 25-27 of Directive 2018/2001/EC (revised RED) where specific caps and multipliers apply for different renewable fuels. If the share was to be calculated according to the methodology in Directives 2009/28/EC and 2015/1513/EC (RED up to 2020) it would be equal to 7%.

[92] Due to geographical conditions, its growth potential in Europe is limited, apart from the extension =of pumped hydropower and small hydropower. Potential developments will need to take into account the need to restore freshwater ecosystems and the natural functions of rivers in order to achieve the objectives of the Water Framework Directive.

Figure 41: Renewable energy production

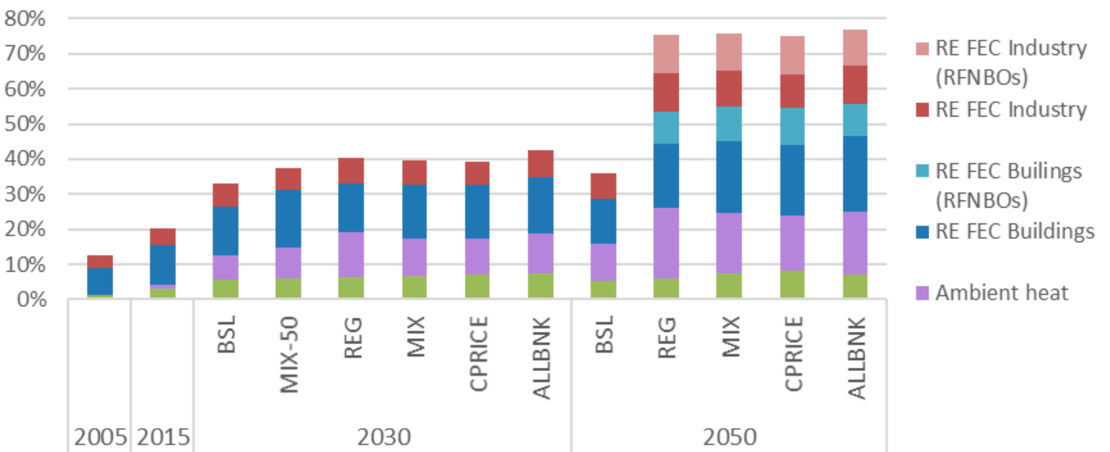


Note: includes biofuel production for international air and maritime bunkers

Source: 2000, 2015: Eurostat, 2030-2050: PRIMES model

Final consumption of renewable energy solutions based on biomass, solar thermal, geothermal and biogases in the industrial and building sectors (excluding derived heat) are the main contributors to renewable energy in the heating and cooling sector by 2030. These renewable-based solutions represent 19-24% of the energy demand for heating and cooling in the policy scenarios. Ambient heat from heat pumps is responsible for 10-13. Renewable derived heat also increases over time, supplying 7% of final consumption in the policy scenarios in 2030. The share of solid fossil fuels and oil as fuel inputs for district heating decreases considerably, as well as the share of gas in the policy scenarios when compared to the BSL. Finally, renewable fuels of non-biological origin (RFNBOs) are expected to play a role after 2030 in the policy scenarios, as they gradually penetrate the industrial and buildings sectors.

Figure 42: Disaggregation of the renewables share in heating and cooling



Source: 2005, 2015: Eurostat, 2030-2050: PRIMES model

Based on the current the RES-T[93] target calculation, renewable electricity would contribute around 9-11% for the target in the main policy scenarios (against 8% in BSL), driven by the

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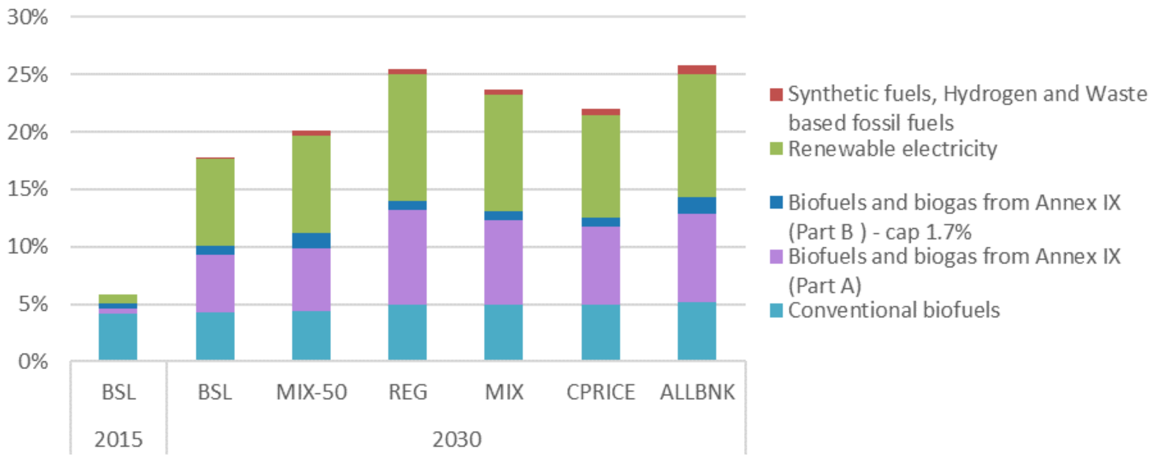
[93] Articles 25-27 revised RED where specific caps and multipliers apply for different renewable fuels

uptake of electric vehicles and further progress in the electrification of rail. This figure drops to 8% in MIX-50 while staying at 11% in ALLBNK.

The modelling results show that the total amount of liquid biofuels used in transport increases in the main policy scenarios, representing a share of 13-14%, compared to 10% in BSL. In the MIX-50 scenario, this value reduces to 11% while in ALLBNK, it stays at the upper level of 14%. The allocation of fuels between transport modes varies for the maritime and aviation sectors, which have fewer options to decarbonise. Advanced biofuels and, in the longer run possibly renewable and low-carbon fuels, including RFNBOs, will be more important.

Figure 43: Disaggregation of the renewable transport target as per RED II



Source: PRIMES model

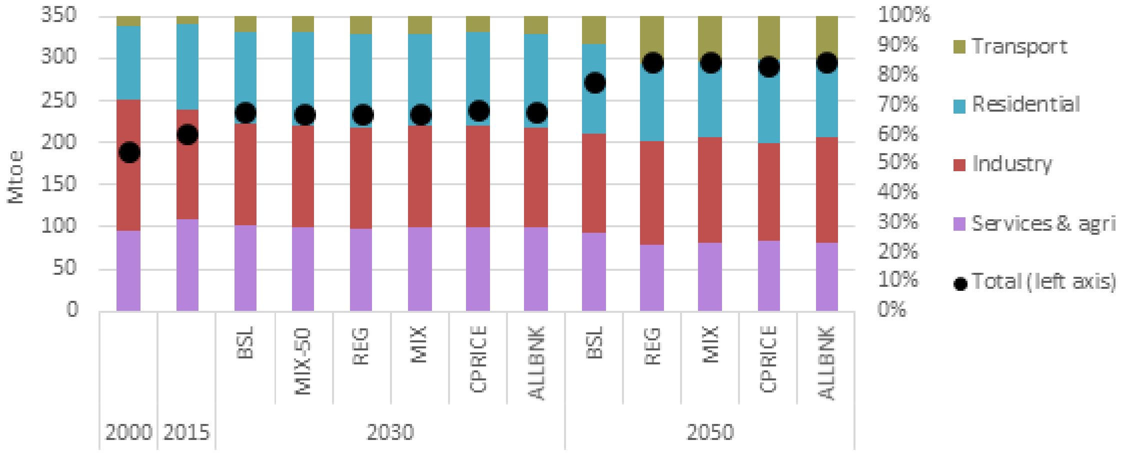
Detailed sectoral overviews on what transformation requires from individual sectors in relation to their energy emissions can be found in annex 9.4.2.1 addresses the electricity sector, annex 9.4.2.4 addressed the gas sector, annex 9.4.2.5 addresses the buildings sector, annex 9.4.2.6 addresses the transport sector and annex 9.4.2.7 addresses the industrial sectors.

9.4.2.3 Electricity supply and demand

In the context of a fuel switch away from fossil fuels to an increasing role of technologies like heat pumps or electric vehicles, the demand for electricity increases in all scenarios between 2015 and 2030, by 11% (REG) to 13% (CPRICE) and grows further by 2050[94].

[94] Relative to the level in 2015, demand increases to between 240 and 250 Mtoe by 2030, between 270 and 290 Mtoe by 2050

Figure 44: Final electricity demand



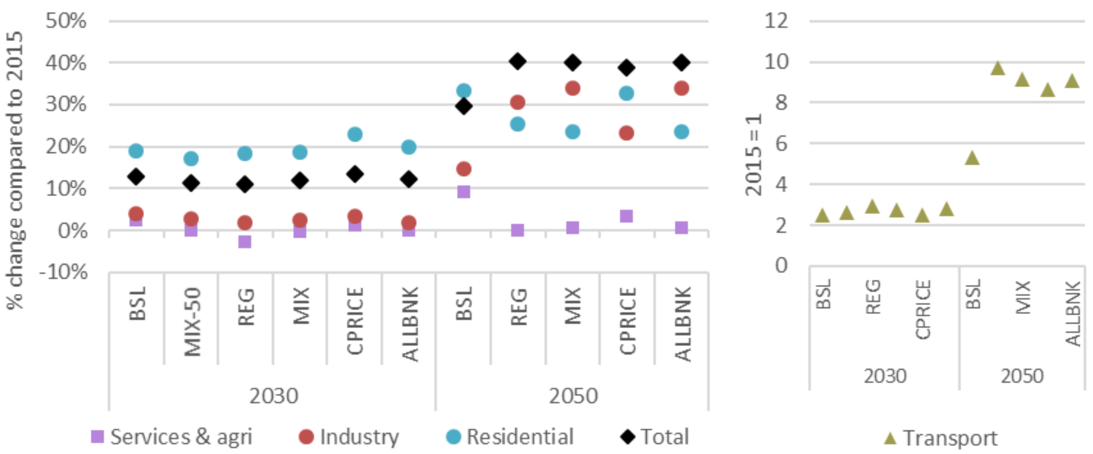
Source: 2015: Eurostat, 2030-2050: PRIMES model

Electrification will be driven by demand growth in the transport, industry and residential sectors while there is some decrease in services and agriculture, as shown in Figure 45.

Experiencing a stronger deployment of electric vehicles and some modal shift towards rail transport, the transport sector shows the strongest growth. Its electricity demand will increase over the period 2015 – 2030 by a factor of 2.5 in BSL and 2.5 - 2.9 in the policy scenarios. The policy scenarios also see a rise in electricity demand in the residential sector between 2015 and 2030 between 18% (REG) - 23% (CPRICE) vs. 19% in BSL. This figure reduces to 17% in MIX-50. The carbon price mechanisms acting in CPRICE leads to a comparatively stronger fuel switch towards electricity, notably for heating purposes, than in REG where increased energy efficiency reduces the demand for electricity (see annexes 9.4.2.5 and 9.4.2.7).

Industry and services show a mixed picture. While electricity consumption in industry grows in all scenarios, it does moderately less so in the policy scenarios (2% in REG and MIX and 3% in CPRICE) compared to BSL (+4% vs. 2015). Electricity consumption in the services and agricultural sectors range from lower than 2015 (REG, -3%) to slightly above (CPRICE, +1%), as a result of the interplay of electrification and energy efficiency.

Figure 45: Evolution of final electricity demand (compared to 2015)



Source: 2015: Eurostat, 2030-2050: PRIMES model

Until 2030 the production of electricity follows the path of the final energy demand for electricity (see Figure 46). In the BSL scenario, electricity generation increases from 2900 TWh in 2015 to 3100 TWh in 2030.

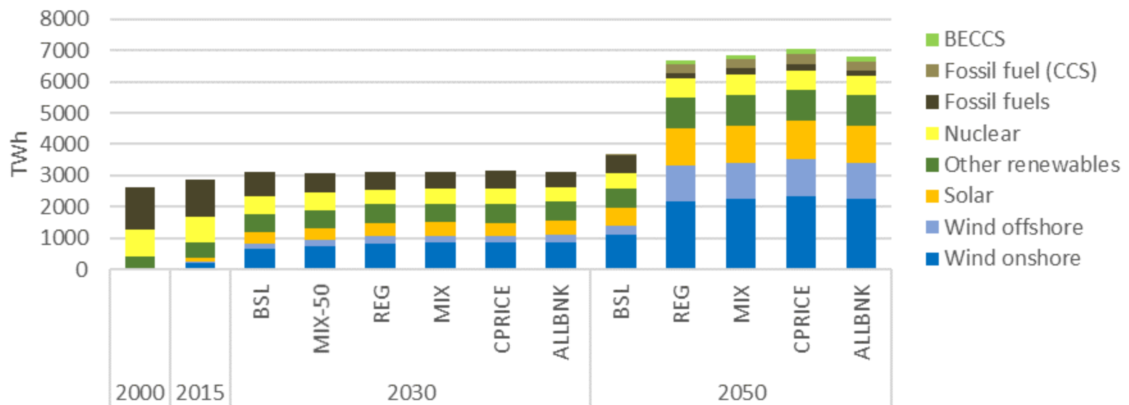
The energy mix of electricity generation continues moving away from fossil fuels. In the BSL scenario, their share in electricity generation falls steeply from 42% in 2015 to 24% in 2030. In the main policy scenarios, it reduces to 17% (MIX) - 18% (REG and CPRICE) in 2030. This figure increases to 20% in MIX-50 and falls further to 16% in ALLBNK. No significant deployment of CCS for power generation is projected in any of the considered scenarios during this time period.

Representing around 31% of gross electricity generation in 2015, the contribution of renewables keeps increasing across all scenarios. In BSL, renewables will be responsible for 57% of electricity generation in 2030, while for the policy scenarios this figure increases to 67% (REG, CPRICE) - 68% (MIX). This figure reduces to 61% for MIX-50 and further increases to 69% for ALLBNK.

The electricity system will increasingly face the need to integrate fluctuating wind and solar generators. Between 2015 and 2030, the share of wind and solar energy in electricity generation is projected to increase from 13% to 39% in BSL and to 48% in the main policy scenarios. The MIX-50 scenario sees a lower share of 43% while the figure further increases to 69% in ALLBNK. By 2030, wind energy would become the single electricity source with the highest share, providing 27% of all electricity in BSL and 34% (REG, CPRICE) - 35% (MIX) in the main policy scenarios. Lowering the GHG ambition leads to a wind share of 30% in MIX-50. In ALLBNK, this figure increases further to 36%. Solar energy will provide 12% of all electricity in BSL and MIX-50 and 14% in all other policy scenarios.

Driven by the Member States' policies, nuclear electricity generation falls by 2030 in both absolute and relative terms compared to 2015 to 585 TWh in BSL and 466 (REG) -493 (CPRICE) TWh in the main policy scenarios.[95] Nuclear generation increases to 578 TWh in theMIX-50 scenario while in ALLBNK, with 469 TWh, the figure stays in the range of the policy scenarios.

Figure 46: Electricity production



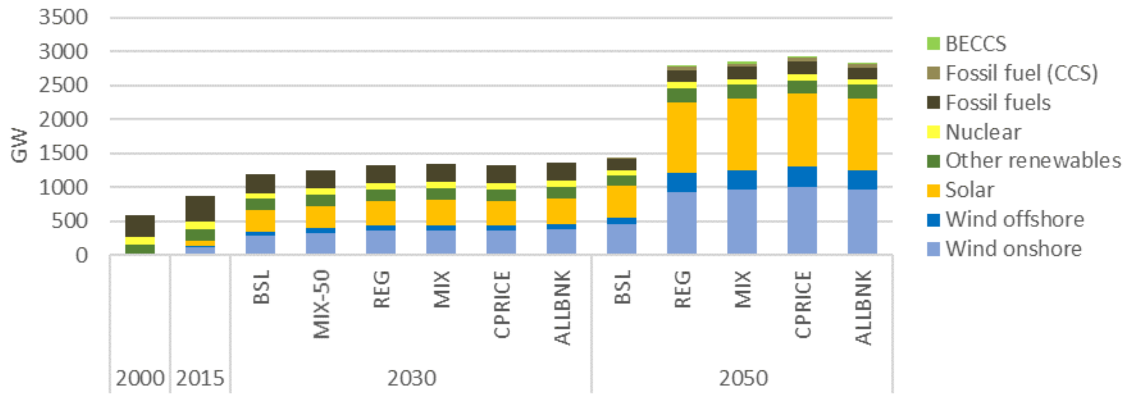
[95] The nuclear capacity somewhat increases post-2035. The 2030 nuclear capacity in the scenarios is close to what appears in the latest Nuclear Illustrative Programme (PINC) as per COM(2017) 237 final. Further information on the assumptions can be found in the methodological annex 7.3.

Source: 2015: Eurostat, 2030-2050: PRIMES model

Due to the meteorologically determined load factors of wind and solar electricity generation, the total installed capacity will have to increase by more than twice the rate than the electricity produced. In BSL, the capacity installed increases from 870 GW in 2015 to 1189 GW in 2030 and to about 1330 – 1343 GW in the main policy scenarios. In MIX-50, this figure reduces to 1241 TWh while it further increases to 1369 in ALLBNK.

By 2030, wind energy will have the highest installed capacity (343 GW in the BSL scenario and 433 – 439 GW in the policy scenarios), with most of the installed capacity being located onshore (295 GW in the BSL scenario and 361 – 365 GW in the policy scenarios). Lowering the GHG reduction ambitions would lead to an installed capacity of 390 GW (of which 326 GW offshore). ALLBNK will see an installed capacity of 452 GW, of which 374 onshore. Europe's seas will be at the forefront of the EU's efforts to go carbon-free: offshore wind[96] will be the fastest growing technology, with the installed capacity in 2030 reaching 48 GW in the BSL scenario and 70 (CPRICE) – 73 (MIX) GW in the policy scenarios. This reduces to 64 GW in MIX-50 and increases to 79 GW in ALLBNK.

Figure 47: Installed power production capacities



Source: 2000, 2015: Eurostat, 2030-2050: PRIMES model

By that date, solar energy will grow to 311 GW in the BSL scenario and to 363 – 370 GW in the policy scenarios. Lowering GHG reduction ambitions leads to an installed PV capacity of 329 GW in MIX-50. In ALLBNK, the installed capacity for solar energy reaches 374 GW.

During the same time, the installed fossil-fuel capacity will decrease to 272 GW in BSL and to 261 – 268 GW in the policy scenarios. By 2030, the combined installed capacity of the EU's nuclear power plants is projected to decline to 92 GW in all scenarios.

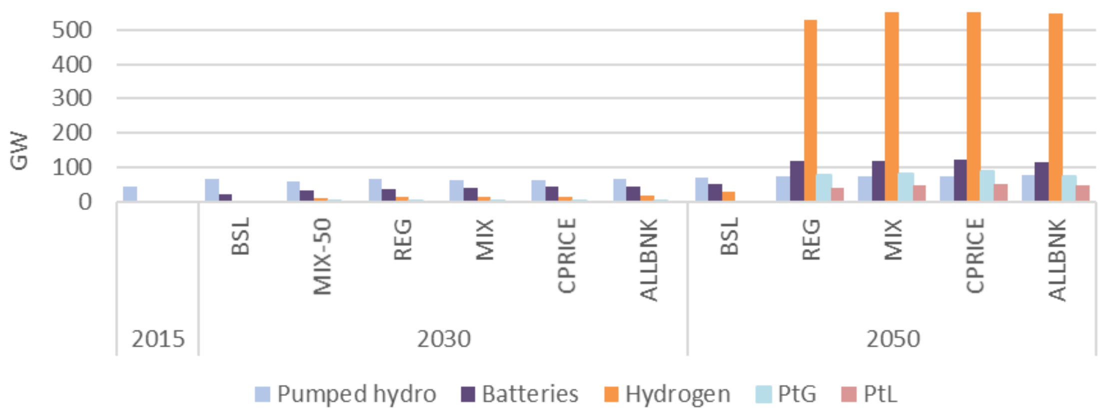
The increasingly volatile nature of the electricity generation sources will require deployment of storage solutions, as shown in Figure 48. Daily storage needs are currently met by pumped hydropower (PHS) and increasingly by batteries. By 2030, the PHS capacity will grow by from currently 45 GW to 64 GW in BSL and to 63 (CPRICE) – 65 (REG) GW in the policy scenarios.

[96] Gearing up these will require overcoming a number of barriers, in terms of costs decrease but also, like for offshore wind, anticipating potential conflicting uses of sea, seabed and coastal areas. It is paramount to guarantee that the expected deployment of offshore renewable energy does not harm the environment and contributes to the wider objectives of the European Green Deal, beyond the climate-neutrality target.

Batteries will add another 21 GW of electricity storage in the BSL scenario and 34 (REG) – 43 GW (CPRICE) in the policy scenarios.

The increasing demand for renewable and low-carbon fuels for transport and industry, in combination with a power system with increasing number of instances where electricity generation exceeds the electricity that can be consumed directly, increases the need for long-term storage of electricity and triggers the deployment of electrolysers for the production of hydrogen. By 2030, the installed electrolyser capacity[97] is projected to reach 1.5 GW in BSL and between 12-13 GW in the policy scenarios. The growth of the installed electrolyser capacity is expected to accelerate significantly after 2030, reaching already between 40 to 70 GW in 2035 and between 528 and 581 GW in 2050 in the policy scenarios. This development will go along with the decarbonisation of the gas system, which may necessitate partial repurposing of gas infrastructure[98].

Figure 48: Electricity storage and new fuels production capacity



Source: PRIMES model

9.4.2.4 Gas supply and demand

The coal phase out, taken into account in BSL, combined with the rising ETS prices promotes coal-to-gas switch in power generation. This was already noticeable in 2019. By 2030, natural gas is expected to remain an important contributor to total energy needs, being only 13% lower than in 2015. This result is in line with the results obtained in comparable modelling exercises.[99] [100]

[97] Measured in terms of electricity going into the electrolyser

[98] The deployment to scale of hydrogen infrastructure implies an enabling regulatory framework to trigger the development of new lead markets as well as sustained research and innovation bringing solutions to the market. Taking all steps would allow for an accelerated deployment of this option towards 2030, as foreseen by the Hydrogen Strategy.

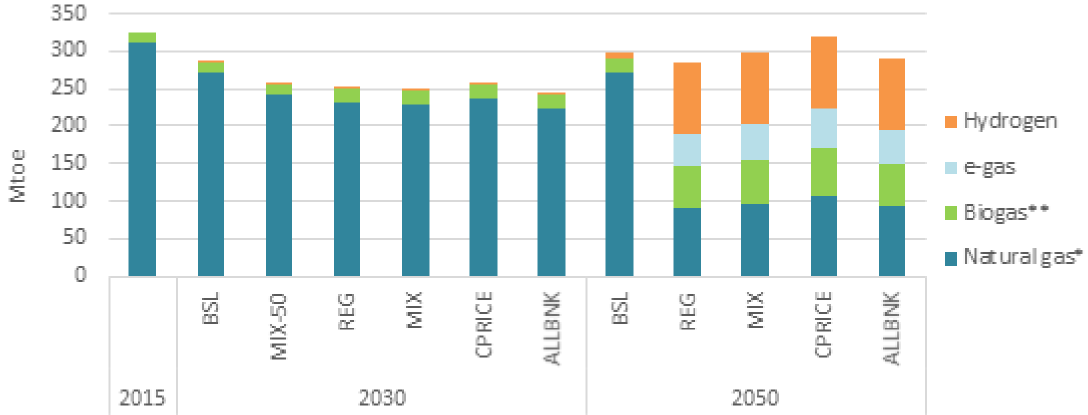
[99] Tsiropoulos I., Nijs W., Tarvydas D., Ruiz Castello P., (2020). Towards net-zero emissions in the EU energy system by 2050 – Insights from scenarios in line with the 2030 and 2050 ambitions of the European Green Deal, EUR 29981 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN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

[100] With similar 2030 climate and energy targets, the in-depth analysis attached to the long term strategy (Communication COM(2018) 773) showed markedly lower demand for natural gas than in the impact assessment: the main difference stems from the consideration, in this impact assessment, of the coal phase out policies announced by Member States.

However, policies aiming at further GHG reductions will lead to the substitution of natural gas by other forms of energy, notably renewables and electricity in final demand. As a consequence, the demand for gaseous fuels in the policy scenarios is lower than in BSL by 10% (CPRICE and MIX-50) - 13% (MIX and REG) (see Figure 49).

Natural gas plays a dominant role among gaseous fuels until 2030. However, by 2050, its unabated use will become incompatible with the climate-neutrality objective and its use is to be reduced by 66 - 71% compared to 2015 (as discussed in section 6.2.1.2).[101] Conversely, the demand for renewable and low-carbon gases is projected to become more than twice as high as the demand for natural gas. This is in sharp contrast with BSL, where renewable and low-carbon gases account for only 9% of the 298 Mtoe of gaseous fuels consumed (see also section 6.2.1.3). This trend constitutes a major technological transformation for the gas industry.

Figure 49: Consumption of gaseous fuels per gas type.



*Note: * includes manufactured gases, ** includes waste gas*

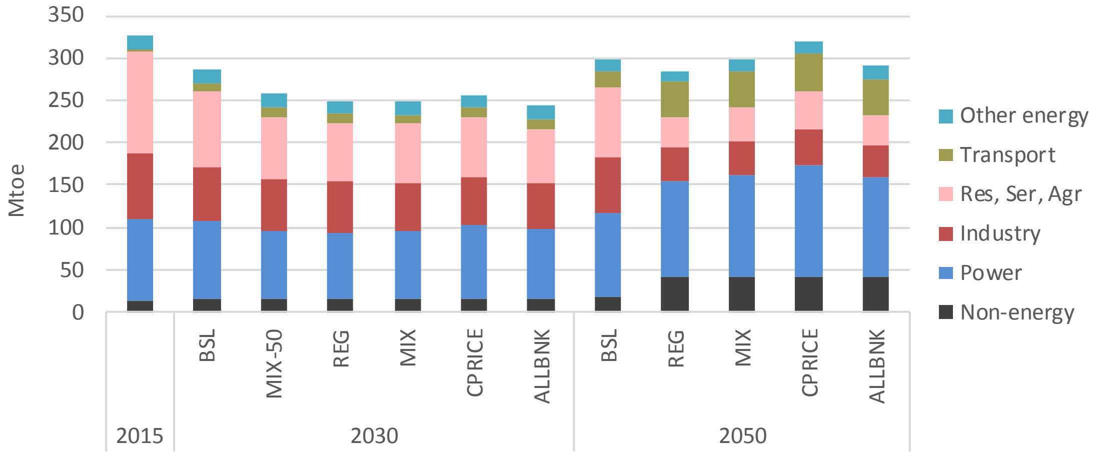
Source: 2015: Eurostat, 2030-2050: PRIMES model

The potential for biogas is limited and it is expected to be fully utilised by 2050. In all policy scenarios, hydrogen and e-gases account for 71% of all renewable and low-carbon gases in 2050. Among renewable and low-carbon gases, hydrogen is the most widely used accounting for approximately 46% (CPRICE) – 49% (REG) of these.

While renewable and low-carbon gases play a limited role by 2030, they are nonetheless increasingly deployed. In 2030, their consumption amounts to 17 (REG) – 20 Mtoe (CPRICE) respectively, compared to 15 Mtoe in BSL (and 16 Mtoe in MIX-50). This mostly includes biogas, while hydrogen is deployed modestly: at 0.4 Mtoe (REG) to 1 (MIX/CPRICE). As discussed in annex 9.4.2.1 dedicated policy measures may result in anticipated deployment of hydrogen and other renewable fuels.

[101] The public consultation revealed that most stakeholders believed that natural gas' continued use will create issues for achieving the 2030 climate ambitions, and that the focus should be on energy efficiency and electrification (2 265 stakeholders, 59%). There was, however, a significant difference between respondents in individual capacity (64%) and respondents in professional capacity (35%). This is also reflected in the responses to infrastructure planning where individuals prioritised electricity transmission and smart grids (40%) while professionals saw a balance between electricity and gas infrastructure as important (34%). The role of gas in the transition was, for example, also made by the paper submitted by EUROGAS.

Figure 50: Consumption of gaseous fuels per sector.



Note: includes natural gas, manufactured gases, biogas, waste gas, hydrogen, e-gas

Source: 2015: Eurostat, 2030-2050: PRIMES model

While consumption of gases in 2030 is similar in all scenarios, there are significant differences in their consumption per sector. Figure 50 shows consumption of gaseous fuels per sector. In 2030, consumption of gaseous fuels in the power sector decreases to 91 Mtoe in BSL and to 78 (REG) – 86 (CPRICE) Mtoe in the policy scenarios.

The situation is different in industry: consumption of gaseous fuels in 2030 amounts to 64 Mtoe in BSL and drops in policy scenarios to 57 (CPRICE) 59 (REG) Mtoe (60 Mtoe in MIX-50). In the residential, services and agricultural sectors, the use of gaseous fuels decreases in the BSL from 119 Mtoe in 2015 to 91 Mtoe in 2030. The decrease is steeper in the policy scenarios, reaching in 2030 75 Mtoe in MIX-50 and 69 (REG, MIX) – 70 (CPRICE) Mtoe in the other scenarios. In the transport sector, the use of gaseous fuels increases from 3 Mtoe in 2015 to 11 Mtoe in 2030.

9.4.2.5 Buildings, including fuel mix

Buildings (residential and non-residential in services sector), currently consume a large share (40%) of final energy in the EU. They are also responsible for 36% of GHG emissions, if emissions from final energy consumption are combined with supply side emissions stemming from electricity and heat consumed in this sector.

The evolution of energy demand is differentiated in the scenario results. In addition to policies present already in the BSL, a carbon price of EUR 60/t of CO_2 in 2030 in CPRICE delivers a significant switch of heating fuels already in 2030, shifting away from natural gas and other fossil fuels[102] to mostly electricity but also renewable energy (e.g. ambient heat consumed by heat pumps, biomass, biogas and solar thermal). REG delivers quite similar results, albeit mostly focused on heat pumps uptake as both incentives for renewable energy in H&C and dedicated policy to support heat pumps are assumed in this scenario.

[102] In 2030, solid fossil fuels and oil have marginal shares in the fuel mix of buildings already in BSL. These fuels are used by buildings that do not have the full menu of options (remote areas or poor households).

On the other hand, the carbon price alone delivers only a weak incentive for the renovation[103] of buildings in CPRICE. Its impacts are limited to a small increase in medium scale renovations, mainly in the services sector. Conversely, in REG, high ambition renovation policies push for a large increase in the rate of deep renovations of buildings envelope – especially in the residential sector but also in services.

MIX uses all four policy levers mentioned above: a carbon price of EUR 44/t of CO_2 in 2030, incentives for renewables in H&C, support for heat pumps and renovation policies - albeit all of them at smaller intensity compared to REG. As a result MIX represents an approach in-between REG and CPRICE. ALLBNK scenario has very similar drivers and performance compared to MIX in terms of renovations. In terms of fuel mix in buildings, ALLBNK achieves the deepest reduction of the fossil fuels share due to very high carbon price of EUR 65/t of CO_2 in 2030. MIX-50 scenario has the same results as CPRICE in terms of renovations while its share of fossil fuels is highest among all policy scenarios in the residential sector and within the range of other scenarios in services.

The projections discussed below show that fuel switch in heating in buildings is the key avenue for buildings to contribute to an increased 2030 climate target. Energy efficiency measures are also a powerful enabler as they lower energy demand needed thus also reducing the size of the heating equipment needed. This also reduces related capital and running costs, shielding vulnerable consumers from the impact of increasing energy prices.

As a result of fuel switch and renovations, in all policy scenarios considered in this IA, buildings generate the largest (amongst other final energy consumption sectors) GHG reduction levels by 2030 (compared to 2015), i.e. 61% to 65% in the residential sector and 54-61% in services for 55% GHG scenarios. Fuel switch is the key factor for the decarbonisation present in all scenarios, triggered by carbon pricing in CPRICE, or renewables incentives and support for heat pumps (in REG) or combination of all drivers (in MIX). Within the range indicated above, ALLBNK and CPRICE achieves the highest reductions in the services sector and REG and ALLBNK in the residential sector. MIX-50 has lower GHG emissions reductions in the residential sector that other policy scenarios but for services, it is results are within the range.

In order to achieve climate neutrality by 2050, both the push for renovations and fuel switch will need to be intensified after 2030, the latter aided by the deployment of renewable and low-carbon gases (notably hydrogen and e-gas).

Energy efficiency in buildings

[103] Energy renovation means the change of one or more building elements (building envelope and technical building systems), which leads to energy savings and improves the energy performance of a building. There are different approaches to define the depth of renovation of the building envelope. It can be defined based on the total floor area affected by renovations (in square meters) or based on achieved energy savings (average annual reduction of energy consumption for different renovation depths, that represent different ranges of energy savings achieved).

- Light renovations (3% ≤ x ≤ 30% savings)
- Medium renovations (30% < x ≤ 60% savings)
- Deep renovations (x > 60% savings)

The different depths do not necessarily need to cover a specific minimum number of measures but are just classified depending on the savings achieved compared to the energy performance level of the building before the energy renovation.

The annual renovation rate is defined as the percentage of the building stock that is renovated. The bulk of the existing building stock was built without serious energy performance requirements, while the current renovation rate is only about 1% annually. The rate of deep renovation is only around 0,2%.

The most important single energy use in buildings is space heating and cooling. Consequently, the key action for energy efficiency in buildings is reducing the demand for heating and cooling via renovation of the building envelope (e.g. insulation and windows), especially for buildings constructed years ago, without high energy performance standards.[104] Renovations of buildings envelope improve thermal integrity of buildings and thus lowers their demand for space heating (and cooling), without lowering the comfort levels in terms of indoor temperature. Besides renovations of the building envelope, minimum energy performance standards for new buildings, standards and labelling for new energy consuming equipment (notably heating equipment), electrification of heating, uptake of renewable solutions (e.g. solar systems) in heating or simply change for a more efficient heating equipment as well as "smart buildings" technologies also lead to moderation of buildings energy demand. Consumer choice can be also a strong driver (as discussed in the in-depth analysis accompanying "Clean Planet for All" Communication) but was not explored in detail in the scenarios of this impact assessment due to the shorter time focus.

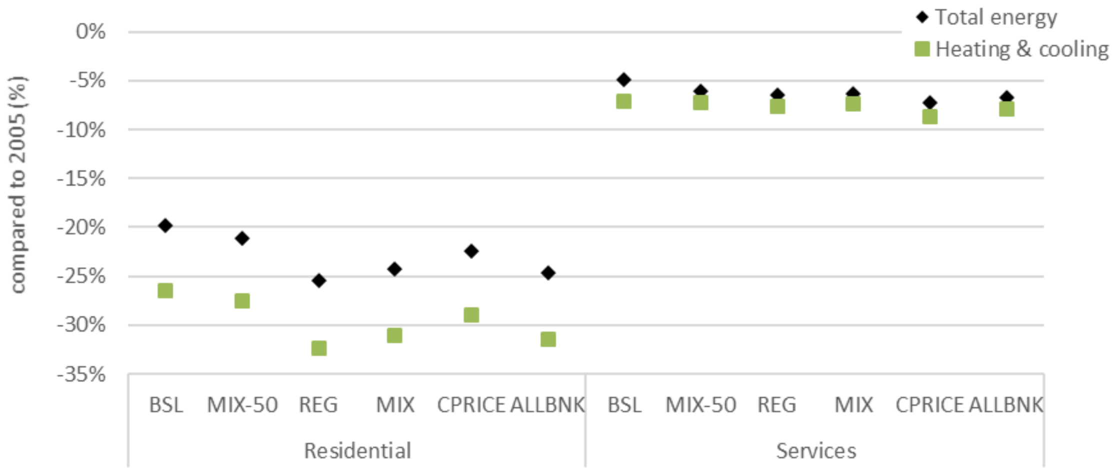
This effort to moderate energy demand needs to happen against the foreseen trend of growing number of dwellings, their size and comfort level in the residential sector. As for the services, energy consumption is expected to raise even faster as their share in the economy grows. These socio-economic trends push up the energy consumption in buildings. While the first trend is of modest strength due to current demographic outlook, the latter is stronger.

Moderation of energy demand is well underway in the EU as illustrated by the BSL scenario, assuming effective policies are put in place to achieve the EE and RES targets. Achieving the existing 2030 energy targets would result in significant final energy savings discussed in annex 9.3.3, and the policy scenarios would lead to further energy consumption reductions. In the residential sector, these would result in reductions ranging from 22% (CPRICE) to 25% (REG) compared to 2005. The ALLBNK scenario is close to the upper range. MIX-50 scenario has lower reductions than all 55% GHG scenarios. Much stronger reductions are achieved in REG, which illustrates the effects of energy efficiency policy targeted at renovations. In the other policy scenarios renovations trends are more modest but electrification of the fuel mix also reduces energy demand. The reductions would deepen by 2050 with a widening range from 27% (MIX-50) to 37% (REG) compared to 2005.

In the services sector, energy savings in all scenarios are projected at between 6-7% compared to 2005, with CPRICE and ALLBNK performing marginally stronger, which illustrates how in the services sector a significant carbon prices would incentivise renovations as well as reduce energy demand through electrification. The reductions would deepen and range would widen by 2050 with reductions ranging from 17% (CPRICE, MIX-50) to 21% (REG), still compared to 2005.

[104] The option rated as most relevant in the public consultation for residential buildings is also improving the thermal properties of buildings ('better isolation') as 1 426 stakeholders (40% rating 5) answered. For non-residential buildings this is not the top option but still achieved rating 5 for 26% of all responses – introducing more energy efficient heating and cooling system also is rated 5 for a high number of respondents. Decarbonising the heating and cooling systems through improving thermal efficiency, substituting fossil fuel heat by different technologies (such as electrification or solar power) and building renovations to upgrade older systems was also the focus of the position papers submitted.

Figure 51: Evolution of the energy consumption in buildings in 2030 (compared to 2005)



Source: 2005: Eurostat, 2030: PRIMES model

The reduction in final energy demand for space heating & cooling follows a similar pattern as total final energy consumption. In the policy scenarios, both in residential and services sectors, further reductions (compared to BSL) are achieved. In the residential sector, the reductions (compared to 2005) are the highest in REG scenario (32%) while in services sector reductions are the highest in CPRICE (9%). By 2050 these reductions magnify in all scenarios. Climate neutrality by 2050 will rely strongly on further reduction of energy demand for space heating and cooling.

The reduction of energy demand for heating and cooling is due, to a large extent, to the improvement of the thermal integrity of the building shell mainly through an increased renovation rate and depth reaching the minimum energy performance standards for renovated buildings. The high energy efficiency performance standards of new buildings as required by the EU legislation have a smaller effect due to very low rate of new constructions[105]. Importantly, the scenarios have results that reflect a broad category of renovations:

- Type 1: improvement of thermal integrity of buildings through renovation of the building shell,
- Type 2: change of heating equipment,
- Type 3: combination of both actions.

A very significant increase of Type 1 renovations is assumed in REG and MIX, with ALLBNK assumptions that are very close to MIX. MIX-50 scenario has assumptions slightly lower than MIX and consequently results close to CPRICE. Renovations in CPRICE is driven mainly by the high carbon price, which appears to incentivise them only very modestly. Type 2 renovations (that lead to fuel switch) are also incentivised by carbon pricing (CPRICE) or the general energy efficiency and renewables in H&C incentives and support from heat pumps uptake (REG) or all four drivers combined (MIX). No specific targets for such rates were, however, assumed. No assumptions were made on Type 3 renovations, which in the results exhibit very low rates and little differentiation among policy scenarios.

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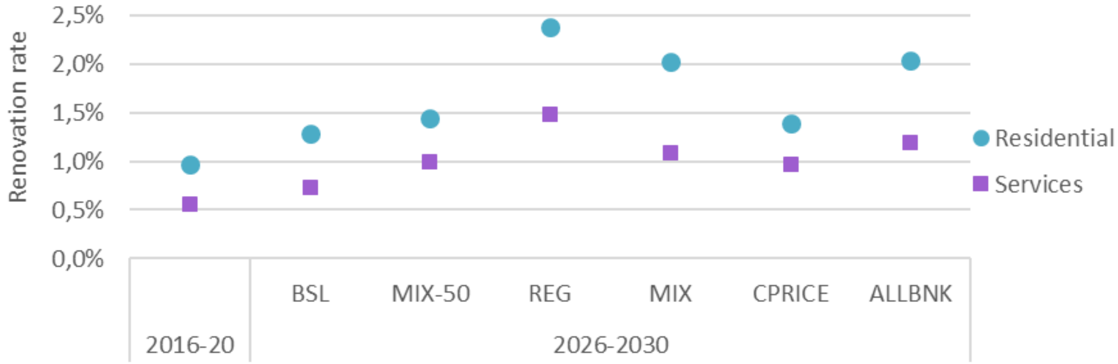
[105] In fact, the BSL and all policy scenarios apply existing measures under the EPBD, which require new buildings to be nearly-zero energy buildings in terms of energy consumption as of 2021 (2019 for public buildings).

Focussing on Type 1 renovations, in the residential sector, MIX assumes a doubling of building shell renovations, from 1% achieved on average in 2016-20 period to 2% on average in 2026-30 period[106]. REG assumes more than a doubling of the rate, from 1% to 2.4% on average in 2026-30 period.

Similarly, in the services sector, MIX reflects a doubling of the rate of building shell renovations from 0.6% achieved in 2016-20 period to 1.1% on average in 2026-30 period. REG assumes more than a doubling of the rate from 0.6% to 1.5% on average in 2026-30 period.

Both scenarios also assume addressing the current market failures (e.g. access to finance, split-incentives, etc.) preventing economic actors from renovations that are cost-effective. As a consequence, the scenarios project higher renovation rates with deeper energy-related renovation than observed historically and in the BSL.

Figure 52: Renovation rates (Type 1) in buildings in 2026-30



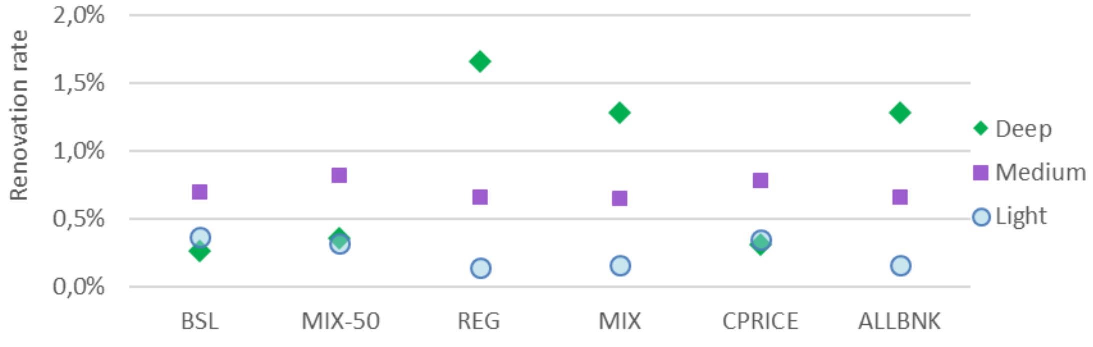
Source: PRIMES model

Both scenarios also assume increased average depth of renovations, with REG aiming at even deeper renovation than MIX. In the residential sector, in the period 2026-30, REG is the scenario that has, by design, the highest rate of deep renovations (i.e. intervention on walls, windows, roof and basement) "at the expense" of light renovations (i.e. intervention on windows only), which are lower than in the BSL. MIX also increases the rate of deep renovations (but less so than REG), while its rates of light renovations are also lower (compared to BSL). Finally, CPRICE keeps all types of renovations stable compared to BSL except for a small uptick in medium renovations (i.e. intervention on walls, windows and roof). The different depths of renovations pursued result in differing energy savings achieved from refurbishment. The savings resulting from all these types of renovations combined vary in the residential sector from 66% (REG) to 52% (CPRICE) compared to 50% in BSL (average annual values for 2026-30).

The results are different in the services sector as here in the period 2026-30 all scenarios further increase (compared to BSL) medium type of renovations albeit with smaller differentiation among policy scenarios. Differentiation is also smaller for deep and light types of renovations. REG has the highest increase of deep, medium and light renovations (compared to BSL). As to the resulting savings from all these types of renovations combined, they are over 40% in all scenarios compared to 37% in BSL (average annual values for 2026-30).

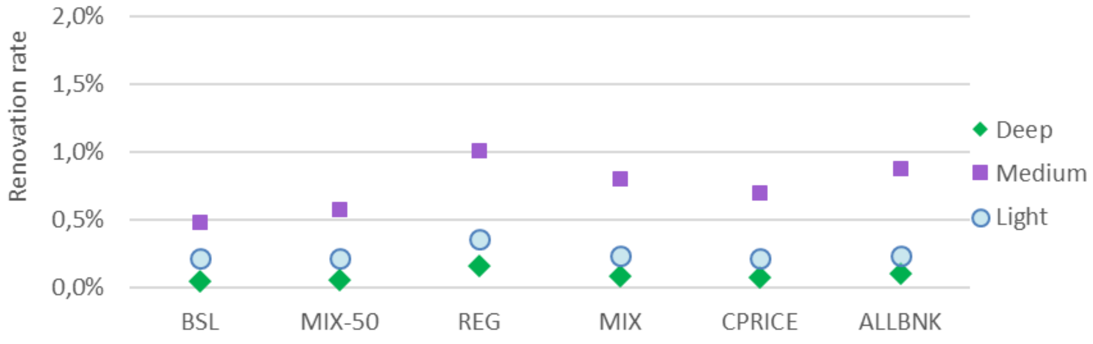
[106] PRIMES model solves for every 5-year period and cannot reflect precisely scaling up of the renovation rates during these 5-year periods.

Figure 53: Renovation rates (Type 1) per type of energy renovation in Residential buildings in 2026-30



Source: PRIMES model

Figure 54: Renovation rates (Type 1) per type of energy renovation in Services buildings in 2026-2030



Source: PRIMES model

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 in order to reach climate neutrality. In this time-frame, REG would still see the highest rate and depth of renovations in both residential and services sectors.

Rates of renovations that concern the change of heating equipment only (Type 2) show less of differences between the scenarios as they are around 4% in all policy scenarios in both residential and services sector. CPRICE achieves slightly higher rate of heating equipment change under the pressure of the carbon price. This rate of renovation reflects in fact the fuel switch described in detail in the section below. Finally, some of the renovations of the building envelope also involve changing the heating equipment (Type 3 renovations). The rate of such renovations is low and differs only slightly among scenarios, between 0.3%-0.6% in residential and services sector. The highest rate of such renovations happen in REG in line with the highest rate of building shell renovations.

Higher and deeper renovation of the building envelope, together with change of heating equipment, lead to higher investment needs (and thus capital costs) for buildings. However, these investments are to some extent (depending on the condition of the building and the type and depth of the renovation) compensated by decreasing energy purchase expenditure, leading to only moderate increases in the total energy system costs, both in residential and services sectors – see annex 9.5.2.1. While energy purchases costs decrease in all scenarios thanks to renovations lowering energy demand, the carbon price in MIX and CPRICE makes these reductions smaller if full energy costs are taken into account[107]. Capital costs can be split into equipment costs (mostly relating to heating equipment but covering also appliances) and renovation costs (for the building envelope). Both equipment capital costs and renovations capital costs are the highest in REG with differences in residential sector more pronounced than in the services.

The sections above describe the main factors in the moderation of energy demand in buildings. It has to be noted that in both sectors, particularly in the services sector, increasing electrification of heating is a strong trend, which also reduces energy demand. The increased uptake of modern electric heating (notably heat pumps) leads in fact to efficiency gains in heating consumption. While the share of electricity in heating increases very fast in policy scenarios, the overall electricity consumption of heating grows at a slower pace thanks to the efficiency of the modern electric heating. This effect is even more pronounced in the services sector, where electricity has already today a higher share, which further increases towards 2030.

Beyond renovation of the building (envelope and heating equipment), improvements in the energy performance of heating equipment and appliances, digitalisation through buildings automation, control and smart systems (BACS, and other "smart buildings" technologies) also contribute to reducing energy demand (especially of useful energy demand) of buildings in the scenarios. A "smart building" can partially reduce the need for renovation. However, the scenarios only included rather conservative and not differentiated assumptions reflecting this aspect (mostly in terms of demand-side response).

Fuel mix in buildings

All scenarios display already by 2030 some fuel switch that is amplified by 2050. Interestingly, this fuel switch is driven by different policy set-up. The key trend that can be observed already historically and in the previous modelling exercises is that buildings will experience a rapid growth of electricity consumption and a decrease of fossil fuels (notably gas). In the residential sector, the share of electricity would increase from almost 25% today to 35-37% in all policy scenarios in 2030 and this share will be around 45% in all scenarios by 2050. In services, the electricity share today is already much higher: almost 50% and would increase to around 55% in all policy scenarios by 2030 and will reach some 60% in all scenarios by 2050. MIX-50 has the electricity shares that are broadly in range with all other policy scenarios albeit at the lower end. Conversely, ALLBNK is also within the range but closer to higher end. As discussed in the in-depth analysis accompanying Clean Planet for All Communication, electrification of the demand combined with decarbonised electricity supply and self-generation of renewables are fundamental aspects in order to reach climate neutrality by 2050[108].

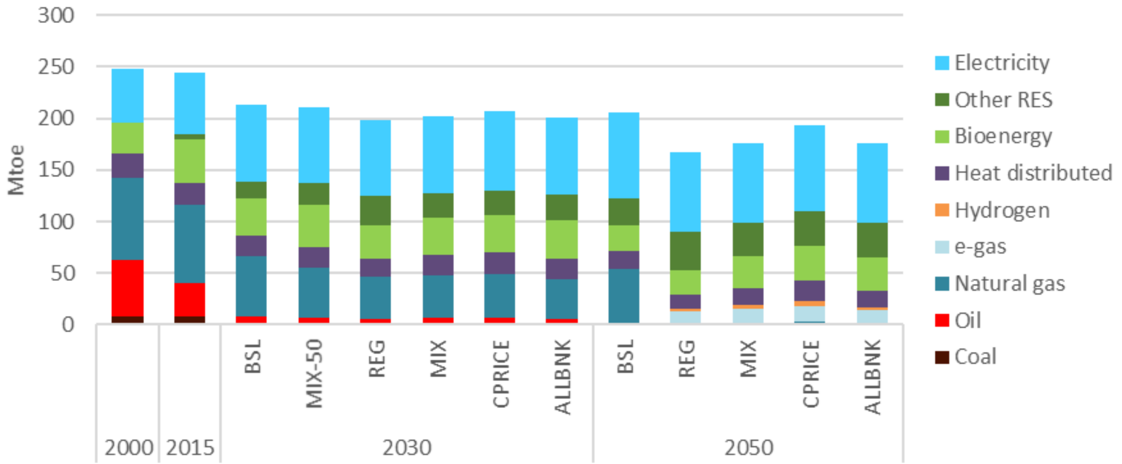
In both sectors, electrification is driven by rapid deployment of modern electric heating that also helps with moderation of energy demand as described in the section above. Efficiency of the use of electricity in buildings sector is well illustrated by the limited growth in absolute consumption of electricity contrasted with rapid increase in electricity shares, especially in services sector.

[107] See discussion in section **Error! Reference source not found.** on the impacts of recycling of carbon price revenues.

[108] The paper submitted by Energy Norway for example also mentions electrification of buildings and its dependency on energy efficiency and infrastructure.

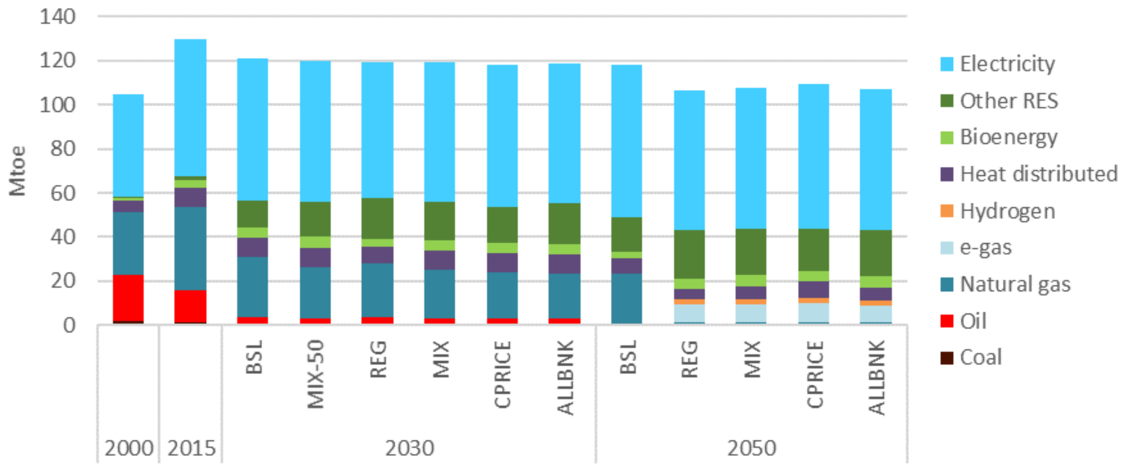
This trend would be amplified by 2050. An ever increasing number and use of appliances (albeit moderated by energy efficiency measures) also drives up electricity demand.

Figure 55: Energy demand in residential buildings



Source: 2000-2015: Eurostat, 2030-2050: PRIMES model

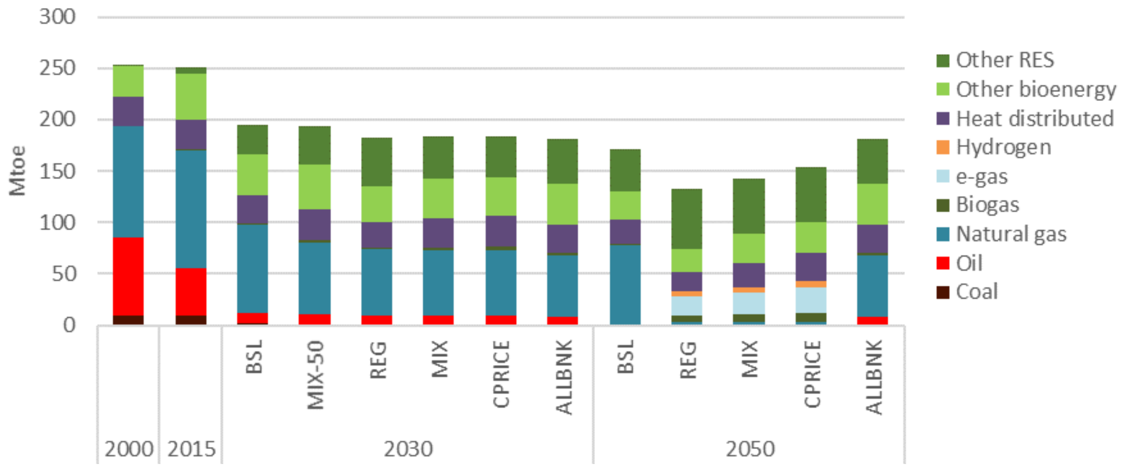
Figure 56: Energy demand in services



Source: 2000-2015: Eurostat, 2030-2050: PRIMES model

With the higher penetration of electricity, and an overall reduction of demand, the consumption of other fuels, notably fossil fuels declines accordingly. Non-electricity fuels are used only for heating purposes and looking at them, the decline of fossil fuels is even more clearly visible.

Figure 57: Non-electricity energy consumption in (residential and services) buildings



Source: 2000-2015: Eurostat, 2030, 2050: PRIMES model

Natural gas still represents the bulk of remaining consumption in final energy consumption in residential buildings albeit falling from the 31% share observed now to slightly over 20% in all policy scenarios in 2030. In the services, from 29% currently observed, gas share decline to also some 20% in all policy scenarios in 2030. Very pronounced fuel switch in ALLBNK, CPRICE and MIX scenarios shows that carbon pricing at levels that are projected for these scenarios has a strong impact at supressing demand for natural gas. But also incentives for renewables deployment in heating and cooling together with support for heat pumps are effective in REG, MIX and ALLBNK scenarios. ALLBNK scenario has the smallest absolute amount of gas use in residential buildings. In services sector it is carbon pricing that leads to smallest absolute amounts of gas use in CPRICE and ALLBNK. MIX-50 has the natural gas shares that are only slightly higher compared to all other policy scenarios in both sectors.

The trends amplify further in 2050 with natural gas shares declining to around some 1% in both residential and services sector in all policy scenarios as in this perspective e-gas and hydrogen uptake would lead to a considerable substitution among gaseous fuels. Neither hydrogen nor e-gas have any uptake in buildings in 2030 perspective.

Renewable energy (other than ambient heat required for heat pumps) increases slightly its share in buildings in the BSL in 2030 and in 2050 perspective. Biomass (used in modern stoves) increases only very slightly its share in residential sector from 17% today to 18% in 2030 in MIX and ALLBNK while REG shows slightly declining share (as here heat pumps uptake dominates the fuel switch) and in CPRICE the share is stable. Likewise, in the services sector the share of biomass in policy scenarios increases very slightly from 3% today to 4% in 2030 in MIX and CPRICE while in REG the share is stable. In modelling results, biogas, solar thermal and geothermal also have only marginal shares in energy consumption. Distributed heat maintains by 2030 its share of today 9% of total energy demand in residential buildings in REG or grows it by 1 p.p. in all other policy scenarios. In services sector the current share of 6% is maintained by 2030 in REG and grows by 1-2 p.p. in other policy scenarios. Both in residential and services sectors, the share of distributed heat remains stable post-2050.

9.4.2.6 Transport, including fuel mix

Overall Transport Activity

In the BSL scenario, which does not take into account the implications of the Covid-19 pandemic, intra-EU passenger transport activity is projected to rise by 19% between 2015 and 2030, with the highest growth seen in intra-EU aviation (56%). Rail would grow by 32%, driven in particular by the opening of the market for domestic passenger rail transport services and the assumed completion of the core TEN-T network, supported by the CEF funding. Activity of private cars is projected to grow at a slower pace, by 14% during 2015-2030. At the same time, international extra-EU aviation[109] is expected to rise by 52%. However, with aviation being one of the most affected sectors by the COVID-19 pandemic and considering the large uncertainties related to the duration of the pandemic and its impacts on transport activity, growth scenarios are likely to be affected, particularly in the coming years. After 2030, also under pre-COVID, passenger transport activity is expected to grow at a slower pace for all transport modes. This is linked to the assumed socio-economic developments and saturation effects (e.g. car ownership is close to saturation levels in many Western European countries).

Regulatory measures and carbon pricing included in scenarios REG, MIX, CPRICE and ALLBNK would lead to some reduction in the overall passenger transport activity of the most polluting modes relative to the BSL. However, passenger transport activity still shows sustained growth relative to 2015 in all scenarios (18-20% by 2030) In CPRICE scenario, the carbon pricing and the gradual internalisation of external costs ("smart" pricing) for buses, cars and vans, favour a shift from road towards rail. The MIX and REG scenarios also reflect specific measures that support multimodal mobility and investments in sustainable, safe and smart transport, measures that incentivise connected mobility and improved traffic management and measures to support sustainable urban transport. In addition, the REG scenario also covers other measures to push digitalisation and automation in transport. The highest impact on rail transport activity is projected in the REG scenario, showing around 13% increase in 2030 compared to BSL Incentives for sustainable urban transport and the review of energy taxation would lead to higher impact on private vehicles in the REG scenario relative to CPRICE, resulting in 1.2% decrease in road activity relative to the BSL in 2030. CPRICE and ALLBNK scenarios show higher impacts on air transport activity, driven by carbon pricing and other technical and operational measures, projecting a decline of 0.7 to 1.1% by 2030 compared to BSL respectively. In general, ALLBNK strengthens the effects of MIX. In the less ambitious MIX-50 scenario, reductions are 0.45% in passenger transport activity compared to BSL.

In BSL scenario, the overall freight transport activity is projected to grow at faster pace than passenger transport activity, at around 33% between 2015 and 2030. The highest growth would take place for rail freight activity (40% by 2030), supported by the completion of the TEN-T core network, followed by heavy goods vehicles activity (34% increase by 2030). Transport activity of freight inland navigation (inland waterways and national maritime navigation) also benefits from the completion of the TEN-T core network and the promotion of inland waterway transport and would grow by 19% by 2030. The significant growth in rail freight activity and freight inland navigation is also supported by road pricing (the revision of the Eurovignette Directive) and the implementation of electronic documentation for freight transport. After 2030, the growth in freight transport activity is projected to slow down in line with the assumed macro-economic developments.

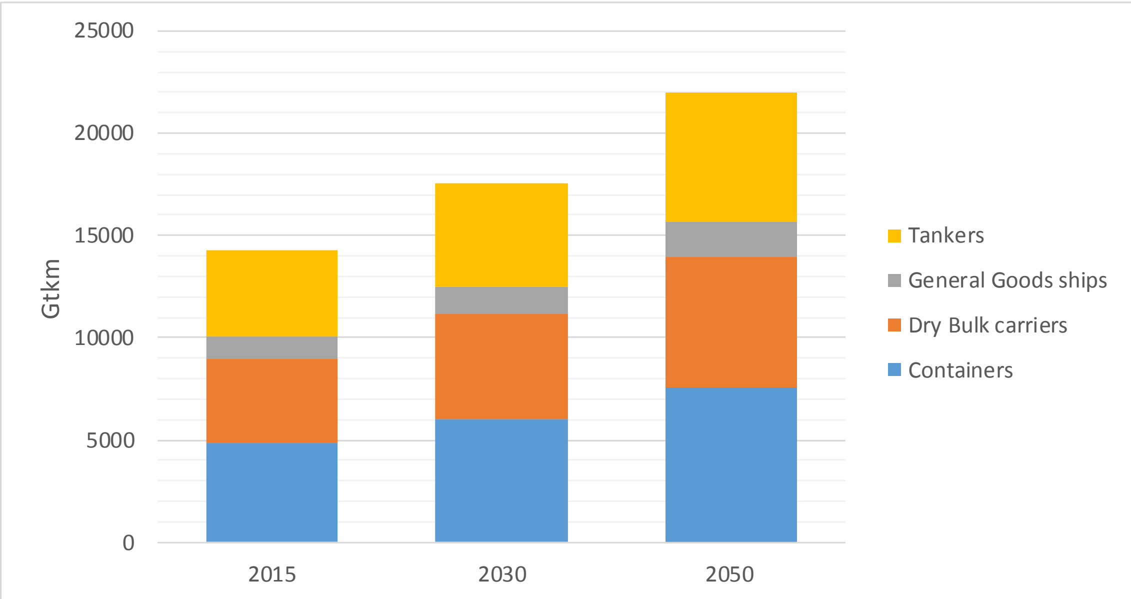
All policy scenarios lead to a shift from road towards rail and inland navigation for freight transport, driven by initiatives to increase and better manage the capacity of railways and

[109] Flights between EU member states and third countries

waterborne transport, incentives for intermodal transport and gradual internalisation of external costs ("smart" pricing). The largest impact on rail freight and inland navigation activity is projected in the REG scenario (13% increase for rail freight in 2030 relative to the BSL and 11% increase for inland navigation) but the impact is positive in all scenarios (0.8 to 13% increase for rail and 0.5 to 11% for inland navigation). On the other hand, road freight activity declines by 1.7 to 3.1% in 2030 relative to the BSL. The highest decrease relative to the BSL is projected in the REG scenario, driven by the revision of energy taxation, ambitious measures to gradually internalise the external costs ("smart" pricing) and other measures to improve the efficiency of road freight transport. In MIX-50, road transport activity declines by 2.2%.

As shown in Figure 58, international maritime transport activity is expected to grow strongly in BSL (by 23% between 2015 and 2030), due to, for instance, rising demand for primary resources and container shipping. In the policy scenarios, the growth in activity is somewhat lower than in BSL (around 22% for 2015-2030) despite some shifts taking place from road to short sea shipping. This is primarily due to lower imports and thus transport demand for fossil fuels.

Figure 58: International maritime freight activity in BSL in 2015, 2030 and 2050

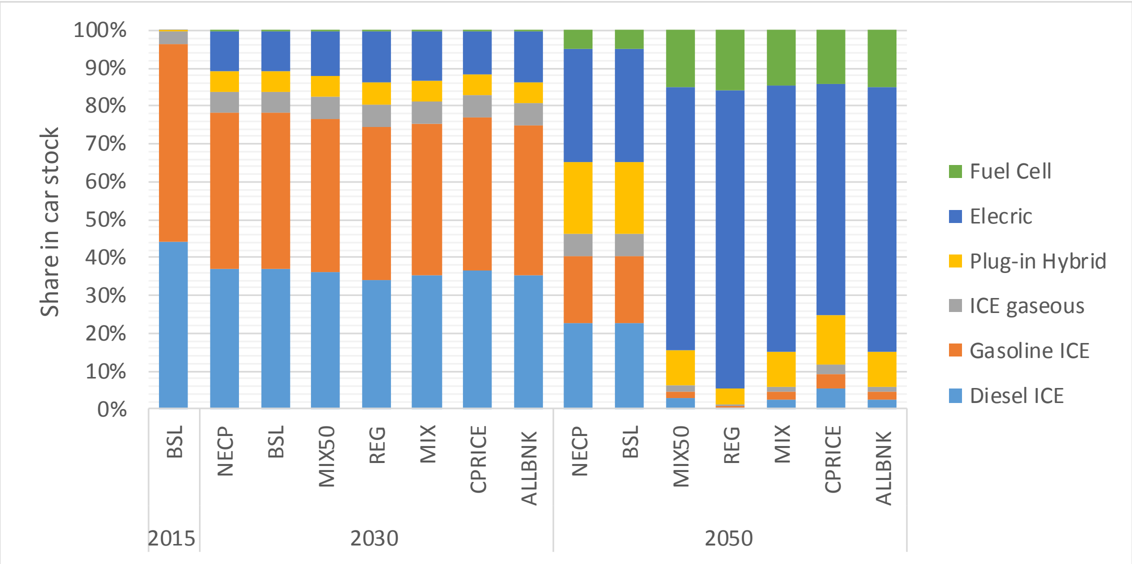


Source: PRIMES model

Vehicle technologies in road and other land based transport

CO_2 emissions standards for vehicles play a key role in emissions reductions, energy consumption and powertrain technologies. Intensification of their ambition level has an important impact on penetration of zero- and low-emission vehicles and on greenhouse gas emission reductions by 2030. It is instrumental to further reduce emissions and energy consumption in the period post-2030 with the renewal of the fleet and a faster penetration of zero-emission vehicles. As shown in Figure 59, the vehicle stock share of electric cars is projected to go up to 11% by 2030 in the BSL scenario and to 11-14% in the policy scenarios. The share of low and zero emission cars (including battery electric, fuel cells and plug-in hybrids) would increase from 16% in 2030 in BSL to up to 20% in the policy scenarios, driven by the assumed tightening of the vehicle standards supported by the deployment of the recharging infrastructure for electric vehicles and refuelling infrastructure for fuel cells. These shares will increase rapidly post 2030 thanks to the fleet renewal (vehicle standards apply to new vehicles therefore there is a delay between their introduction and the powertrain changes in the stock of vehicles), driving down greenhouse gas emissions from road transport even more intensely than in the period up to 2030. For example, the REG scenario has 47% zero and low emissions cars (ZLEV), out of which 33% zero emission cars (ZEV) by 2035, whereas in the CPRICE scenario the numbers are 33% ZLEV and 23% ZEV, and in the baseline 27% LEV and 17% ZEV. This shows that the impact of vehicle efficiency standards set for 2030 would be very significant, albeit with a time delay. By 2050, almost all cars (between 88-99% of the vehicle stock) need to be low or zero emission in order for the climate neutrality target to be attainable. Large scale deployment of recharging infrastructure for electric vehicles and refuelling infrastructure for fuel cells would be needed to support these developments. In 2050 zero emission vehicles are projected to represent 99% of the fleet in REG, due to strong vehicle efficiency policies. On the other hand, with existing policies and targets, as in BSL, low emission vehicles are projected to reach 54% of the stock in 2050, but fossil ICEs remain common in the fleet. This analysis confirms that intensification of the existing CO_2 emission standards is necessary.

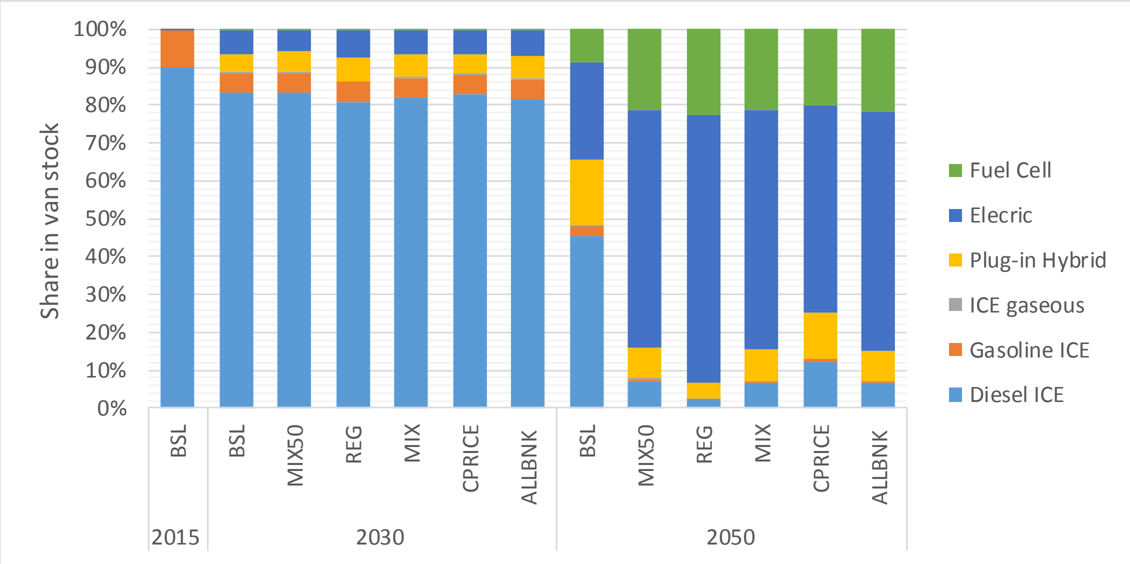
Figure 59: Car stock by type of drivetrain in 2030 and 2050



Source: PRIMES model

The penetration of zero emission vans in the vehicle fleet in 2030 is projected to go up from 7% in BSL to up to 8% in the policy scenarios, while the share of plug-in hybrids would increase from 5% in BSL to around 8% in the policy scenarios. Similarly to cars, these developments would need to be driven by tighter vehicle efficiency standards supported by the deployment of recharging and refuelling infrastructure. In the long run, the share of low emission vans would range from 87% in CPRICE to 97% in REG, while zero emission vans would represent between 75% and 93% in the same scenarios. Similar considerations as for the cars segment applies to the vans, including the need to intensify the existing CO_2 emission standards.

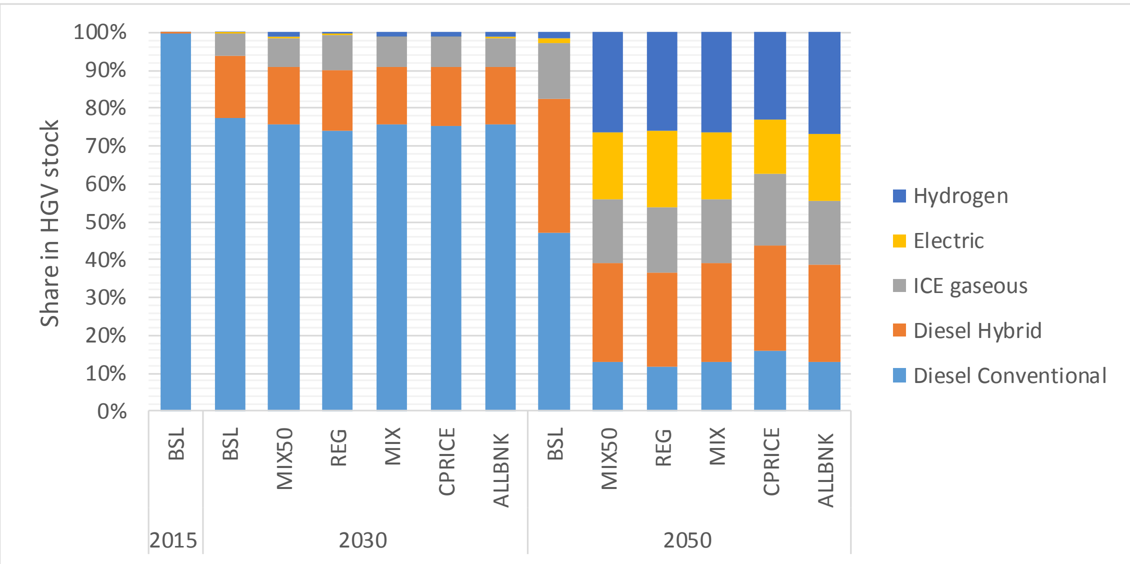
Figure 60: Van stock by type of drivetrain in 2030 and 2050



Source: PRIMES model

In the heavy goods vehicle segment, as shown in Figure 61, hybrids are projected to represent around 16% of the stock in 2030 in BSL while ICE running on gaseous fuels (LPG and LNG) around 6% of the stock. In the policy scenarios, tighter vehicle standards would result in an increase to 8-9% of gas-fuelled ICEs by 2030, as well as a possible penetration of up to 1% zero emission vehicles. Again, due to the slow turnover of the vehicle stock, the CO_2 standards for new vehicles in 2030 would take time to show impacts in terms of changes in the structure of the fleet. However, by 2050 the structure of the fleet changes significantly, with the share of hydrogen trucks representing between 23% in CPRICE and 26-27% in REG, MIX (and MIX-50) and ALLBNK. The share of electric trucks would go up from only 1% in BSL in 2050 to 14% to 20% in CPRICE and REG respectively. Conventional, mild hybrid and gaseous ICEs make up the rest of the fleet in 2050, requiring low and zero-carbon fuels to reach climate neutrality.

Figure 61: Heavy Goods Vehicle stock by type of drivetrain in 2030 and 2050



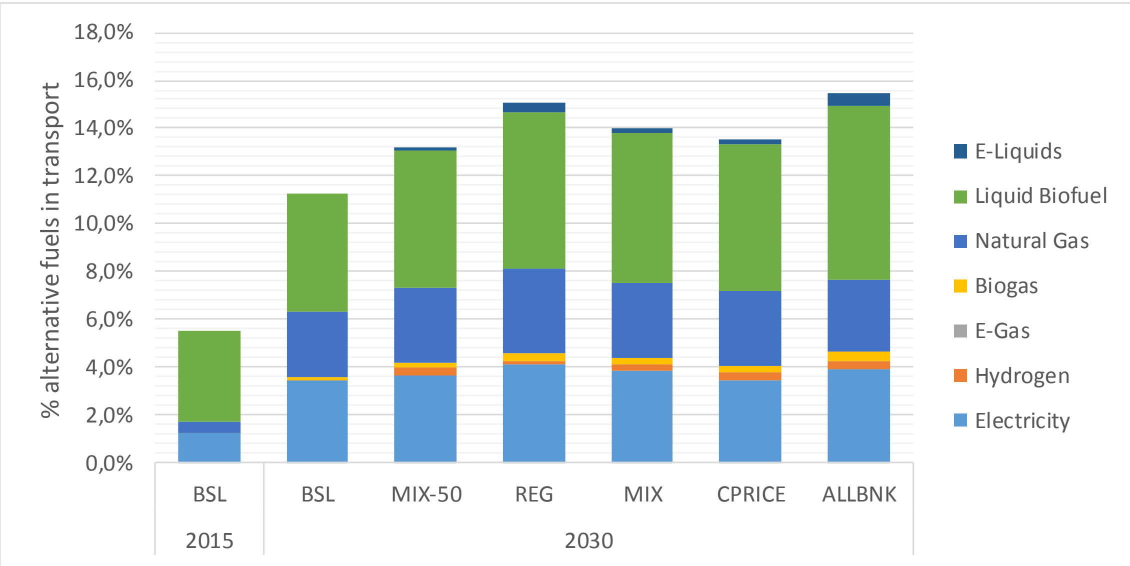
Source: PRIMES model

Fuel mix in land based transport, aviation and navigation

The share of alternative fuels[110], including fossil-sourced natural gas, is projected to represent 11.3% of transport energy demand (including international aviation and international maritime transport) in BSL by 2030. Around 5% of all transport fuels in 2030 would be of biological origin, as shown in Figure 62, driven by policy measures such as the Renewable Energy Directive.

In CPRICE scenario the share of alternative fuels would go up to 13.5% by 2030, driven by carbon pricing and policy measures towards reducing emissions in aviation and maritime navigation. Biofuels and biomethane would represent 6.4% in CPRICE by 2030. The share of biofuels and biomethane increases further in MIX and REG scenarios by 2030 (6.6% and 6.9% of transport energy demand, respectively) thanks to dedicated fuel policies, including for aviation and maritime navigation. Overall, total alternative fuels are projected at around 14% of the transport fuel mix in MIX and 15.1% in REG by 2030. E-fuels would represent around 0.2% of the transport energy demand in CPRICE and MIX and 0.4% in REG, driven by fuel obligations for aviation and maritime navigation. The share of alternative fuels would go up to 15.5% in ALLBNK, driven by the highest ambition policies focussed in particular on aviation and navigation fuels in this scenario, and higher carbon pricing. The share of e-fuels would also be slightly higher at around 0.5% by 2030 in ALLBNK. In MIX-50, the alternative fuels share is around 13.2%.

Figure 62: Share of alternative fuels in Transport (incl. aviation and maritime navigation)



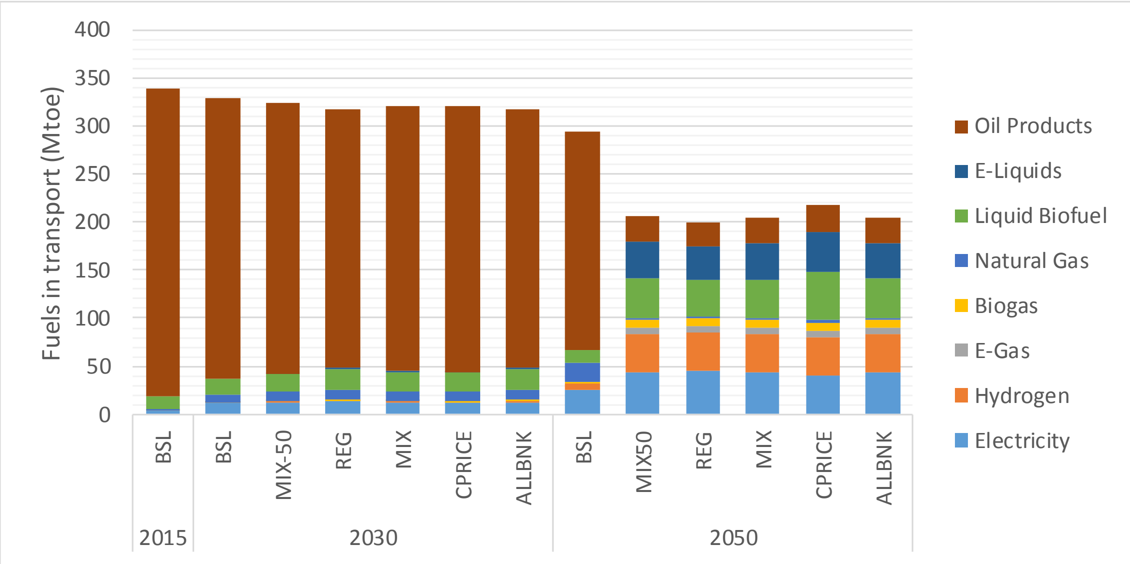
Source: PRIMES model

By 2050, the large majority of fossil fuels will be replaced in all scenarios, in order to reach climate neutrality. Over 85% of fuels will not be based on fossil oil sources, with oil products remaining primarily in sectors such as aviation and maritime navigation. Energy demand in the

110 According to the Directive 2014/94/EU, 'alternative fuels' means fuels or power sources which serve, at least partly, as a substitute for fossil oil sources in the energy supply to transport and which have the potential to contribute to its decarbonisation and enhance the environmental performance of the transport sector. They include, inter alia: electricity, hydrogen, biofuels, synthetic and paraffinic fuels, natural gas, including biomethane, in gaseous form (compressed natural gas (CNG)) and liquefied form (liquefied natural gas (LNG)), and liquefied petroleum gas (LPG).

transport sector is projected to decline by 13% in BSL during 2015-2050, and by 35-41% in the policy scenarios (between CPRICE and REG respectively) driven by improvements in energy efficiency and in the efficiency of the transport system. In the policy scenarios, the bulk of transport fuels are projected to cover a mix of electricity, hydrogen, biofuels, biomethane and e-fuels in addition to some remaining fossil fuels. Electrification in road transport will further increase, as a consequence of stricter CO_2 emission standards for vehicles and increased availability of the necessary charging infrastructure.

Figure 63: Fuels in transport (including aviation and maritime navigation)



Source: PRIMES model

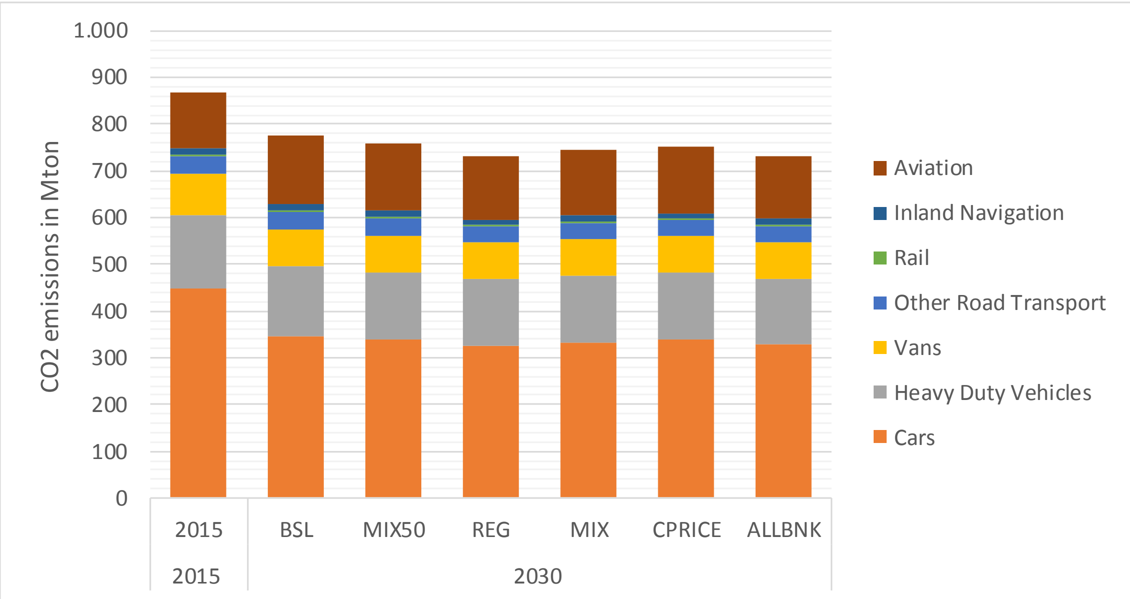
Greenhouse gas emissions in land based transport, aviation and navigation

Total CO_2 emissions from transport (excluding international maritime navigation) are projected to decline by 10% in BSL by 2030 compared to 2015, and between 13% (CPRICE, MIX-50) to 16% (REG, ALLBNK) in the policy scenarios. As shown in Figure 64, by far the largest contribution to this decline is due to increased fuel efficiency of cars, as well as vans. Intensification of the CO_2 emission standards for vehicles in 2030 has in fact a very important impact already for emission reduction by 2030. This will be instrumental to further reduce emissions and energy consumption in the period post-2030, when the effects will be even stronger as a result of the fleet renewal. Aviation has been one of the fastest growing sectors in terms of CO_2 emissions over the past decades. Total CO_2 emissions from flights departing from the EU27 and domestic flights within the territory of a Member State of the EU27 grew from around 111 million tonnes (Mt) in 2005 to 120 Mt in 2015, equal to a 7.9% increase. For the future, significant further growth is projected: 25% by 2030 relative to 2015 in the BSL scenario, equivalent to 34% growth over the 2005-2030 period. Taken together however, declines in cars and vans emissions over the 2015-2030 horizon are around 111 Mt in BSL and 112 Mt to 139 Mt in the other scenarios.

CO_2 emissions from passenger transport decline by 13% in BSL by 2030 compared to 2015, and between 15% (CPRICE) and 18% (REG, ALLBNK) in the other scenarios. The largest contribution comes from passenger cars, driven by vehicle efficiency standards. Intensification of the CO_2 emission standards for vehicles in 2030 has in fact an important impact already for emission reduction by 2030, and it is instrumental to further reduce emissions and energy consumption in the period post-2030, when the effects will be even stronger as a result of the fleet renewal. CO_2 emissions from freight transport go down by 3% in BSL by 2030 compared to 2015, and decline between 8% (CPRICE, MIX, REG,) and 9% (ALLBNK) in the other scenarios, driven by vehicle efficiency standards and initiatives to increase and better manage the capacity of railways and waterborne transport, incentives for intermodal transport and gradual internalisation of external costs ("smart" pricing). In MIX-50, by 2030, CO_2 emissions from passenger transport decline by 13%, whereas CO_2 emissions from freight transport go down by 7%, both compared to 2015.

By 2050, CO_2 emissions from transport are projected to go down by over 90% compared to 2015 in order to meet the climate neutrality targets. This implies a very rapid decline in emissions post-2030. The emissions reduction profile is strongly impacted by the type of policy combinations developed for 2030. The size of these declines, especially in road transport, are consistent with the impact of stringent vehicle standards, as well as of renewable fuels and policies driving improvements in the overall efficiency of the transport system and shifts towards more sustainable transport modes.

Figure 64: CO_2 emissions from Transport



Source: PRIMES model

In international maritime navigation, emissions are expected to increase in all scenarios except ALLBNK from 2015-2030, between 3-4% in REG, MIX, CPRICE and 18% in BSL. In ALLBNK we see that emissions decline by 4% with a carbon price at €65 and blending mandates similar to the MIX scenario.

However, literature suggests that the maritime sector could achieve higher reduction potentials through regulatory and pricing instruments over time. A comprehensive literature review[111] found that emissions could be reduced by 33-77% compared to a 2050 baseline scenario based on current technologies only. Actions listed that can reduce emissions include improving ship operations (e.g. speed optimisation, weather routing, scheduling), improving ship design (e.g. hull design, power and propulsion optimisation, vessel size), using renewable energy sources

[111] Bouman, E. A., Lindstad, E., Rialland, A. I., & Strømman, A. H. (2017).

(e.g. wind) or using sustainable alternative fuels or electrification where appropriate. Tapping into these greenhouse gas emission reduction potentials will require an appropriate basket of measures to reduce energy end-use and promote the uptake of sustainable alternative fuels. Considering that it is difficult to fully capture in the current modelling greenhouse gas emission reduction related to operational efficiency improvements and retro-fitting options, additional and complementary analysis will be required to assess the impact of specific shipping measures, as announced in the European Green Deal. A more detailed study will be performed in the forthcoming impact assessment for measures in the maritime sector itself, which will be taking a more in-depth look at the possibilities to curb emission growth in the maritime sector, including the extension of emissions trading to the maritime sector.

Overall the scenarios analysed in this impact assessment confirm that the reduction of emissions from the transport sector will require large scale deployment of zero-emission drivetrains or for those sectors where this is not feasible low- and zero-carbon fuels, as well as large scale system efficiency improvements, making full use of the benefits of transport digitalisation and connected, cooperative and automated mobility. This will likely require a combination of actions and measures and pricing policies. Finally as demonstrated in the ALLBNK scenario compared to the other policy scenario, a 2030 EU GHG target that sees aviation maintained and inclusion of maritime emissions in its scope, will require bringing about additional emissions reductions in other sectors and transport modes to compensate for this growth.

The transport sector was also a focus for several stakeholders who responded to the public consultation. Stakeholders mentioned as key topics the development of high-speed rail network, reducing private vehicles in urban areas, the introduction of low emission zones (LEZs) infrastructure changes to promote sustainable life, the uptake of sustainable biofuels, ban on vehicles with combustion engines, electrification of vehicles and national development of charging infrastructures to support this transition.

9.4.2.7 Industry, including fuel mix

All the different scenarios have an impact in the industry sector, notably for those sub-sectors consuming currently more fossil fuels. The industrial sector is composed by many diverse subsectors with different energy and material needs resulting in different types, mixture, volumes and concentration of industrial effluents containing greenhouse gases.

Industry has been steadily reducing its emissions and increasing its energy savings over the past decades. Only in the last fifteen years between 2004 and 2018 European industry[112] reduced its emissions by 20%, while compared to 1990 reductions are estimated to have surpassed 30%. Despite facing strong international competition, European industry has adapted its business models and practices in line with the climate and energy ambitions of Europe, and in a viable economic manner.

The industry stakeholders and associations that participated in the public consultation of this initiative[113] do see opportunities in further increasing the climate ambition for 2030, notably in

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[112] Total industrial emissions (energy combustion and process emissions), including refineries sector.

[113] Including the submissions in the public consultation of major industrial associations, including Business Europe, CEFIC, CEMBUREAU, CEPI, CERAME-UNIE, EUROFER, Eurometaux, European Aluminium, Fertilisers Europe, Fuels Europe, Glass Alliance Europe, IFIEC Europe and confederations of national industries e.g. from AU, CZ, DE, FR, PL, etc.

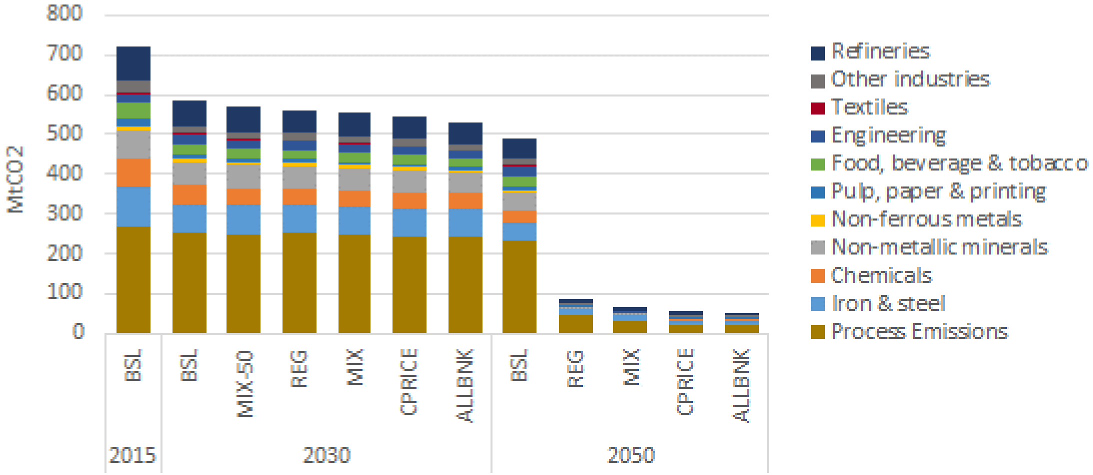
terms of jobs creation and contribution to an economic growth based on new production and consumption models (e.g. circular economy approach). However, the significant investment challenge and the risk in terms of international competitiveness if the EU acts alone are also stressed. 2030 is considered a fairly short time horizon, compared to the long investment cycles of industry, for a significant contribution of industrial sectors in terms of GHG reductions by then.

Achieving further reductions in industry will depend increasingly on: (i) proving the technical and economic feasibility of expensive breakthrough technologies, particularly for energy intensive industrial processes, still under development or at the demonstration level, and on: (ii) the deployment of infrastructure necessary to deliver at their installations renewable energy and low carbon solutions like e.g. hydrogen and e-fuels. In addition, many stakeholders note the need to have a stronger EU Emissions Trading System carbon price signal, coherent with other price signals like taxes and levies for incentivising clean energy technologies, as well as importance of making mandatory the implementation of the recommendations in energy audits.

Overall, the PRIMES model results show relatively limited additional GHG emission reductions in the next decade in the policy scenarios compared to the baseline. In BSL, industrial sectors including refineries see CO_2 emissions reduced by 19% in 2030 compared to 2015, mainly driven by the use of more energy efficient processes (improved waste heat recovery) and to a lesser extent due to fuel switching from fossil fuels to electricity and biomass. In the policy scenarios the reductions improve, with REG and MIX delivering a 23% reduction compared to 2015. CPRICE and ALLBNK, where the carbon price increases to €60-65/tCO_2, complemented by further energy efficiency and renewable energy policies in the case of ALLBNK, reduce emissions by 24% and 26% respectively.

Significant additional effort will be required to decarbonise the industrial sectors between 2030 and 2050, when EU’s climate neutrality ambition will require industry to reduce its emissions to around 90-95% compared to 1990 levels, as explained in the Long Term Strategy. The policy scenarios on this impact assessment achieve from 88% reductions compared to 2015 (REG) up to 92% (CPRICE) and 93% (ALLBNK). A major part of the reductions in 2050 is due to technologies such as clean gases and carbon capture and storage and carbon removals, including CCUS technologies and CO_2 storage in materials. Clearly, the step up of technology deployment between 2030 and 2050 will be a significant challenge.

Figure 65: CO_2 emissions in industry by sector and type (sectoral emissions refer to energy-related emissions)

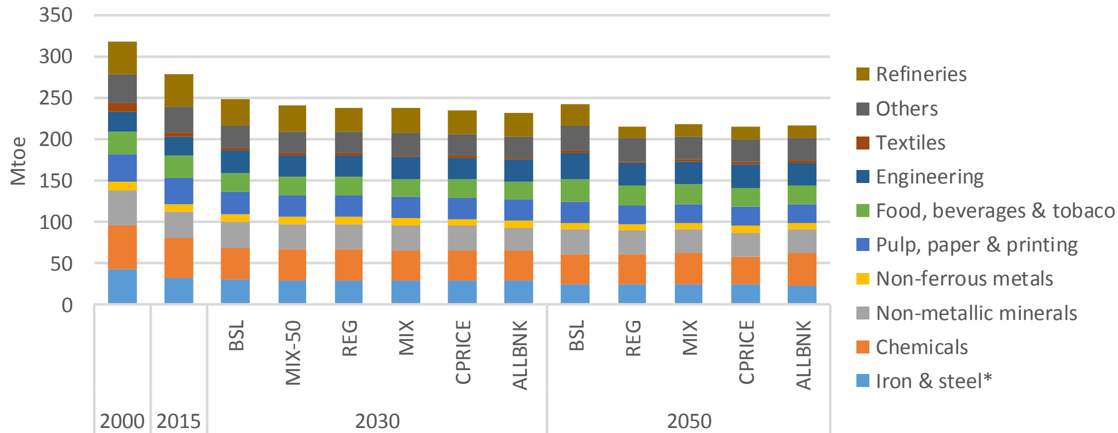


Source: PRIMES model.

Currently, energy efficiency and electrification of industrial heat and steam production seem to be the most technologically mature options for reducing energy-related industrial emissions. Electrification of processes also has a high potential, but not across all industrial sectors.

The potential of further energy savings in different parts of industry can be seen in Figure 66. In the BSL, the combination of energy and climate policies deliver in 2030 around 10.6% energy savings in industry compared to 2015. The scenario focusing more on regulatory measures REG, with strong policies driving improvements in waste heat recovery, increase the energy savings by 4 p.p. to 14.7%. The scenario based on carbon pricing CPRICE triggers more energy savings (15.8%) than the MIX scenario (14.9%). The highest energy savings are achieved by ALLBNK (16.8%). In all four scenarios, the textile, food & drink, chemicals and refinery sectors show by 2030 the biggest energy savings, between 6% and 13% more than in BSL.

Figure 66: Energy Consumption in Industrial Sectors



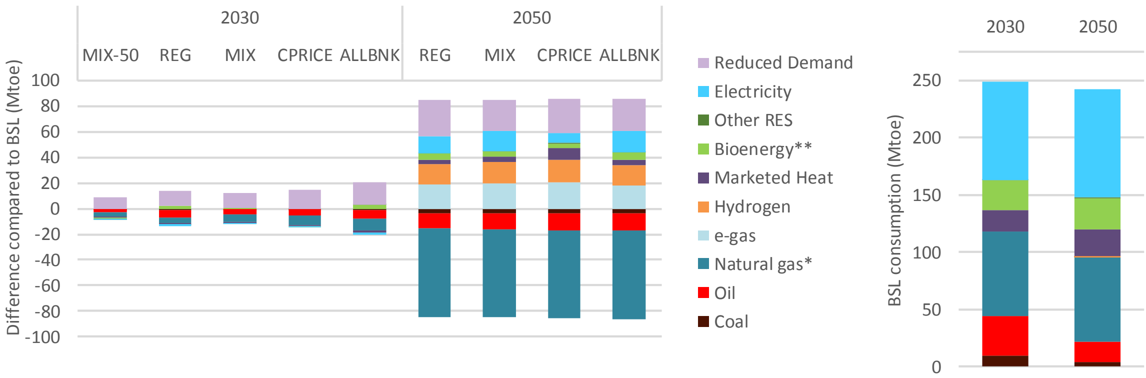
*Note: Includes final energy consumption in industry, consumption in refineries, *includes blast furnace*

Source: 2000-2015: Eurostat, 2030, 2050: PRIMES model

The shares of fuels in total energy consumption in industry provide insights on how energy demand is met. Overall, the scenarios exhibit a similar fuel mix for industry in 2030, with electricity ranging between 34.6% in BSL to 36.5% in CPRICE and ALLBNK, natural gas between 28.4% in CPRICE (28.1% for ALLBNK) to 29.6% in BSL, oil between 12.6% in CPRICE (11.8% in ALLBNK) to 13.7% in BSL and finally bioenergy ranges between 9% in BSL to 12.1% in REG (12.6% in ALLBNK). The fuel mix changes significantly by 2050 for all policy scenarios when half of the energy demand is satisfied by electricity (slightly less in CPRICE), 14-15% from biomass, 8%-9% from e-gas, 8% from hydrogen and between 12-15% from steam.

Concerning the angle of energy related emissions, it is interesting to see the differences in fuel consumption of the various policy scenarios against the baseline. This indicates how energy related emissions are mitigated and what type of fuel switching takes place. Figure 67 reports these differences on the left hand side for 2030 and in the centre for 2050, while on the right side one can see the fuel mix of the baseline. In 2030, fuel switching remains still limited. Instead by 2050 significant fuel switching is displayed with associated energy savings, with almost all natural gas being replaced by low-carbon gases, i.e. hydrogen, e-gas and a little biogas. There is additionally some more electrification, including a higher share of energy produced by CHP.

Figure 67: Differences in energy consumption in industry compared to Baseline



*Note: Includes final energy consumption in industry, consumption in refineries and blast furnace, *includes manufactured gas, **includes waste*

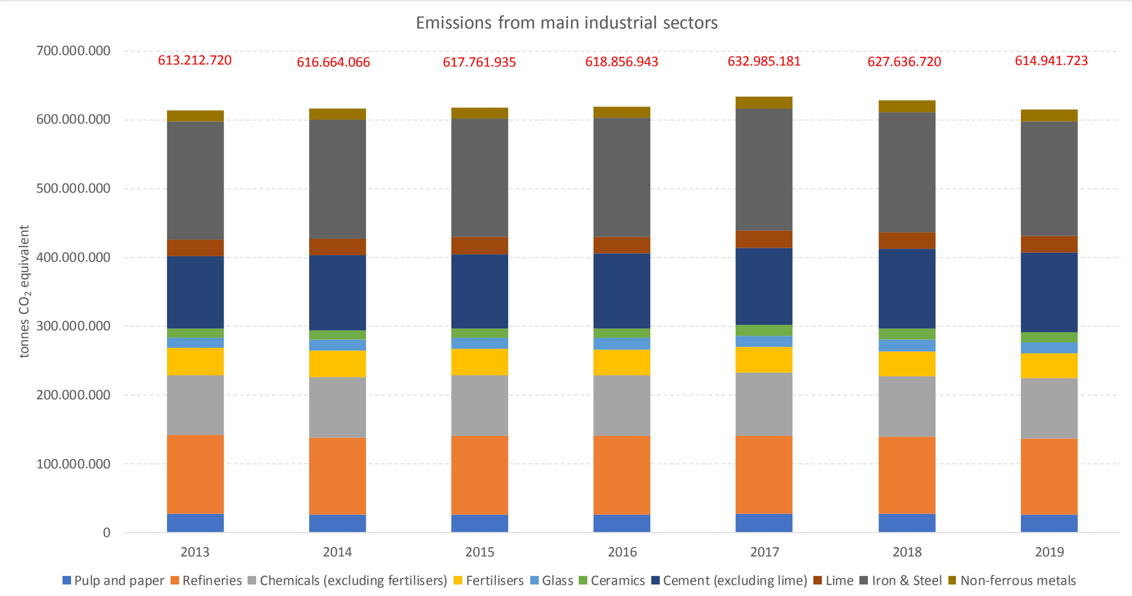
Source: 2000-2015: Eurostat, 2030, 2050: PRIMES model

An important conclusion resulting from this modelling exercise is with carbon prices increasing up to €65/tCO_2, additional GHG reductions compared to 2015 are lower than other sectors except transport. The industrial sector has already significantly invested in improving its energy efficiency, mainly to address its high energy costs compared to its international competitors. Thus, further strengthening energy efficiency policies, mainly targeting the increase of waste heat recovery, are insufficient to drive significant additional emissions reductions.

Innovative low carbon and carbon neutral technologies, such as CCS or hydrogen based steel production, are necessary to turn industry carbon neutral. These are not expected to enter the market at scale at the carbon price levels observed in the projections in 2030, but closer to 2035 or 2040. CCS for instance enters in significant numbers only by 2040 with carbon prices at that time of €200/tCO_2 or more. Deployment of such solutions requires the necessary energy and CO_2 infrastructure to be in place when the related technologies have been proved at scale. At the same time a supporting regulatory framework is necessary[114] that will promote the deployment of such technologies, both on the production side, but also on the side of demand, creating for example lead markets for low carbon products[115,116].

The figure below presents an overview of the development of the emissions in the main industrial sectors during phase 3 of the ETS (2013-2020)[117]. Four sectors out of industry represent more than 75% of direct industrial emissions under the ETS (refineries, chemicals excluding fertilisers, cement excluding lime and iron & steel). The ETS has seen relatively stable and slightly increasing industrial emissions since 2013 up to 2017, a period where carbon prices were very low due to the surplus of allowances on the market. Since 2018, with the establishment and considerable strengthening of the Market Stability Reserve, carbon prices have recovered again. The GHG emissions trend changed also for industrial emissions starting to decrease again. In 2018, emissions from industrial installations decreased by almost 1% compared with 2017. The reversed trend accelerated in 2019 with an additional decrease in emissions of 2%, compared to 2018.

Figure 68: Historic GHG emissions related to industrial sectors in the EU ETS (EU27, Norway and Iceland)



[114] Wyns et. al., (2019), Industrial Transformation 2050 – Towards an Industrial Strategy for a Climate Neutral Europe, IES

[115] ICF & DIW (2020), Industrial Innovation: Pathways to deep decarbonisation of Industry. Part 3: Policy Implications

[116] Climate Strategies (2019), Building blocks for a climate-neutral European industrial sector

[117] Based on date from the European Transaction Log of verified emissions reported by industrial installations with adjustments made to take into consideration the heat flows between installations, the emissions related to electricity production and the transfer of waste gases outside of the installations boundaries for electricity production. Data collected in the National Implementation Measures submitted under the ETS Directive by September 2019 was used for correcting EUTL emissions. Data presented is for EU27 plus Norway and Iceland, while the PRIMES projections presented only cover EU27. Furthermore, PRIMES includes a number of installations that produces heath or electricity linked to industrial in the power sector, while these are included in industrial emissions in this assessment based on the European Transaction Log of verified emissions.

Source: Own calculation based on EUTL Data combined with data provided in the NIMs for calculating corrections for heat imports and exports, waste gases exports and electricity production for the years 2014 to 2018. For years 2013 and 2019 extrapolation of NIMs data for corrections.

Based on NIMs[118] data it is possible to calculate the evolution of the specific emissions expressed in tonnes CO_2 per tonne of product for the different product benchmarks used for calculating the free allocation received by different sectors.

Using this data per sector, different scenarios can be constructed for identifying the readily available emission reduction potentials of implementing already existing technologies in most installations in a sector.[119] Two methods are explored:

- One with relatively high ambition estimating the impact on GHG of a shift of all installations in the sector with emissions above those representing the average of the 10% best installations to the level of emissions of the 10% best.
- One focussed on the worst performing installations (those with emissions above the median) in the sector and assuming they would reduce their emissions to a level equivalent to the emissions of the 2016/2017 "median" installation in the sector;

Table 40: Emission reduction potential based on provisional updated benchmarks repressing medium and best performing installations

Sector	Emissions in 2019 ($MtCO_2$)	Savings (Median) ($MtCO_2$)		Savings (Best 10%) ($MtCO_2$)	
Cement (excl. lime)	117.7	2.4	2.0%	13.9	11.8%
Ceramics	14.9	0.2	1.4%	1.1	7.3%
Chemicals (excl. fertilisers)	93.3	8.8	9.4%	29.4	31.5%
Fertilisers	39.2	3.5	9.0%	17.8	45.4%
Glass	17.9	0.8	4.2%	3.1	17.4%
Iron & Steel	185.6	13.3	7.2%	41.1	22.1%
Lime	25.7	1.6	6.2%	8.0	31.0%
Non-ferrous metals	16.7	1.7	9.9%	2.8	16.7%
Pulp & Paper	27.0	14.8	55.0%	26.5	98.2%
Refineries	126.3	6.3	5.0%	51.4	40.7%
Total	**664.3**	**53.4**	**8.0%**	**195.0**	**29.4%**

The potentials, referring to 2019 emission levels, vary per sector, from relatively modest values for sectors with important shares of process emissions (cement, ceramics, lime) to high potentials in sectors such as chemicals and fertilisers. For all sectors combined, the abatement potential of further deployment of existing technologies up to the level of the current best 10% can be estimated at almost 30% of the 2019 emissions. Simply making the worst performers move to the existing median performer would already reduce emissions compared to 2019 by 8%.

[118] National Implementation Measures submitted under the ETS Directive by September 2019 with industrial historical emission and production data

[119] Small and very small emitters excluded under Articles 27 and 27a of the ETS Directive, installations renouncing to free allocation and installations for which data is incomplete have been removed from the analysis.

The PRIMES projections sit within this range of total estimated reduction potentials based on the benchmarking data.

This is a relatively static assessment of mitigation potential which might not be possible to achieve by all installations and by 2030. It does not take into account the development of new technologies. Some technologies are incremental while others, including some climate neutral technologies like high temperature heat pumps, electric boilers, hydrogen or CCS will allow for significant further reductions.

A recent study[120] revisited bottom up the mitigation potential in the main ETS industrial sectors. The study used the production projections of the PRIMES modelling and assessed bottom up for a number of existing and new technologies what the resulting mitigation potential could be. Most reduction potential by 2030 assessed came from existing technologies with only limited use of technologies no yet applied in EU ETS installations. Overall, this bottom up exercise has identified a total mitigation potential by 2030 of between 16% and 25% compared to 2019 for the four main industrial sectors in terms of GHG emissions (iron & steel, refineries cement and chemicals) combined. The lower end of the mitigation potential assumes that only technologies already in place in some installations will be further deployed in others, while the higher range of the estimation assumes that some new technologies will start to be implemented by 2030.

Looking at the potential revealed based on the PRIMES model projections, the benchmark data and the recent bottom up study estimates for additional reduction potential by industrial emitters are within the same order of magnitude.

Most of these reductions by 2030 are based on existing technologies and show a levelling off of additional mitigation potential. With a view on decarbonising the industrial sector as a whole towards 2050, new clean technologies will need to be deployed at scale. Higher carbon prices will be needed for both existing and new technologies.

Some new technologies have costs that are higher than projected carbon prices in the next decade. Other enabling measures might be needed to ensure the implementation in the market of these new technologies. These enabling measures include inter alia the Innovation Fund for first of its kind project and contracts for difference.

The modelling above does not include the impacts of the COVID-19 outbreak in Europe and the lower emissions which will be registered in 2020. In addition, the economic downturn caused by the outbreak will probably impact the possibilities of companies to carry out investments to reduce its emissions. On the other hand, financial support programmes for industry are being put in place.

9.4.3 Non-CO_2 sectoral mitigation potential

The below table reports the historic emission profile of the EU's non-CO_2 emissions using two different standards. The reason for reporting both accounting standards is transparency: presently the official greenhouse gas emissions inventories are being reported according to the 4th IPCC Assessment Report global warming potentials for calculations of CO_2 equivalents of non-CO_2 emissions over 100 years (AR4). The inventory reporting will, however, change in the near future

[120] Study contract – Assessment of potential carbon leakage in the third and fourth trading phase of EU Emissions Trading System. Under Framework contract CLIMA.001/FRA/2015/0014. Öko-Institut, Trinomics, Ricardo, Adelphi, (2020).

to reflect updated IPCC inventory guidelines using global warming potentials from the 5th IPCC assessment report (AR 5). This change, moreover, has already been included in the EU regulatory framework covering emissions from 2021 onwards[121]. The forward-looking modelling, including the exploration of mitigation options, is therefore based on AR5 calculations. However, the AR4 numbers allow to directly compare numbers to the current official greenhouse gas inventories. As can be seen in Table 41, in 2015, methane was the dominant non-CO_2 greenhouse gas in the European Union. According to the baseline estimate based on GAINS, in 2030 there will still be emissions of 366 MtCO_2-eq of methane, 180 MtCO_2-eq of nitrous oxide, and overall 35 MtCO_2-eq emissions of different fluorinated greenhouse gases (F-gases for short).

Table 41: Emissions of non-CO_2 greenhouse gases in AR4 and AR5 across all sectors (MtCO_2-eq)

	1990		2005		2015		2030-BSL
MtCO_2-eq	AR4	AR5	AR4	AR5	AR4	AR5	AR5
Sum CH_4	595	666	459	513	406	455	366
Sum N_2O	335	298	260	231	215	191	180
Sum F-gases	55	53	79	73	104	99	35
Sum Non-CO_2 GHGs	985	1017	798	820	725	745	581

Source: EU GHG inventory under UNFCCC and GAINS model

Sector-wise, agriculture emits the largest share of non-CO_2 greenhouse gases, followed by energy, waste and industrial emissions or manufactured products that include F-gases (see Table 42). Whereas non-CO_2 greenhouse gas emissions in energy, waste and industry are projected to significantly decrease already in the baseline, this is not the case with agriculture where the decrease is projected to be more limited. It should be noted that the baseline does not incorporate any specific policies that might be undertaken under the future Member States' CAP strategic plans or other new policy initiatives under the European Green Deal.

Table 42: Baseline emissions for non-CO_2 greenhouse gases by sector (MtCO_2-eq, AR5)

MtCO_2-eq	2005	2010	2015	2020	2025	2030
Energy (incl. heating and cooling)	167	170	170	149	118	85
Agriculture	409	394	404	388	380	375
Waste (incl. wastewater)	203	190	166	150	120	106
Industry and other	77	42	36	27	25	22

Source: GAINS model

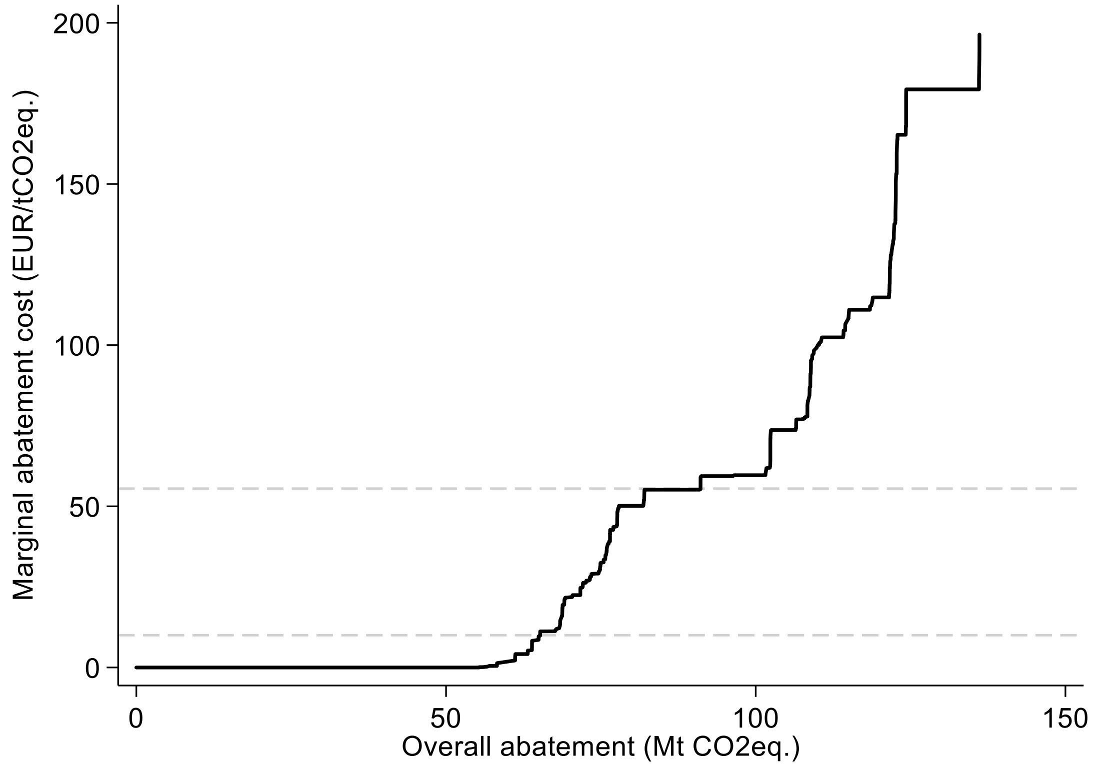
Figure 69 below shows that there is still significant potential to reduce non-CO_2 emissions in 2030 compared to the baseline. The order of magnitude depends also on the efforts made on energy efficiency and renewable energy and the resulting carbon prices in the various options.

The figure shows at which carbon price this would become economically feasible. The GAINS model estimates that from the bottom up perspective taken in the analysis, significant win-win mitigation potential exists, that can reduce non-CO_2 emissions at a marginal cost of zero €/tCO_2-eq. The dotted grey lines indicate abatement costs of €10/tCO_2-eq and €55/tCO_2-eq, respectively

[121] COMMISSION DELEGATED REGULATION (EU) 2020/1044 of 8 May 2020 supplementing Regulation (EU) 2018/1999 of the European Parliament and of the Council with regard to values for global warming potentials and the inventory guidelines and with regard to the Union inventory system and repealing Commission Delegated Regulation (EU) No 666/2014.

to illustrate the economic mitigation potential still available through 2030 in the non-CO_2 greenhouse gases.

Figure 69: 2030 marginal abatement cost curve across all non-CO_2 greenhouse gases



Source: GAINS model

These mitigation potentials are quantitatively shown in the Table 43. It looks at mitigation potential that could be tapped within a range of €0/tCO_2-eq to €55/tCO_2-eq.

Table 43: 2030 mitigation options for non-CO_2 GHG emissions across all sectors in the EU27 compared to baseline (MtCO_2-eq, AR5)

	BSL	*€0/tCO_2-eq*	*€10/tCO_2-eq*	*€44/tCO_2-eq*	*€55/tCO_2-eq*
Mitigation	n.a.	MtCO_2-eq	MtCO_2-eq	MtCO_2-eq	MtCO_2-eq
CH_4	n.a.	29.3	34.3	44.3	44.9
N_2O	n.a.	8.4	10.6	11.8	24.7
F-gases	n.a.	17.6	20.3	21.5	21.5
Sum	n.a.	55.3	65.2	77.6	91.1
2030 emissions after mitigation	581	525.7	515.8	503.4	489.9
Reduction compared to 2005	-29%	-36%	-37%	-38%	-40%
Reduction compared to 2015	-22%	-29%	-31%	-32%	-34%

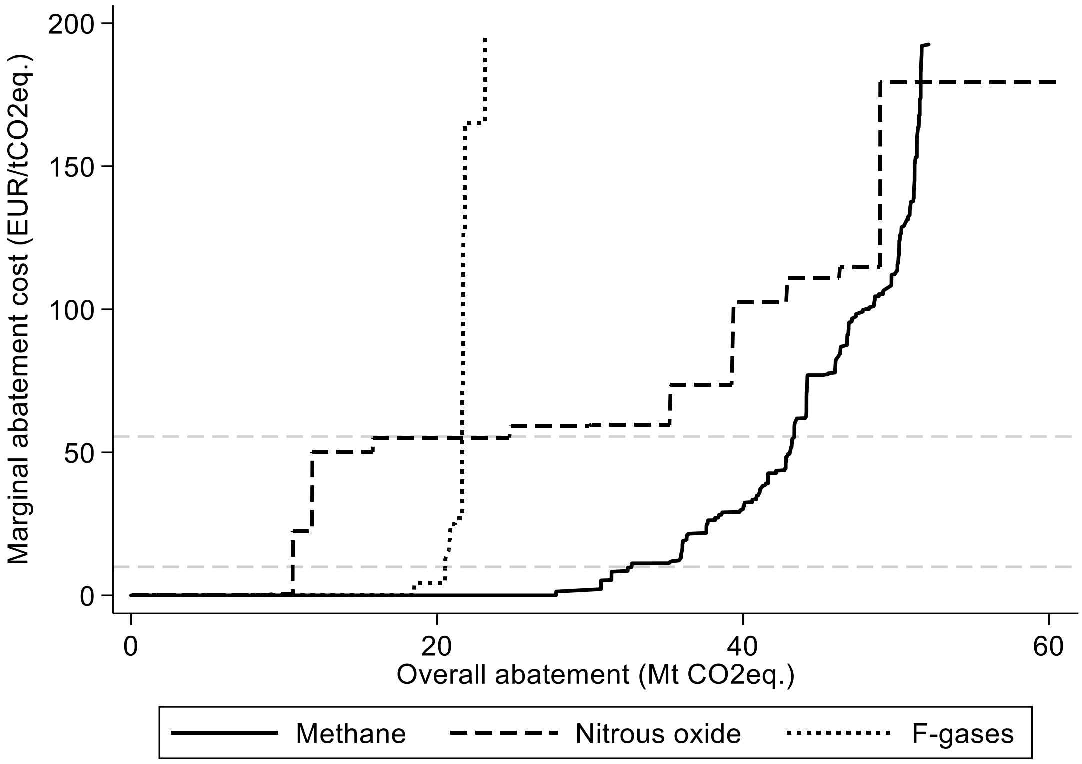
Source: GAINS model

The figure below illustrates the reduction potential beyond baseline for each of the gases separately. Methane emissions are expected to go down by 34% in the baseline compared to 2005. At a marginal cost of €55/tCO_2-eq, additional mitigation still remains at a level of 44.9 MtCO_2-eq in 2030. At zero cost and at €10/tCO_2-eq there is already a large mitigation potential, mainly stemming from the energy sector as well as heating and cooling applications (see below for sectoral discussion). At a marginal cost of €55/tCO_2-eq, methane is reduced at a rate of 38% in 2030 compared to 2005.

For nitrous oxides, which predominantly stem from the use of mineral and organic fertilisers in agriculture, similar reductions are expected at marginal costs of €55/tCO_2-eq, yielding a mitigation of overall 33% in 2030 compared to 2005. At marginal costs of zero and €10/t, reductions in nitrous oxides emissions are significantly lower since some of the options (e.g. variable rate technology in agriculture) are only available at higher marginal costs. In baseline, N_2O emissions reduce by 22% in 2030 compared to 2005, and this increases at a marginal cost of €55 to 33%.

For F-gases, emissions will already be reduced by 53% in 2030 compared to 2005 in the baseline, due to strong existing regulations increasingly banning the use and release of F-gases in the EU. For marginal costs of €55/tCO_2-eq this increases to 82% but beyond that there is not much further reduction potential.

Figure 70: 2030 marginal abatement cost curve by non-CO_2 greenhouse gas



Source: GAINS model

Turning now to the mitigation potential by economic sector, at lower marginal costs the energy sector clearly has the highest potential to reduce non-CO_2 greenhouse gas emissions, in particular for CH_4, compared to the baseline. These zero- and low-cost mitigation options reflect the wider international landscape on the cost of reducing methane emissions in the oil and gas sector. The IEA methane tracker website[122], for instance, uses detailed data to estimate possible mitigation

[122] https://www.iea.org/reports/methane-tracker-2020/methane-abatement-options#abstract

actions and the associated cost for the whole sector. Upstream operations generally show a variety of negative cost mitigation options, while a large number of mitigation options at near zero cost are available throughout the whole sector. This is reflected in the estimates shown above for this impact assessment. Academic research confirms these conclusions based on a detailed study of natural gas production in the United States[123], and similar conclusions are to be found in the NGO community[124]. Options to reduce methane are good practice-leakage control and addressing major leaks in production of crude oil and natural gas to reduce methane and pre-mining degasification of coal mining but also doubling of the control frequency of gas distribution networks, tools mentioned by stakeholders in Europe[125], who nevertheless caution that action on energy methane emissions should be accompanied by a phase-out of fossil gas by 2035. Reducing the leakage of long-distance gas transmission is another option. Modification in fluidised bed combustion will reduce nitrous oxides emissions in the power sector and industry. Finally, further reductions of energy combustion will also reduce further fugitive emissions as well as emissions from incomplete combustion of fuels. These mitigation options are generally cost-effective, suggesting that the energy sector is responsive to the level of the carbon value starting from low levels.

The energy sector also includes heating and cooling applications that can lead to emissions of F gases. For F gases, as shown above, zero cost abatement options exist that would, given the right regulatory framework, be available at current technologies. From a technical modelling point of view, it is important to note that the PRIMES model implements the marginal abatement cost curves from GAINS via a smooth function for purposes of optimization. For this technical reason, PRIMES can yield a lower mitigation potential for the lower range of carbon values for non-CO_2 greenhouse emissions compared to GAINS.

Table 44: Potential emission reductions of non-CO_2 greenhouse gases by sector in 2030 in the EU27 compared to baseline (AR5)

	€0/tCO_2-*eq*	*€10/t*CO_2-*eq*	*€44/t*CO_2-*eq*	*€55/t*CO_2-*eq*
Sector	MtCO_2-eq	MtCO_2-eq	MtCO_2-eq	MtCO_2-eq
Agriculture	12.3	12.3	17.2	30.6
Energy (incl. heating and cooling)	30.0	34.9	41.3	41.3
Waste (incl. wastewater)	7.8	7.8	7.8	8.0
Industry and other	5.2	10.1	11.2	11.2
Total	55.3	65.2	77.6	91.1

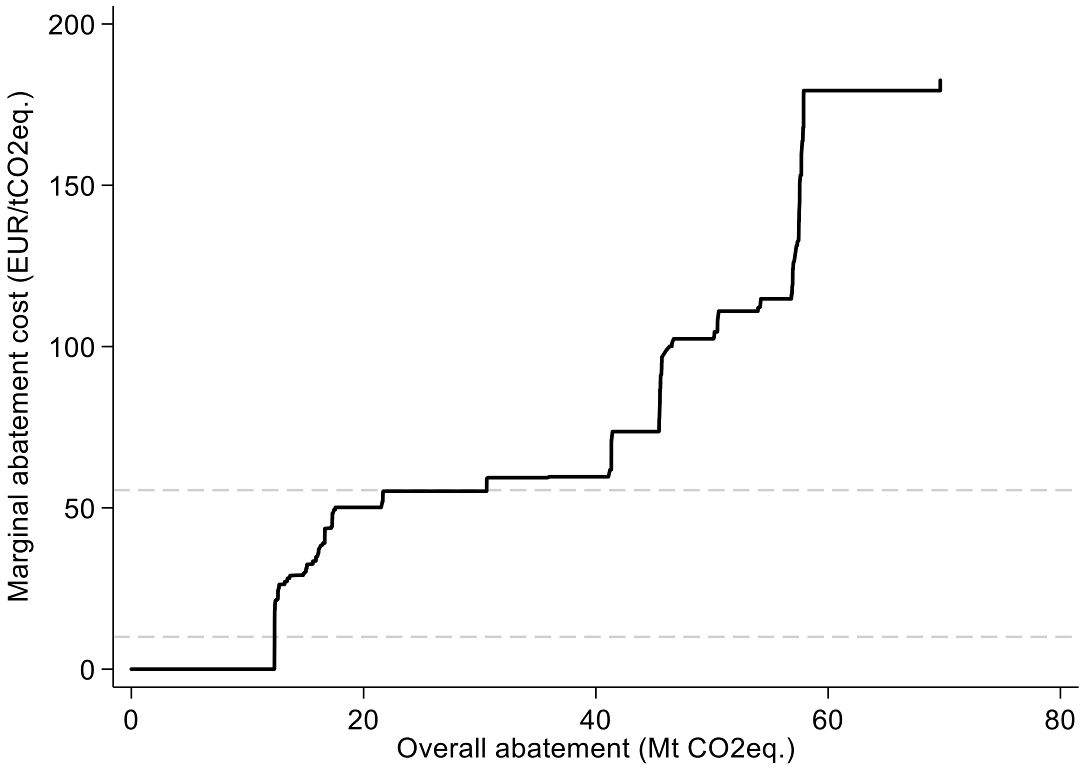
Source: GAINS model

Agriculture is the sector with the second highest-abatement potential, particularly at the higher carbon price. The figure below illustrates this potential, and shows that mitigation options exist at significant price differences. The dotted lines indicate marginal mitigation cost of €10/tCO_2-eq and €55/tCO_2-eq, respectively reducing emissions by between 3% and 8% compared to baseline in 2030. Of the most economical options that represent clear win-win strategies, farm-scale

[123] Marks, Levi (2019): "The Abatement Cost of Methane Emissions from Natural Gas Production", Job Market Paper, University of California at Santa Barbara.
[124] https://www.edf.org/icf-methane-cost-curve-report
[125] Environmental Investigation Agency (2020): "Environmental Investigation Agency's contribution to the Public consultation on the Roadmap "2030 Climate Target Plan".

anaerobic digestion with biogas recovery is an important emission reduction technology for dairy cows and cattle farms, for both small and large farms. Its use would also allow to increase the supply of biomass available for biomethane production[126][127], a technology which stakeholders see as relevant for the future[128]. Breeding through selection could enhance productivity, fertility and longevity to minimise the methane intensity of dairy and meat products is an option both for dairy cows and sheep. Moreover, feed additives combined with changed feed management practices can reduce methane emissions, again in large and small farms. Overall, the results show that a significant number of win-win abatement technologies exist for agriculture. Nitrification inhibitors are an option at higher marginal costs for larger farms (30 to 150 hectare) to reduce nitrous oxides at scale. The same applies for variable rate technology to reduce emissions of nitrous oxide emissions related to more efficient fertiliser use.

Figure 71: 2030 marginal abatement cost curve for all non-CO_2 greenhouse gas emissions in the agricultural sector



Source: GAINS model

[126] Municipal Waste Europe (2020): "MWE Response to the European Commission Roadmap on the Inception impact assessment on the Climate 2030 Target Plan", dated April 2020.
[127] Orsted (2020): "Roadmap 2030 Climate Target Plan – Inception impact assessment. Orsted comments."
[128] International Association of Oil & Gas Producers (2020): "IOGP feedback to the Impact Inception Assessment '2030 Climate Target Plan'", dated 15 April 2020.

The JRC has also closely examined the options to mitigate non-CO_2 greenhouse gas emissions[129]. While JRC calculations also include options to reduce CO_2 emissions from land use (notably winter cover crops and fallowing histosols for carbon storage, see LULUCF section 6.10), the non-CO_2 greenhouse gas reduction potential found at a price of €40/tCO_2-eq is of a similar order of magnitude as calculated with the GAINS model, though estimates of costs of individual technologies differ.

In the context of the EU Biodiversity Strategy[130], promoting the goal of zero pollution from nitrogen and phosphorus fertilisers through reducing nutrient losses by at least 50% and reduce the use of fertilisers by at least 20% in the EU could have significant co-benefits in reducing related nitrous oxide emissions in the future.

In this regard, another modelling exercise[131] conducted by the European Commission's Joint Research Centre provides a quantitative assessment of the effects of the targets stemming from the Biodiversity and Farm to Fork Strategies in combination with the implementation of the future Common Agricultural Policy (CAP), based on the 2018 Legal Proposal of the Commission and assuming an enhanced climatic ambition in Member States' Strategic Plans. This work confirms the significant role the CAP would play, in particular thanks to the boosted uptake of mitigation technologies and changes in farming practices, and linked to the implementation of the targets with 17.4% reduction of non-CO_2 GHG emissions in the agricultural sector by 2030, going up to 19.0% with the additional budget made available under the "Next Generation EU".

Another driver for reductions in non-CO_2 greenhouse gas emissions related to agriculture in the EU can be changes in lifestyle choices of European citizens and consumers. For instance, changes in dietary choices can affect the related agricultural emissions of methane and nitrous oxide. Traditionally, red meat has played a strong role in European society. However, observed trends have been changing recently. In its in-depth analysis for the Long-Term Strategy[132], the European Commission explored, through a sensitivity analysis, the greenhouse gas mitigation implications of 5 different possible diets, ranging from light decreases in meat and dairy (diet 1) to more substantial decreases (diet 5). These diets would bring with them benefits for the health of Europeans, and would avoid food waste. In all diets, dairy and meat consumption would still remain at a relatively high level.

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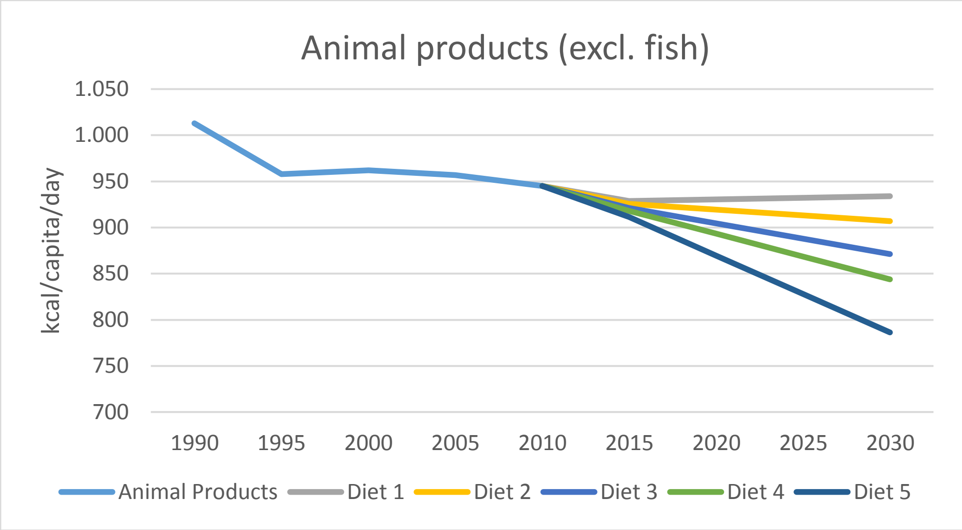
[129] Forthcoming: Pérez Domínguez I., Fellmann T., Witzke P., Weiss F., Hristov J., Himics M., Barreiro Hurle J., Gómez Barbero M., Leip A. (2020), Economic assessment of GHG mitigation policy options for EU agriculture: A closer look at mitigation options and regional mitigation costs (EcAMPA 3), EUR 30164 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-17854-5, doi:10.2760/4668, JRC120355

[130] COM(2020) 380 final

[131] Barreiro-Hurle, J., Bogonos, M., Himics, M., Hristov, J., Pérez-Domiguez, I., Sahoo, A., Salputra, G., Weiss, F., Baldoni, E., Elleby, C. 2020. Modelling environmental and climatic ambition in the agricultural sector with the CAPRI model. The case of the Farm to Fork and Biodiversity strategies and the 2030 Climate targets, EUR30317, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-20889-1, doi: 10.2760/98160.

[132] https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf

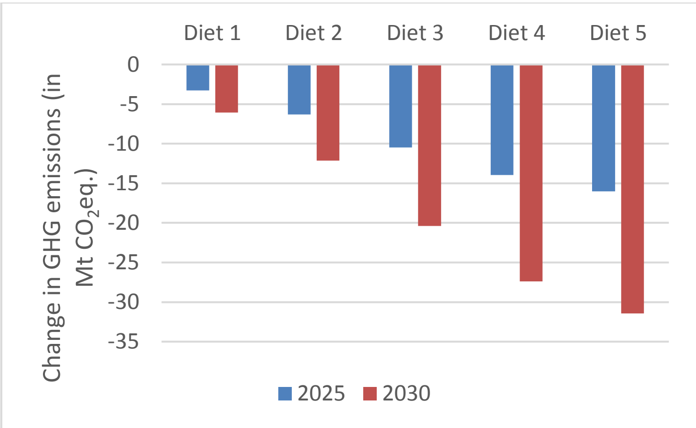
Figure 72: Evolution of consumption of animal products for five different possible dietary choice



Source: FAO

As shown in the figure above, the consumption of animal products in terms of kcal per person per day evolves differently through 2030. Diet 5 sees the largest drop in consumption of animal products for nutrition. The greenhouse gas mitigation benefits of these changes are shown in Figure 73 below. As can be seen, mitigation gains on top of baseline reductions as analysed for the Long-Term Strategy are substantial, and can exceed 30 $MtCO_2$-eq though they do not take into account any feedback effects for instance if this would change. Any such effects were not included in the BSL nor policy scenarios by 2030, but would be of an order of magnitude equivalent to the technical reduction potentials of the agriculture sector.

Figure 73: Greenhouse gas emissions effects of different dietary choices through 2030



Source: GLOBIOM and GAINS models

The Farm to Fork Strategy[133] also concludes that a pathway to more plant-based diet with less red and processed meat and with more fruits and vegetables will reduce not only risks of life-threatening diseases, but also the environmental impact of the food system[134].

Another avenue for reducing food chain-related greenhouse gas emissions, releasing land and relieving pressure on freshwater resources and biodiversity is the production of protein from aquaculture, shellfish and algae[135]. The Commission's Group of Scientific Advisors considered that oceans can produce more food through low-trophic aquaculture[136]. These feed on the excess nutrients that are causing eutrophication in Europe's seas. A number of studies have looked for instance at the impact of increased cultivation of these in new offshore wind turbines parks which can bring benefits in reduced GHG emissions[137]. The feasibility of scaling up production to these levels is demonstrated by marine production in China which is 30 times greater than the EU27 for shellfish and 100,000 times for algae[138].

Emissions from the waste sector could benefit from treatment of wastewater both for domestic wastewater as well as for the paper and food industries. In all of these applications, cost-efficient biogas recovery from anaerobic digestion offers significant mitigation potential by 2030. Wastewater treatment could additionally use optimised processes aimed at reducing N_2O to mitigation emissions further at reasonable cost. Both options start to be triggered at a low carbon price, thus explaining why mitigation potential becomes available at €10/tCO_2-eq.

The last sector with a still large additional potential, heating and cooling, is part of the energy sector but its applications often rely on technical F-gases, some of which are highly potent greenhouse gases. Alternative agents (including ammonia, CO_2 or HCFs with a GWP below 150) can be used for air conditioning as well as refrigeration in industry and the commercial sector. In other sectors where HFC are used they could be replaced, too, with alternative agents. The use of SF_6 could be banned in some applications. Fire extinguishers and stationary air-conditioning could use alternative agents such as CO_2. The semiconductor industry could switch from PFC to NF_3 (with destruction of the latter in the process) or other alternatives.

9.4.4 The LULUCF sector

Historic GHG emissions and removals in the LULUCF sector

Since 1990, the land use and forestry sector has removed from the atmosphere an average of 300 MtCO_2-eq annually with inter-annual variations ranging from 250 MtCO_2-eq in 1992 to 336 MtCO_2-eq in 2006. In 2018, the last reported year from 2020 UNFCCC inventories, the LULUCF sink removed 264 MtCO_2-eq from the atmosphere with a net removal of 283 MtCO_2 of carbon dioxide and an emission of 6 MtCO_2-eq of methane and 13 MtCO_2-eq of nitrous oxide. It also includes the removal of 42 MtCO_2 through harvested wood material produced in 2018. On average over the last 5 years the sink was equivalent to 279 MtCO_2-eq.

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133 COM(2020) 381 final

134 FAO and WHO (2019), Sustainable healthy diets – guiding principles.

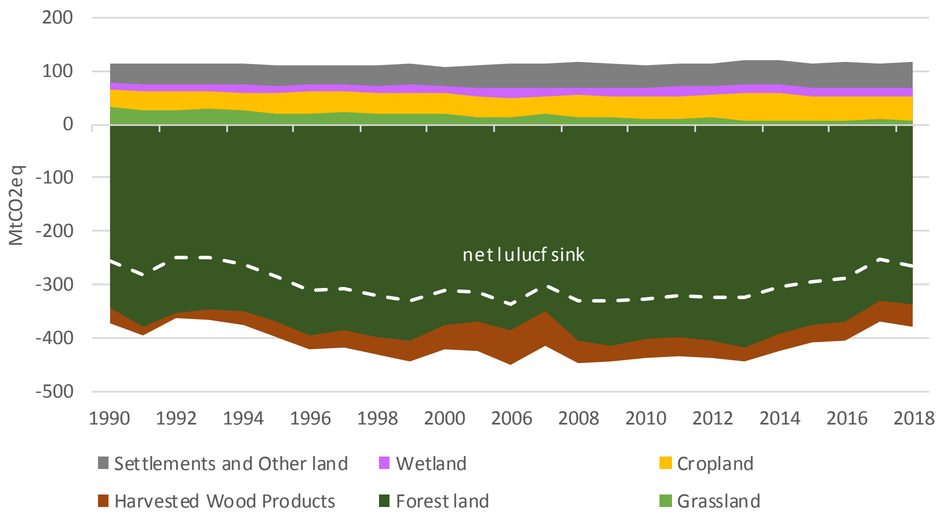
135 Aquaculture is not part of the mitigation options modelled in this impact assessment.

136 High Level Group of Scientific Advisers "Food from the Oceans", 2017

137 Nijdam et al. (2012): "The price of protein: Review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes", Food Policy, Volume 37, Issue 6, December 2012, pages 760-770

138 FAO Aquaculture, Capture and Global production databases

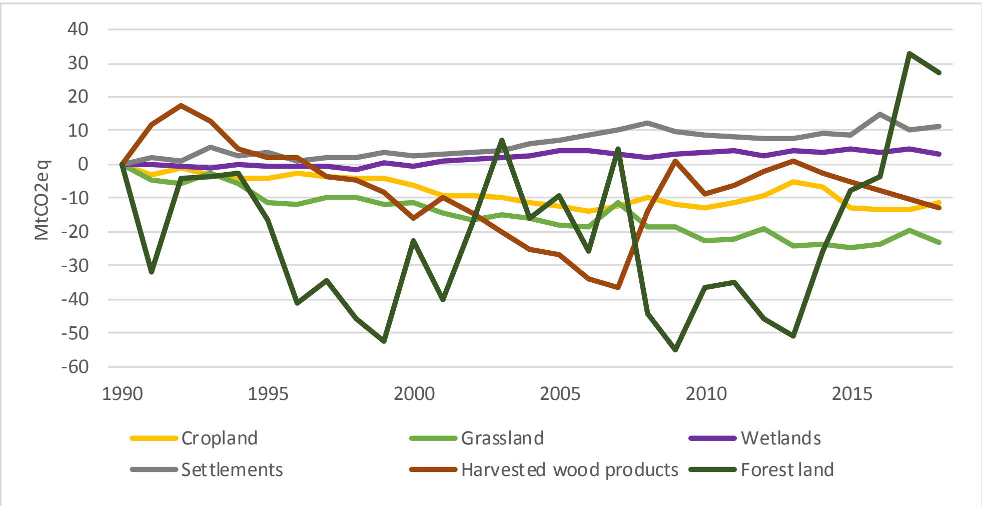
Figure 74: LULUCF emissions and removals in the EU



Source: UNFCCC inventories 2020

The detail of LULUCF categories shows a continuous reduction of LULUCF emissions for cropland and grassland since 1990 but an increase in emissions for settlements and wetlands. The forest areas are responsible for most of the variability in the inventories of the EU LULUCF sink, with a notable reduction of the forest sink in the last 5 years. Wood harvest (for material and energy purposes), forest ageing and natural hazards drive most of the variations of the forest removals. For a detailed discussion on these drivers as well as expected increases in biomass needs for energy, see annex 9.4.4.

Figure 75: Changes vs. 1990 in emissions or removals by LULUCF category in the EU



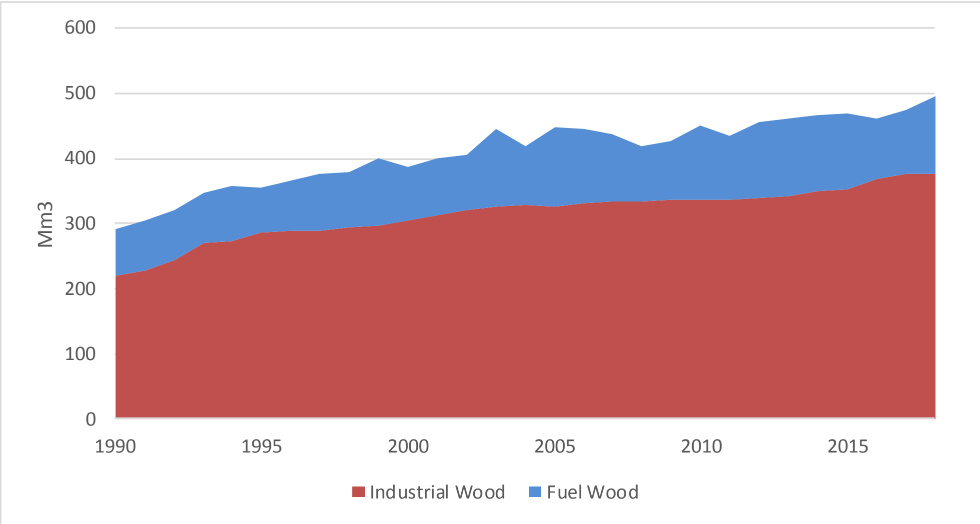
Source: UNFCCC inventories 2020

<u>*The role of bioenergy demand on increased biomass production*</u>

Use of forest resources in the EU has an impact on the overall sink function. The production of biomass for industrial and energy purposes in the EU has continuously increased over the last 30 years, with a stable share of approximately 25% fuel wood and 75% industrial wood. While industrial wood is primarily harvested to be processed in sawmills, wood pulp and panel industries, a substantial share of this wood (e.g. process residuals or industrial wastes) is indirectly used as energy feedstock. The JRC Biomass Study[139] indicates that about half of the total wood harvested in the EU is directly or indirectly used for the production of energy, even though significant uncertainty remains in the reported statistics of biomass supply and demand in the EU. The 2020 UNFCCC inventories report that a caloric value of 128 Mtoe of forest, agriculture and waste biomass was used as substitute for fossil fuel in the energy sector of the EU. The combustion of an equivalent caloric content of the 2018 EU fossil fuel mix would have released about 345 Mt of fossil fuel CO_2 to the atmosphere.

Sustainable forest management practices in the EU[140] have enabled an increase in wood production of 200 Mm^3 between 1990 and 2018, without a direct major impact on the forest sink up to now – though recent years show a limited decline due to pests, wildfires but also an intensification of harvesting activities[141]. Maintaining a sustainable management of the European forest is of key importance to ensure that this decline does not become the beginning of a continuous reduction of forest removals.

Figure 76: Wood production in the EU



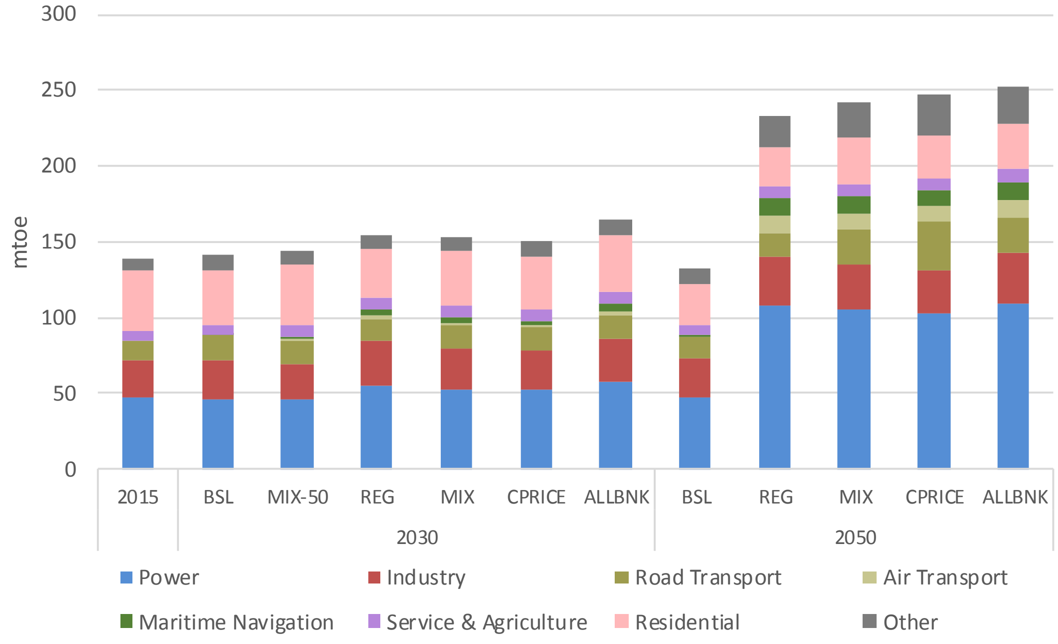
Source: FAOstat 2020

All the scenarios analysed in this assessment rely on a substantial use of biomass for energy with a consumption of bioenergy by 2030 at around 150 Mtoe. Power generation and residential heating today make up most of the biomass demand. By 2030, the use of biomass in the residential sector is expected to decrease slightly but the overall picture will not change dramatically. By 2050, the power sector would absorb most of the additional demand in bioenergy in all scenarios, with more than a doubling of the bioenergy dedicated to the production of electricity. In this time-frame, coupling the use of solid biomass with CCS installations in power and industry sectors will contribute to the removal of CO_2 from the atmosphere. The decarbonisation of road, maritime and air transport requires advanced biofuels

[139] Cazzaniga N.E., Jonsson R., Pilli R., Camia A. (2019). Wood Resource Balances of EU-28 and Member States. EC Joint Research Centre, Publications Office of the European Union, Luxembourg, doi:10.2760/020267, JRC114889.
[140] EEA Report No 5/2016 – European Forest ecosystems – State and trends333
[141] Ceccherini, G., Duveiller, G., Grassi, G. et al. Abrupt increase in harvested forest area over Europe after 2015. Nature 583, 72–77 (2020). https://doi.org/10.1038/s41586-020-2438-y

that could be produced at scale after 2030, nevertheless it would not represent more than 20% of the total use of biomass in any of the scenarios.

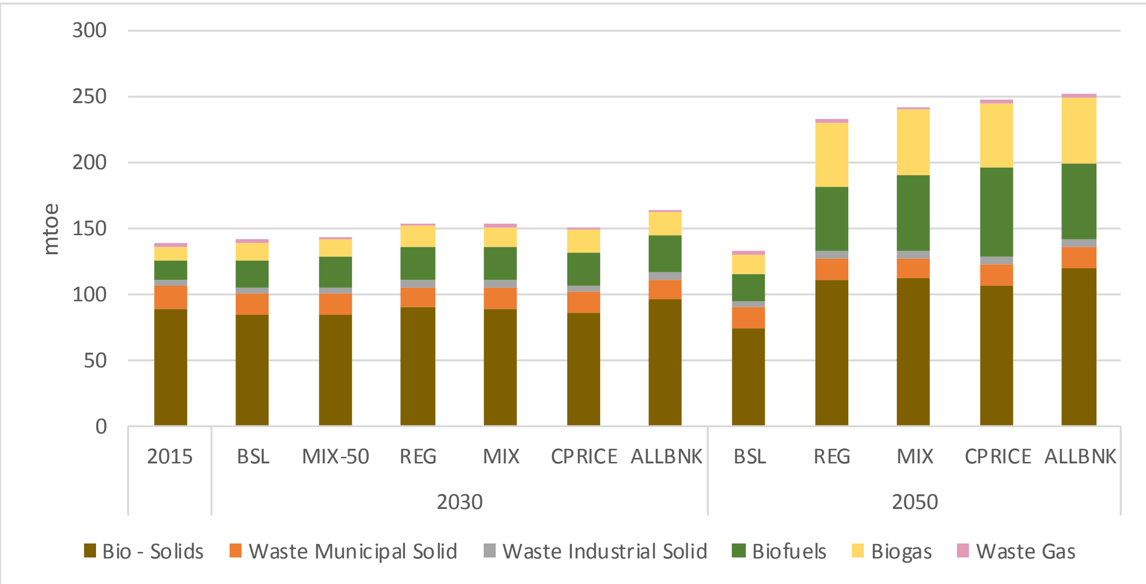
Figure 77: Use of bioenergy by sector and by scenario



Source: PRIMES model

Towards 2050, an increase in solid forms of bioenergy and a strong increase in liquid and gaseous forms is projected to reach the objective of net-zero emissions in hard to abate sectors or to generate net removals in combination with CCS. The total gross available energy from biomass and waste ranges from 230 Mtoe to 250 Mtoe across the policy scenarios.

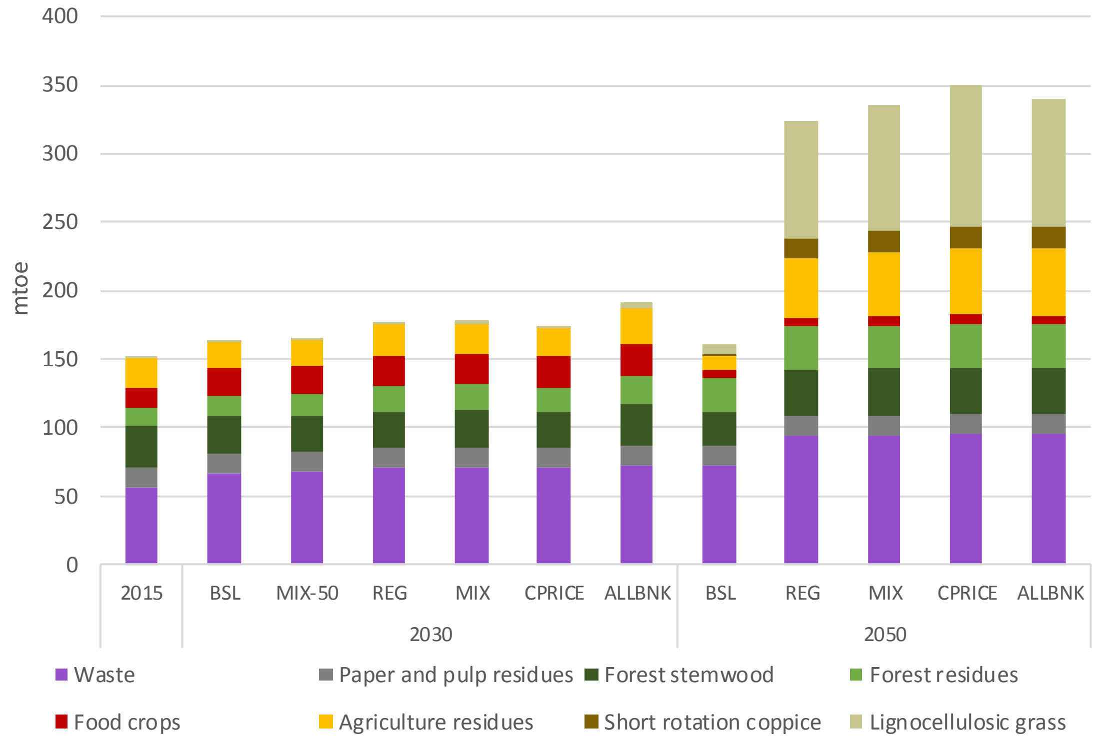
Figure 78: Gross inland consumption of biomass and waste for energy



Source: PRIMES model

The combination of feedstock used to supply the demand in bioenergy by 2030 is similar to today's needs with in particular biofuels relying on cereal and oil crops. The long term is characterised by a phase out of conventional biofuels, to be replaced by much larger volumes of advanced biofuels produced from energy crops and a better mobilisation of agriculture residues. Another significant share of bioenergy feedstocks comes from the waste sector with a progressive improvement in the industrial and municipal waste collection. The use of harvested stemwood increases slightly compared to 2015 level while the increase in the sustainable extraction of forest residues is more pronounced. The optimisation of the sustainable exploitation of all sources of biomass would supply in the most demanding scenario up to 350 Mtoe of feedstock for bioenergy production to the EU economy in 2050.[142]

Figure 79: Break down of bioenergy feedstocks



Source: PRIMES model

In all the scenarios, more than 93% of the bioenergy used in the EU economy is produced domestically in 2030 as well as in 2050.

Imports increase only marginally from 2020 to 2030 to remain around 8 Mtoe or less (Figure 80). Solid biomass makes up most of the biomass imported from third countries. The respect of RED II criteria will ensure this biomass is imported from sustainable sources and correctly accounted in global UNFCCC emission inventories[143]. Bioenergy imports drop by 2050 in the baseline but increase up to 14 Mtoe in the policy scenarios.

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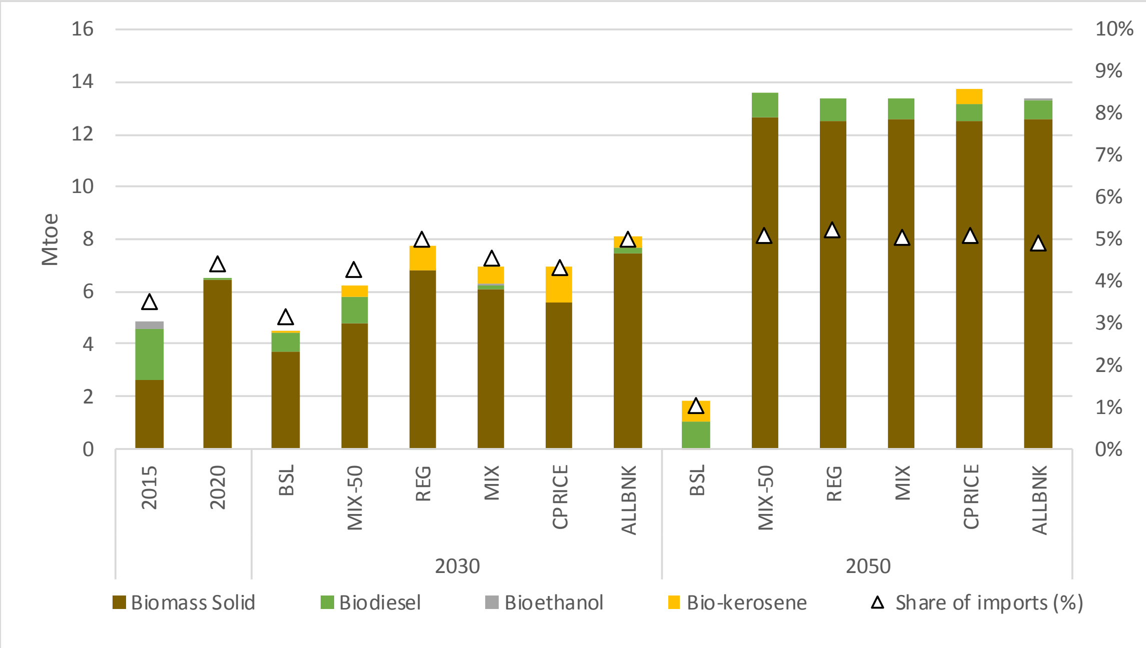
[142] The energy losses in the transformation of the bioenergy feedstock to the final form of bioenergy explain the differences in energy content shown in Figure 77 and Figure 79.

[143] Since the 2030 bioenergy imports are very similar in baseline and policy scenarios, the differences across baseline and policy scenarios in emission impacted and accounted in third countries from EU bioenergy imports would be marginal. The difference between baseline and policy scenarios would be more noticeable by 2050 depending on the sources of the biomass.

Figure 80: Imports of Bioenergy



Source: PRIMES model

As indicated in section 6.2.3 the optimisation of the sustainable exploitation of all sources of biomass would supply in the most demanding scenario up to 350 Mtoe of feedstock for bioenergy production to the EU economy in 2050 in the PRIMES-GAINS-GLOBIOM modelling tool.

This is in line with estimates of the S2Biom project[144]. It reviewed existing publications on the potential and projections for the future of biomass supply for bioenergy production in the EU28. The study considered feedstock such as energy crops, agriculture residues, forest biomass and biomass waste to estimate that the EU has a potential to provide a minimum of 260 Mtoe and a maximum of 540 Mtoe from biomass for its energy consumption, compatible with the volumes of biomass used in PRIMES modelling.

Enhancing the LULUCF sink

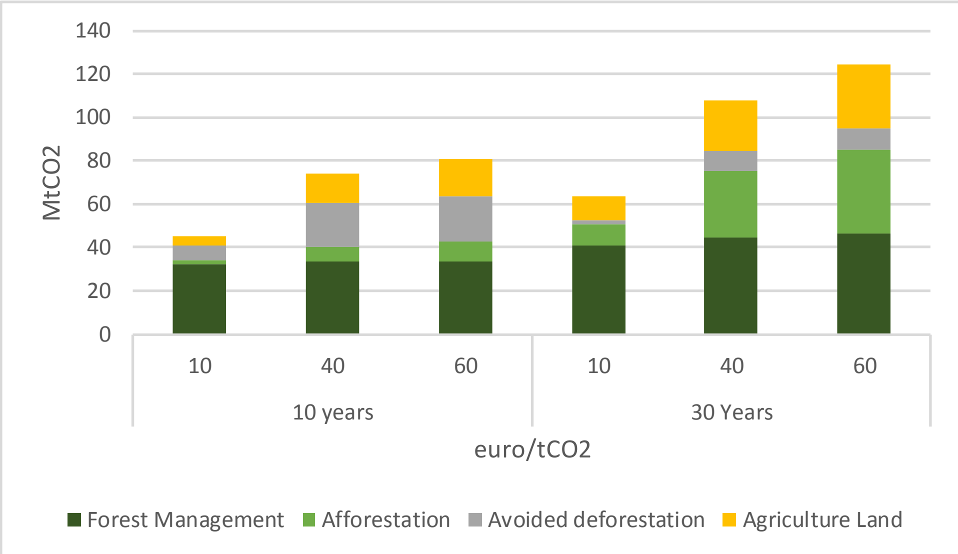
The analysis carried out in the context of the communication “A Clean Planet for All”[145] showed that a climate-neutral EU will have to rely on a substantial amount of carbon removals, well beyond the current sink. By 2050 about 500 MtCO_2 of annual carbon dioxide removal is required to offset residual emissions too difficult to abate. Both nature-based and technological solutions are required and their mix is scenario-dependent. All scenarios need a strong LULUCF sink and technological solutions that often involve the use of biomass to capture the CO_2 from the atmosphere.

The deployment of nature-based solutions to enable the long-term enhancement of the LULUCF sink is a slow process – one that should start now to maximise the 2050 carbon removal potential. However, some concrete forest and agriculture management actions can also generate carbon removal benefits in the short term, and therefore support the EU 2030 climate ambition. The

[144] www.s2biom.eu
[145] https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf

potential for the enhancement of the LULUCF sink at 10 year and 30 year time horizons is illustrated in Figure 81. GLOBIOM modelling shows that some measures such as limiting deforestation, or some soil carbon sequestration and forest management practices could already generate up to 80 $MtCO_2$ of additional LULUCF sink within 10 years. Beyond 30 years, the potential for enhancement from reducing deforestation is almost exhausted and replaced by the removal of carbon by new, actively growing 20 to 30 year old forests. These new forests are additional to the standing old-grown forests. A right balance needs to be found in the sustainable management of the natural resources in terms of climate, biodiversity and other environmental considerations. This requires short term action that reflect long-term objectives to optimise the contribution of the LULUCF sink to the 2050 climate neutrality goal while preserving other ecosystem services.

Figure 81: Potential for carbon sequestration and LULUCF sink enhancement at different carbon prices in 2030



Source: GLOBIOM model

The 2020 UNFCCC inventory submissions indicate that the exploitation of organic soils in the EU, in particular drained peatlands, emitted about 100 $MtCO_2$ with around 70 $MtCO_2$ from a very restricted area of agriculture lands.

Protecting organic soils from intensive use would be highly beneficial from the perspective of climate action in the agriculture sector. It could be achieved by limiting or using appropriate agriculture management on these limited areas, and by restoring peatlands and wetlands through the elevation of groundwater level, in order to reduce the oxidation of the organic material.

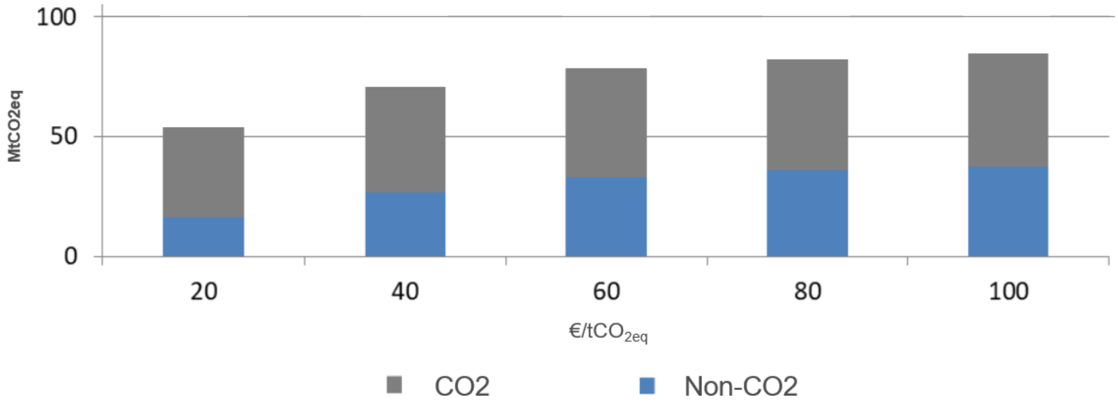
The GLOBIOM model does not cover mitigation measures addressing the specificity of organic soils, and their CO_2 emission reduction potential is therefore not represented in Figure 10, section 6.2.3. The EcAMPA 3 study[146] however includes the option to fallow organic soils, and estimates that the CO_2 emissions from agricultural activities could be reduced by about 50 $MtCO_2$ in 2030

[146] Pérez Domínguez I., et al. (2020). Economic assessment of GHG mitigation policy options for EU agriculture: A closer look at mitigation options and regional mitigation costs (EcAMPA 3), EUR 30164 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-17854-5, doi:10.2760/4668, JRC120355

at reasonable cost (Figure 82). The CAPRI model used in EcAMPA considers this option as one of the most efficient solutions to reduce GHG emissions in agriculture.

There is a potential to enhance at a reasonable cost the LULUCF sink to levels similar to the net LULUCF removals from the climate-neutral scenarios of the EU long-term strategy. It would require, however, measures to trigger land actions at the most optimal location in the Union.

Figure 82: Technical potential for CO_2 and non-CO_2 emission reductions on agriculture land by 2030 (EcAMPA 3)



Source: CAPRI model (EcAMPA 3)

Natural disturbances and need for adaptation

Climate change is already affecting Europe's forests ecosystems – whether intensively managed for wood production, or protected as forest nature reserve – and it will continue to do so throughout this century. In fact, many European forests are vulnerable to forest fires, water scarcity, storms, pest attacks and other disturbances, which climate change exacerbates directly and indirectly[147].

Modelling and assessing forest response to climate change is very difficult, notably because of uncertainties when it comes to tree mortality[148]. However, there are many reasons to be deeply concerned and to follow a precautionary approach.

In fact, during the last three years, a series of large-scale forest disturbances have occurred that can be linked to the exceptional dry and warm weather conditions – including exceptional bark beetle outbreaks in Central and Eastern Europe, uncontrollable 'mega-fires' in Swedish forests, or drought-related forest dieback in Germany.

The frequency of meteorological droughts in many parts of Europe has already gone up and this trend will continue, exposing many forests to more frequent, severe, and longer lasting droughts. Water scarcity reduces photosynthesis and tree growth, impairs important tree defence mechanisms against insect attacks, and can kill trees directly through hydraulic failure. Extreme

[147] https://www.eea.europa.eu/publications/climate-change-impacts-and-vulnerability-2016#tab-figures-used; https://ec.europa.eu/jrc/en/peseta-iii

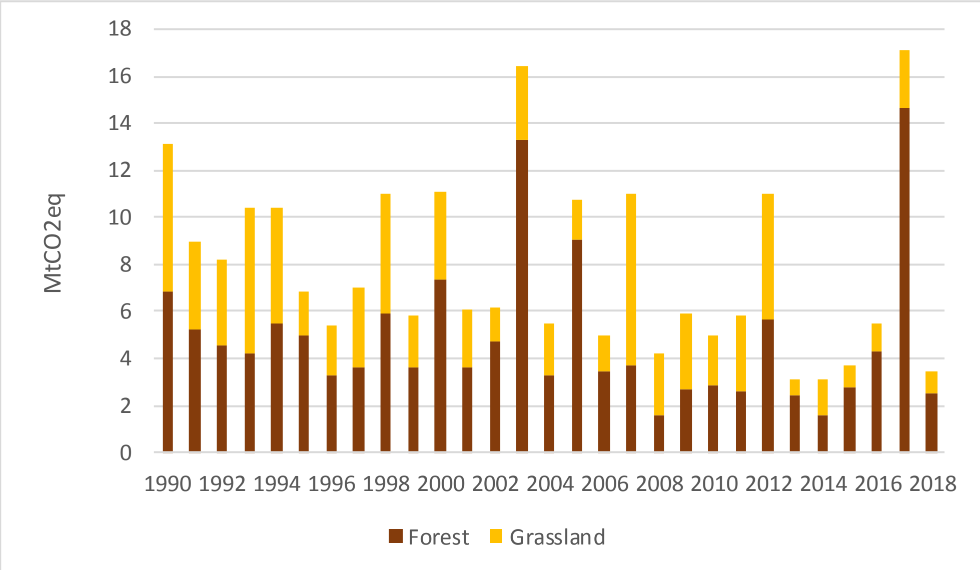
[148] Bugmann, H., et al. 2019. Tree mortality submodels drive simulated long- term forest dynamics: assessing 15 models from the stand to global scale. Ecosphere 10(2)

heat and drought are increasing forest fire risks, their frequency, intensity and severity, the area at risk and the probability of extreme wildfire events.

Efforts to improve fire management have generally been successful in the last 30 years and have resulted in a slightly decreasing trend of burnt area in the Mediterranean – even though the meteorological fire hazard has increased over the same period[149]. This trend is also captured in the UNFCCC inventories (Figure 74). However, there is high inter-annual variability and more European countries suffered large forest fires in 2018 than ever before; for example, Sweden experienced the worst fire season in reporting history. The unprecedented forest fires in several European countries in 2017 and 2018 coincided with record droughts and heatwaves.

It is imperative to adapt forests to the changing climate is thus so as to maintain the many functions they provide. The forthcoming EU adaptation strategy and EU forest strategy will put forward initiatives to enhance natural sink and resilience of forests to climate change, support effective preservation and restoration of forest in the EU, reduce the vulnerability to natural disturbances and promote the bio-economy, in full respect for ecological principles favourable to biodiversity.

Figure 83: GHG emissions from wildfire in the EU28



Source: UNFCCC inventories 2020

<u>Adaptation for a resilient natural sink</u>

The study PESETA IV[150] has analysed the potential vulnerability of forest ecosystems to windstorms, wildfire and insect outbreaks and assessed the possible evolution of natural disturbances impacts in the future.

The study concluded that although windstorms are amongst the most damaging natural hazards in Europe, climate model projections do not suggest they will become more intense or happen more frequently with global warming over most of the European continent. By contrast, global warming will likely increase disturbances from fires and insect outbreaks.

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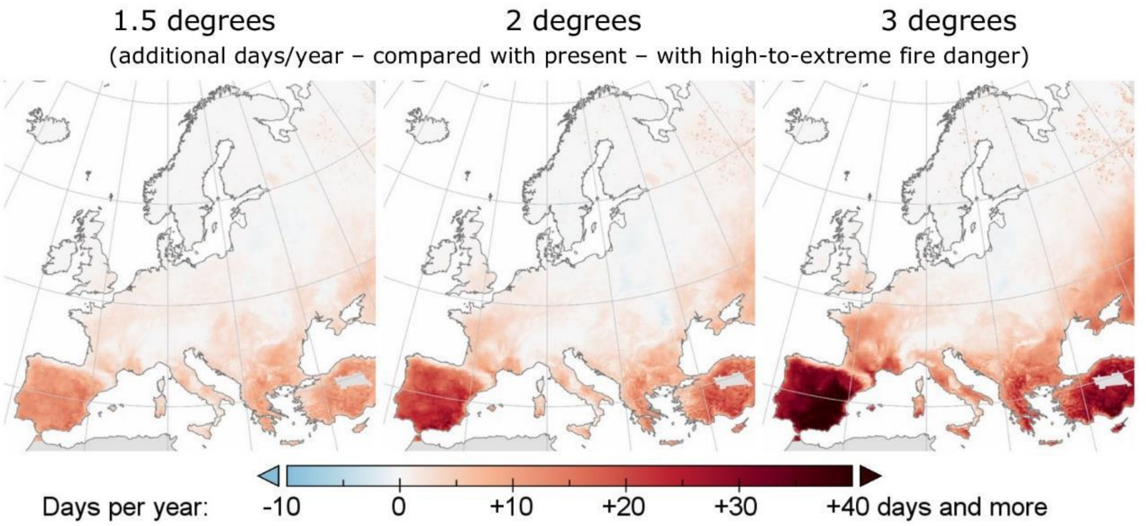
[149] EEA indicator assessment of forest fires – Januray 2020
[150] https://ec.europa.eu/jrc/en/peseta-iv

The probability of high-to-extreme wildfire danger is projected to rise as a result of changing weather conditions. The increase in fire danger intensity and number of days with high-fire potential amplifies with the level of warming, and would be strongest in southern European countries, where fires already occur more often and are more intense (Figure 84).

Climate conditions play a prominent role in insect outbreaks. The last two decades have shown that an increasing amount of forests in Europe has become vulnerable to insect outbreaks and global warming will worsen the trend.

Figure 84: Additional number of days per year with high-to-extreme fire danger for different levels of global warming compared to present (1981-2010).



Source: PESETA IV

Trees have some adaptive traits and capacity to buffer heat and droughts, but the rapid advance of climate change with its various negative impacts will be a shock for many of them. Trees individuals and entire species that cannot resist in a certain region will disappear. Many of them will be gradually replaced by more drought-tolerant species and the forest as such will eventually recover, but this may take several human generations and many regions will not have the same forests as before.

Pro-active adaptive measures are therefore needed to minimise climate change impacts on forests by making forest ecosystems more resilient to climate change and, where needed, supporting their conversion to more adapted forest types. Promising silvicultural ‘no-regret’ adaptation measures depend on location and species, and may include among others the improvement of age class forests structure, more genetically and biologically diverse stands, structure-rich forests, managed in a continuous cover forestry regime. Mixed-species forests can be more resilient to disturbance and still perform in terms of forest productivity and hence carbon sink.

Pro-active adapting measures are also needed for the protection of carbon rich soils other than forests, such as peatland and wetland, as well as managed agricultural land with good level of soil organic carbon.

9.5 Environmental, economic, social impacts – details

9.5.1 Synergies and trade-offs of bio-energy use and land management in the context of increase climate ambition with biodiversity

The five main direct drivers of biodiversity loss identified by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services[151] are changes in land and sea use, overexploitation of natural resources, climate change, pollution, and invasive alien species. Climate change is a direct driver that is increasingly exacerbating the impact of other drivers, reducing the GHG emission is essential to preserve our ecosystems and their biodiversity.

The deployment of renewable energy is at the heart of the EU climate action, including the use of bioenergy as an alternative to fossil fuels[152]. The Renewable Energy Directive contains a set of sustainability criteria to ensure that the production, imports and use of bioenergy in the EU and does not harm the environment. In particular, the land criteria aims at preventing the conversion of biodiverse and carbon-rich land for bioenergy feedstock and other requirements address/minimise soil quality and soil carbon impacts that could be associated to the use of agricultural and forest residues for advanced biofuel production.

Increasing the EU climate ambition for 2030 may increase demand for bioenergy. Assessing its potential impact on biodiversity is not straightforward and depends on the type of biomass used, for instance woody biomass from existing forests or plantations, from agriculture lands or through increased waste recycling and cascading use.

Biodiversity loss is a complex matter[153] to model. The International Institute for Applied System Analysis (IIASA) has developed a methodology to analyse the impact of EU energy policies on biodiversity through the two main drivers that are land use change and overexploitation of natural resources. This methodology relies on the PDF indicator (Potentially Disappeared Fraction of global species) to evaluate the potential of land use and forest management practices on species (expressed as a share of global species) compared to a situation where global ecosystems would be in their undisturbed original state (i.e. without human intervention)[154,155]. Applied to the EU, it estimates how much EU land use affects global species diversity compared to the undisturbed state and expresses the impact as a percentage of global species. The PDF indicator differentiates extensive and intensive forest management or fast growing tree plantations but does not capture all the diversity within management practices for a given use of land. This methodology does not provide a complete overview of biodiversity impacts since population abundance, community composition, habitats and ecosystems extent or intactness are other important aspects not addressed here, results should therefore be interpreted with care.

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[151] IPBES 2019

[152] This section focuses on the assessment of the impact on biodiversity of bioenergy deployments. Other renewables are not addressed due to the lack of information that could allow an assessment of their impact on biodiversity, however this impact is expected to be rather limited and can be positive in some circumstances (e.g. offshore wind, can allow for fish stock regeneration).

[153] IPBES, glossary, at: https://ipbes.net/glossary/biodiversity-loss

[154] Chaudhary et al. 2015. Quantifying land use impacts on biodiversity: combining species−area models and vulnerability indicators. Environ. Sci. Technol. 2015, 49 (16), 9987−9995.

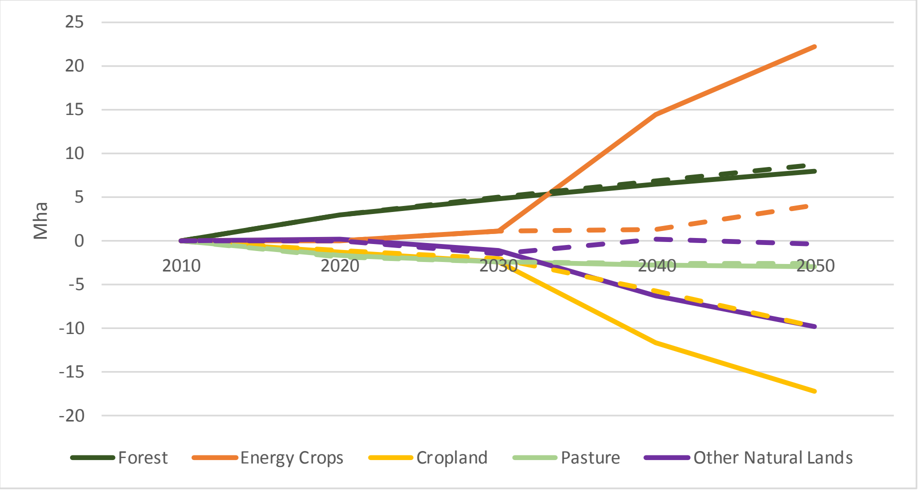
[155] The PDG indicator builds on the responses of species to different land uses and intensities of forest management for four vertebrate taxa (mammals, birds, amphibians, and reptiles) and for vascular plants and includes 804 ecoregions. It follows a methodology recommended by the joint Life Cycle Initiative under the United Nations Environment Programme (UNEP) and the Society of Environmental Toxicology and Chemistry (SETAC).

The PDF value of a hypothetical undisturbed EU state is 0, i.e. the EU land use would not have driven any extinction of global species. The PDF of EU land use in 2010 instead is estimated to be equivalent to 0.64% of global species, meaning that the way EU land was managed in 2010 has potentially reduced species in the EU in a manner that would have reduced global species totals by 0.64% compared to a state without human-induced disturbances. This is driven by the combined effect of land use practices that have affected the bulk of EU land in a predominant temperate zone, which is on a global scale relatively less dense in species than for instance the tropics. The largest impact is from cropland with a PDF associated five time greater than for pasture land, while covering an area that is only the double of the pasture land area relatively richer in species diversity.

The global extinction of vertebrates (amphibians, birds, mammals and reptiles) due to global land use change has been estimated at 11.1% in the year 2000 compared to pristine land conditions[156]. A PDF of 0.64% indicates that the EU land use would be responsible of approximately 6% of the species losses happening at global level (both methodology cover similar taxa).

This indicator thus allows comparing the relative impact of various scenarios affecting land use in the EU (expressed as impact on global species loss). Figure 85 shows the changes in land use compared to 2010 in the baseline and in a policy scenario (MIX). The trajectories are very similar until 2030 but diverge significantly afterwards when more bioenergy is required to reach net zero emissions by 2050.

Figure 85: Changes in land use in the baseline scenario (dashed line) and in the mitigation scenario (solid line)



Source: GLOBIOM model

Forest areas increase by approximately 2 Mha between 2020 and 2030 and keep increasing at the same pace post 2030. This is an afforestation or reforestation rate in line with the roadmap announced in the EU Biodiversity Strategy to plant at least 3 billion additional trees in the EU by 2030. The forest will have to expand through sustainable forest management practices to not cause unfavourable and bad conservation status of forest habitats and species under the EU

[156] Newbold et al. 2018. Future effects of climate and land-use change on terrestrial vertebrate community diversity under different scenarios. https://doi.org/10.1098/rspb.2018.0792

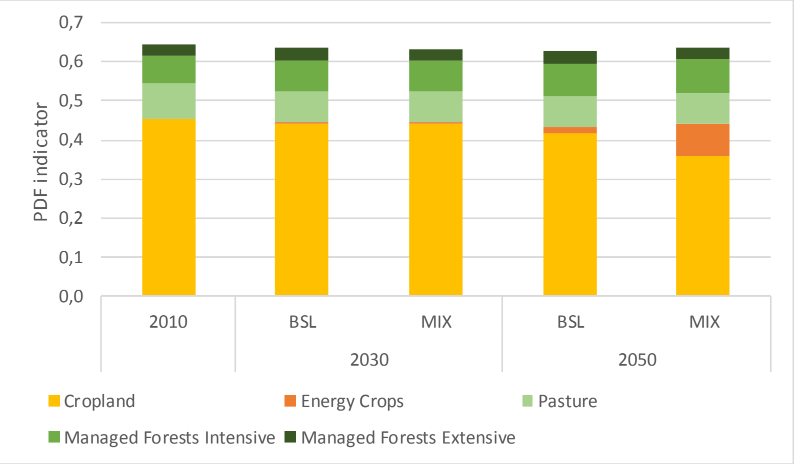
Habitats Directive[157]. Replacing old-growth and diversified forests by fast growing monocultures like eucalyptus plantations would affect biodiversity, carbon retention in soil and risks of forest fires.

What is most striking is the increase in production of energy crops on agriculture land for sustainable advanced biofuels and other type of bioenergy after 2030. The land required to produce this feedstock is taken from cropland previously dedicated to the production of conventional biofuel and from other natural land. The other natural land category includes for instance non-productive grassland, agriculture land set aside, fallowed or abandoned and other type of vegetation not classified in other categories. This land category may represent biodiversity- and carbon-rich ecosystems, they are therefore considered as pristine ecosystems in the modelling to specifically account for the potential negative impact of the conversion to energy crops[158].

This PDF indicator varies over time in baseline, though marginally. Impact are more significant in the policy scenario relying on a significant amount of biomass feedstock for energy. The overall impact of EU land use remains relatively stable towards 2050 (Figure 86) but the relative impact of the land use categories changes substantially. This stability is the result of the combined effects triggered by the production of bioenergy feedstock in the mitigation scenario:

- the PDF for managed forests increases in the mitigation scenario due to net afforestation expanding the area of managed forests and a limited intensification of the forest management, with intensive management of forests increasing by 11% between 2010 and 2050 in the baseline and by 13% in the mitigation scenario;
- the PDF of energy crops increases. Where it replaces other natural land it leads to a deterioration of the overall PDF but where it replaces cropland it actually improves the overall PDF because energy crops are permanent crops with a lesser impact on biodiversity than the annual crops they replace, such as rapeseed used for the current production of biodiesel.

Figure 86: Potentially Disappeared Fraction of global species (PDF) indicator



Source: IIASA

[157] EEA, 2015, State of nature in the EU, EEA Technical Report No 2/2015, European Environment Agency.
[158] In this exercise the category 'other natural land' was assumed to have a similar PDF as undisturbed land, i.e. 0 to recognise it is typically more species diverse.

Combined these impacts result in a relatively stable PDF over time, even in case of increased biomass production in the EU for energy purposes. But impact on biodiversity could be larger. The expansion of energy crops over other natural land only without a substantial share of annual existing cropland substitution or a further intensification of forest management would have a larger overall impact.

These are two key variables that condition the sustainability of the bioenergy production in Europe. Furthermore, impacts could also be larger if biomass is not produced in the EU but imported from regions with land use practices more harmful for the biodiversity than in the EU[159].

Finally, a potential large scale deployment of energy crops should not increase the risk for an alien species to become invasive and cause damages to native ecosystems. The EU should produce its bioenergy feedstocks in accordance with the objective of the EU Biodiversity Strategy for 2030 to reduce by 50% the number of Red List species threatened by invasive alien species. Appropriate species selection and land use planning is required to minimise the risk and possibly provide environmental benefits such as water filtration, ecosystem niches for insects and wild animals, protection against strong wind or soil carbon increase.

9.5.2 Energy system – economic impacts

9.5.2.1 Energy system costs

Energy system costs for the entire energy system include capital costs (for energy installations such as power plants and energy infrastructure, energy using equipment, appliances and energy related costs of transport), energy purchase costs (fuels + electricity + steam) and direct efficiency investment costs, the latter being also expenditures of capital nature. Capital costs (also for the equipment that is scrapped prematurely, i.e. reflecting the costs of stranded assets) are expressed in annuity payments, calculated on the basis of sector-specific discount rates. For transport, only the additional capital costs for energy purposes (additional capital costs for improving energy efficiency or for using alternative fuels) are covered, but not other costs including the significant transport related infrastructure costs e.g. related to rail to accommodate the increased rail capacity. Direct efficiency investment costs include additional costs for house insulation, double/triple glazing, control systems, energy management and for efficiency enhancing changes in production processes not accounted for under energy capital and fuel/electricity purchase costs. Unless specified, energy system cost do not include any disutility costs associated with changed behaviour, nor the cost related to auctioning of allowances which lead to corresponding revenues which can be recycled. Energy system costs are calculated ex post after the model is solved[160].

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[159] The PDF indicator used for this assessment focuses on land use management and land use changes in the EU. It does not reflect the potential impact on biodiversity of indirect land use changes (ILUC) that could happen in other regions of the world in case of a non-sustainable production or consumption of bioenergy. The Renewable Energy Directive sets limits on high ILUC-risk biofuels, bioliquids and biomass fuels with a significant expansion in land with high carbon stock and that could also impact biodiversity.

[160] The calculated cost is influenced by the discount rate used. The discount rate of 10% is used to reflect in the perspective of the private investor faced with real world investment constraints. It is also applied ex-post to calculate system costs. The value of 10% is kept constant between modelling scenarios, including BSL to ensure comparability with of scenarios. For planning investments, the model uses slightly different discount rates that are representative of

Table 45 gives a detailed overview of how this translates in energy system costs per sector, split between capital costs and energy purchases.

Table 45: Sectoral disaggregation of Energy System Costs

Energy System Costs per Sector in bn €'15 (average annual 2021-2030) (excl. carbon pricing payments and disutility costs)	**BSL**	**MIX-50**	**REG**	**MIX**	***MIX-nonCO2****	**CPRICE**	**ALLBNK**
Industry	220	224	224	224	*223*	222	221
Residential	551	563	581	574	*572*	571	581
Tertiary	276	278	281	281	*279*	281	283
Transport	545	547	569	547	*547*	546	547
Total	*1,593*	*1,612*	*1,654*	*1,626*	*1,621*	*1,620*	*1,633*
Capital Costs and Direct Efficiency Investment Costs	**BSL**	**MIX-50**	**REG**	**MIX**	***MIX-nonCO2****	**CPRICE**	**ALLBNK**
Industry	27	28	28	28	*28*	28	29
Residential	251	263	289	276	*276*	266	277
Tertiary	81	85	88	86	*86*	86	87
Transport	108	110	110	111	*111*	110	111
Total in demand side	*467*	*486*	*515*	*501*	*501*	*490*	*505*
Energy purchases (excluding carbon pricing payments)	**BSL**	**MIX-50**	**REG**	**MIX**	***MIX-nonCO2****	**CPRICE**	**ALLBNK**
Industry	194	196	196	196	*194*	193	192
Residential	299	299	292	298	*296*	306	304
Tertiary	195	193	193	195	*193*	196	196
Transport	438	437	459	437	*436*	435	436
Total	*1,126*	*1,125*	*1,139*	*1,125*	*1,120*	*1,130*	*1,128*

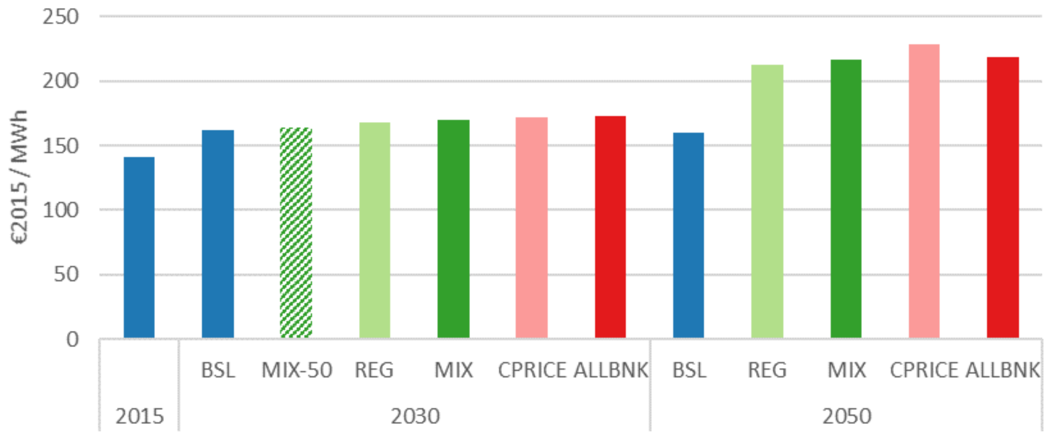
Source: PRIMES model

Sectoral system costs are most contrasted across scenarios in the residential sector. In terms of capital costs, REG is the more expensive than CPRICE due to the specific investments it requires for renovations (see section 6.4.1.3), while MIX is in-between. Conversely, energy purchases in REG are the lowest for residential and services, in line with lower energy demand, while for these two sectors CPRICE has the highest energy purchases costs. Similarly, for transport, REG is much more expensive for energy purchases due to the more ambitious fuel policies with MIX in the middle.

Energy purchase costs are driven in part by electricity prices that tend to rise over the modelling horizon. Figure 87 shows the average price of electricity for final consumers is not significantly differentiated across policy scenarios for each project period, which means that the reduction in energy purchase expenditure is mainly due to reduced energy consumption.

investors' hurdle rates in the sector. For a detailed explanation we can refer to the 2016 reference projection that included a full annex dedicated to this methodology.
https://ec.europa.eu/energy/data-analysis/energy-modelling/eu-reference-scenario-2016_en)

Figure 87: Average price of electricity



Source: PRIMES model

Importantly, energy system modelling captures well the energy system costs but the costs associated with the transition are much broader and the challenge to address them much bigger. Rapid structural change will lead to the devaluation of equipment and other assets of several industries notably in fossil fuels extraction and processing. It will also force consumers to replace durable consumer goods and renovate houses more quickly. Workers with sector specific knowledge might lose part of their investment in training and education. These phenomenon will have to be addressed by active labour market policies with greater demand on public expenditures.

9.5.2.2 Investment challenge across the sectors

While section 6.4.1.3 discusses the overall investment challenge linked to higher climate ambition and different policy set-up this annex looks at investments needs of specific sectors.

In all policy scenarios, supply side investments would represent almost 30% of total energy system investment (excl. transport) at some EUR 105-125 billion annually in 2021-2030, with a nearly equal repartition between grid investments and capacity investments (mainly in power generation)[161]. Increases in power generation and the grid would both be necessary. However, a sharper increase in generation relative to BSL would be needed (in 55% GHG policy scenarios, there is some 30% increase for generation compared with around 15% for the grid) in order to achieve a renewables share of over 60% in electricity production by 2030, which is a feature of all 55% GHG policy scenarios. Across scenarios, REG (and even more so MIX-nonCO2 variant) would be slightly less investment-intensive than MIX, CPRICE or ALLBNK in terms of supply side investment, though (in case of REG) the difference is small and counter-balanced by a significantly higher investment intensity on the demand side.

Supply-side investments would be expected to increase less, relative to BSL, than demand-side investments (excl. transport) as the bulk of energy system investments needs to take place in demand sectors (some 70% of total energy system investment for all the policy scenarios). While supply side investments vary little across scenarios, REG requires a significantly higher level of

[161] Capacity investments cover power generation installations and electrolysers for hydrogen production. In the former category there are also fossil fuels capacities that will be scrapped prematurely (i.e. stranded assets).

investment than CPRICE, MIX and ALLBNK on the demand side, in particular for the residential and tertiary sectors. Average annual energy system investment needs on the demand side amount to EUR 319 billion in 2021-2030 under REG, compared to EUR 282 billion and EUR 241 billion under CPRICE and BSL, respectively.

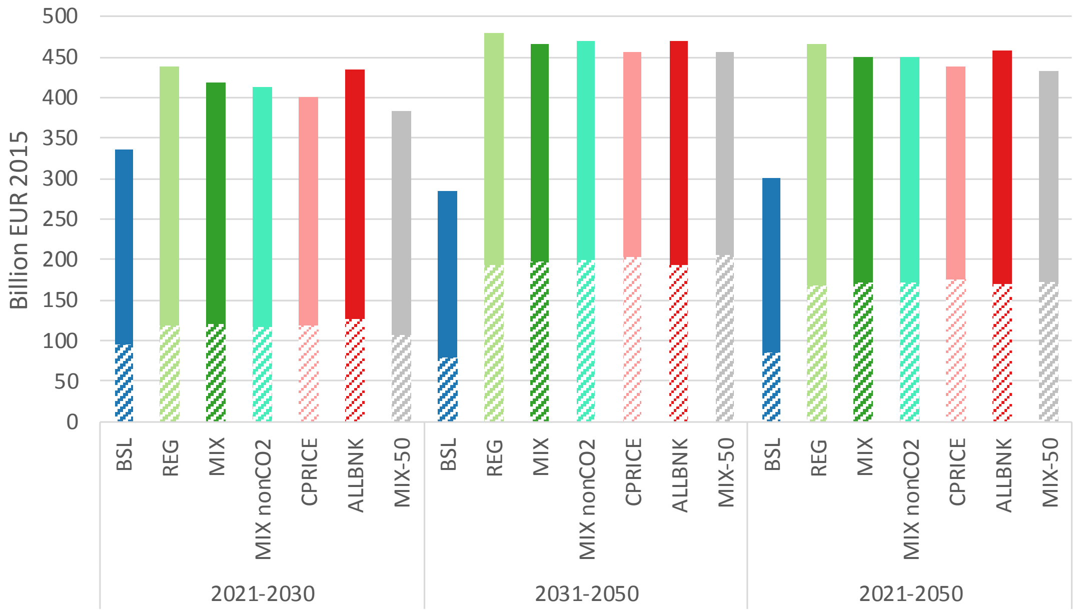
Under the 55% GHG policy scenarios, the bulk of the increase is expected to be required in the residential sector to improve thermal integrity of buildings and to reduce share of fossil fuels in heating, with substantial additional investment also in the tertiary sector for similar purposes. The REG scenario requires a level of energy system investment in the residential sector of EUR 213 billion annually in 2021-2030. This is 23% (EUR 40 billion) higher than under CPRICE and 41% (EUR 61 billion) higher than in BSL. This reflects the high reliance of the REG on renovations as an abatement option. The REG scenario also points to higher energy system investment levels in the tertiary sector than the CPRICE scenario, though the difference is significantly less pronounced.

It should be noted that CPRICE and MIX generate very similar levels and patterns of energy system investment, though with a more noticeable difference in the residential sector. This implies that in the modelling results, the extension of carbon pricing to new sectors is susceptible of altering investment behaviour also at the lower levels of the MIX scenario - if combined with regulatory measures. In general, modelling illustrates that carbon prices are an effective market-based instrument to foster the deployment of least-cost mitigation options.

In MIX-50, the additional investment needs are smaller than under more ambitious scenarios but the pattern is very similar. The additional effort would remain skewed towards the demand side, dominated by residential investment with an extra EUR 15 billion per annum. Additional supply side investment needs would be of smaller magnitude, with EUR 6 billion of incremental needs per annum in power generation and EUR 2 billion in grids - compared to BSL.

Figure 88 and Table 46 show the investments needs projections across all energy system sectors, for all scenarios.

Figure 88: Average annual energy system investment on the supply (patterned bars) and demand sides (full bars), baseline, 55% scenarios and MIX-50, 2021-2030, 2031-2050 and 2021-2050 (billion euros 2015)



Source: PRIMES model

Table 46: Average annual investment for BSL, all policy scenarios and MIX-nonCO2 variant (2011-2015, 2016-2020, 2021-2030 and 2031-2050, billion euros 2015)

	BSL			MIX-50		REG		MIX		*MIX-nonCO2 variant*		CPRICE		ALLBNK	
EU27	**Average 2011-2020**	**Average 2021-2030**	**Average 2031-2050**	**Average 2021-2030**	**Average 2031-2050**	**Average 2021-2030**	**Average 2031-2050**	**Average 2021-2030**	**Average 2031-2050**	***Average 2021-2030***	***Average 2031-2050***	**Average 2021-2030**	**Average 2031-2050**	**Average 2021-2030**	**Average 2031-2050**
Investments in power grid	24.0	50.5	50.7	52.7	84.1	57.4	83.0	58.2	80.9	*57.0*	*81.8*	58.3	82.4	60.1	80.3
Investments in power plants	30.9	42.1	26.4	48.1	94.4	55.7	85.4	56.5	88.5	*54.0*	*89.7*	55.5	92.0	59.6	85.4
Investments in boilers	1.8	2.0	2.0	3.4	1.6	3.9	1.2	3.8	1.3	*3.6*	*1.2*	4.1	1.6	4.6	1.4
Investments in new fuels production and distribution	..	0.2	0.6	1.0	27.7	1.7	24.7	1.4	26.6	*1.4*	*26.3*	1.3	28.3	2.2	25.9
Total supply side investments	56.7	94.7	79.7	105.2	207.7	118.7	194.2	119.9	197.3	*115.9*	*199.1*	119.2	204.3	126.4	193.0
Industrial sector investments	9.0	16.9	10.0	19.4	14.7	19.4	16.0	20.3	14.4	*20.2*	*14.4*	20.5	13.4	21.9	14.8
Residential sector investments	83.7	151.2	137.2	166.6	156.7	212.6	192.3	190.0	174.4	*189.3*	*174.8*	172.4	153.7	193.1	176.1
Tertiary sector investments	41.7	73.2	56.9	83.4	81.4	87.3	77.4	87.7	80.7	*87.3*	*81.1*	89.3	85.0	92.9	86.0
Transport sector investments	492.2	610.5	697.0	620.8	726.4	622.8	735.8	621.8	728.2	*622.1*	*728.4*	608.0	730.3	620.3	726.0
Total demand side investments	*626.6*	851.8	901.1	890.1	979.3	942.1	1021.6	919.8	997.7	*918.8*	*998.6*	890.2	982.4	928.2	1003.0
Total demand side investments excl. transport	*134.4*	*241.3*	204.1	269.3	*252.9*	*319.3*	*285.8*	*298.0*	*269.5*	*296.8*	*270.2*	*282.2*	*252.1*	*307.9*	*277.0*
Total energy system investments	**683.3**	**946.5**	**980.8**	**995.3**	**1187.0**	**1060.8**	**1215.8**	**1039.7**	**1195.0**	***1034.8***	***1197.7***	**1009.4**	**1186.7**	**1054.7**	**1196.0**
Total energy system investments excl. transport	**191.1**	***336.0***	***283.8***	***374.5***	***460.6***	***438.0***	***480.0***	***417.8***	***466.8***	***412.7***	***469.3***	***401.4***	***456.4***	***434.3***	***470.0***
Memorandum: Real GDP	*12848.1*	*14839.7*	*17851.4*	*14839.7*	*17851.4*	*14839.7*	*17851.4*	*14839.7*	*17851.4*	*14839.7*	*17851.4*	*14839.7*	*17851.4*	*14839.7*	*17851.4*

Source: PRIMES model

9.5.3 Macro-economic impacts (GDP, employment, competitiveness)

The economic literature identifies a number of “megatrends” susceptible to generate major implications on macro-economic aggregates over the next decades[162]. The climate and energy transition is one such megatrend, which also include automation, artificial intelligence, globalisation, demographic changes/ageing of populations, or resource scarcity.

The macro-economic impacts of the 50% and 55% levels of ambition for 2030 and associated policies are assessed in isolation from these other trends. The baseline of likely long-term developments is based upon short-, medium- and long-term real GDP projections from the Directorate General Economic and Financial Affairs (DG ECFIN). Short-term projections (up to 2021) are from DG ECFIN’s autumn 2019 economic forecast. Medium-term projections (up to 2024) are based on an estimate of potential output growth and a rule to close any gap in potential output that may exist in 2021 within three years. Long-term projections (from 2025) are based on potential output growth, i.e. based on a growth accounting methodology that uses the population projections from Eurostat and builds upon assumptions regarding trends in the labour force and the growth of total factor productivity, which is assumed to converge across Member States in the long run. Projections are made subsequently regarding sectoral trends to define a macro-economic baseline down to the level of sectoral value added, using a computable general equilibrium model for the decomposition. Consistency between the macro-economic baseline and the energy system baseline is ensured.

Three modelling tools sharing this common baseline are used to assess the macro-economic impacts of the increased level of climate ambition for 2030: (1) JRC-GEM-E3, a computable general equilibrium model; (2) Cambridge Econometrics’ E3ME, a macro-econometric model; and (3) DG ECFIN’s E-QUEST, a New-Keynesian dynamic stochastic general equilibrium model that has recently been enriched with a representation of the energy system.

In order to ensure consistency between the macro-economic modelling and the energy-system modelling regarding the type and scale of decarbonisation technologies, some results from the PRIMES model and POLES-JRC model are imposed on the macro-economic models as exogenous assumptions for the EU and the rest of the world. The PRIMES MIX scenario is used as the “central scenario” for this purpose at the EU level.

This section provides additional details on a number of matters discussed in section 6.4.2.

In terms of investment, JRC-GEM-E3 points to a positive impact of almost 1% by 2030 under the 55% fragmented action setups. The impact on investment is lower under the global action setups because of a more significant drop in overall GDP. In both cases, there is a significant reallocation in expenditure away from private consumption and towards investment. E3ME also indicates a positive impact on investment but, in contrast to JRC-GEM-E3, the increase does not come at the expense of a reduction in private consumption. This reflects the fundamental difference in the economic assumptions underpinning the two models, with JRC-GEM-E3 assuming that the economy is at an equilibrium without spare capacity while E3ME assumes that economy has some unused resources to begin with and that debt-finance can fund additional investment without full crowding out. The aggregate positive impact on GDP under E3ME means

[162] https://ec.europa.eu/knowledge4policy/foresight_en

that higher investment occurs alongside private consumption, and leading to overall increased growth.

E-QUEST projects a positive impact on investment of 0.62% relative to the baseline under a 55% level of ambition if revenues from carbon pricing are used to support green investment. Where such revenues are transferred back to households, the impact on total investment is somewhat negative (-0.55%), also because the impact on GDP is negative. As far as consumption is concerned, E-QUEST points to a small positive impact relative to baseline when carbon revenues are used either to support green investment or to reduce labour taxation on lower-skilled workers, while lump-sum transfers generates a small negative impact as it is a generally less favourable policy setting in terms of overall GDP effect.

As stressed in section 6.4.2, it is projected that the sectoral composition of investment will be significantly affected by higher climate ambition. As expected, investment in fossil fuels would drop sharply, even though the case of gas differs from other fossil fuels given its role as a transition fuel.

Table 47: Impacts of 50% and 55% reduction on EU sectoral investment (deviation from baseline, percent)

Investment vs. baseline, 2030 (range of impacts due to increased EU GHG ambition across scenarios with diversified policy setups).				
	50%		**55%**	
	Fragmented action	**Global action**	**Fragmented action**	**Global action**
Coal	-12.8 | -11.3	-10.8 | -9.6	-25.3 | -24.2	-24.1 | -23.0
Crude Oil	-9.0 | -4.4	-12.6 | -10.0	-9.9 | -4.9	-13.6 | -10.7
Oil	-4.7 | -3.2	-6.5 | -4.7	-5.3 | -3.6	-7.3 | -5.2
Gas	-2.8 | -0.1	3.1 | 4.8	12.2 | 15.9	19.2 | 21.5
Electricity supply	1.0 | 1.4	4.5 | 5.2	3.1 | 3.5	6.3 | 7.1
Ferrous metals	-3.8 | 0.1	3.1 | 7.6	-4.6 | -0.3	1.9 | 7.0
Non-ferrous metals	-1.5 | 0.3	4.3 | 6.7	-2.4 | -0.5	3.2 | 5.7
Chemical products	-0.6 | 0.0	1.1 | 1.7	-0.7 | -0.2	0.9 | 1.4
Paper products	-0.2 | -0.1	0.5 | 0.6	-0.5 | -0.3	0.2 | 0.3
Non-metallic minerals	-1.4 | 0.4	1.7 | 3.7	-1.9 | 0.1	1.0 | 3.3
Electric goods	0.5 | 1.1	3.4 | 4.2	-0.1 | 0.6	2.8 | 3.6
Transport (air)	-4.4 | 0.2	-4.4 | 1.3	-5.0 | 0.2	-5.3 | 1.3
Transport (land)	-0.2 | -0.1	-0.1 | 0.1	-0.4 | -0.3	-0.3 | -0.2
Transport (water)	-0.4 | -0.1	-3.5 | -3.0	-0.4 | -0.2	-3.6 | -3.2
Transport equipment	-0.2 | 0.2	1.0 | 1.5	-0.3 | 0.1	0.7 | 1.3
Construction	0.6 | 0.7	0.6 | 0.8	0.2 | 0.4	0.1 | 0.3
Market services	-0.2 | -0.1	-1.0 | -0.9	-0.3 | -0.2	-1.1 | -1.0

Source: JRC-GEM-E3 model

Section 6.4.2 highlighted the impact of higher climate ambition on relative prices in the economy and indicated the fact that scope extension (MIX and CPRICE scenarios as compared to REG) could have sizeable effects on the relative prices of fuels and powers for consumers. It also stressed the impact that the REG scenario, with a higher reliance on regulations and standards, could have on the relative price of housing. Using the MIX scenario as the central set up, it is also evident from Table 48 that relative prices will be affected more under global action than under fragmented action and more under a 55% level of ambition than under a 50% level of ambition. This therefore implies contrasted impacts on households, as discussed in section Impact on households.

Table 48: Impacts of 50% and 55% reduction on EU consumer prices (deviation from baseline, percent)

Consumer prices vs. baseline, 2030 (range of impacts due to increased EU GHG ambition across scenarios with diversified policy setups).				
	50%		**55%**	
	Fragmented action	**Global action**	**Fragmented action**	**Global action**
Food beverages and tobacco	0.0 | 0.1	1.4 | 1.7	0.1 | 0.2	1.5 | 1.8
Housing and water charges	0.2 | 0.4	1.5 | 1.8	1.6 | 1.9	2.9 | 3.2
Fuels and power	3.2 | 4.3	5.9 | 7.3	3.4 | 4.6	6.5 | 8.2
Household equipment and operation excl. heating and cooking	0.0 | 0.1	1.5 | 1.7	0.0 | 0.1	1.5 | 1.7
Heating and cooking appliances	0.0 | 0.1	1.6 | 1.7	0.0 | 0.1	1.6 | 1.8
Purchase of vehicles	0.5 | 0.6	2.1 | 2.2	0.6 | 0.7	2.1 | 2.3
Operation of personal transport equipment	1.4 | 2.0	3.6 | 4.4	1.4 | 2.2	3.8 | 4.8
Transport services	1.0 | 1.6	3.0 | 3.7	1.1 | 1.7	3.2 | 4.0
Miscellaneous goods and services	-0.1 | 0.1	1.2 | 1.5	-0.1 | 0.1	1.2 | 1.5

Source: JRC-GEM-E3 model

Section 6.4.2 stresses the importance of the international context in terms of the impacts on EU industry, including energy-intensive industries, and that industry could benefit from a first-mover advantage. It also highlights that the importance of domestic factors and policies, in particular the free allocation of ETS allowances and the use of carbon revenues. While world output under JRC-GEM-E3 is negatively affected by an increase in global action, thereby reducing the size of the export market, the increase in competitiveness outweighs that effect to result in higher export market shares for energy intensive industries under the global action scenarios than under the fragmented action scenarios, with the former exceeding baseline levels for some model setups. Ferrous metals is most sensitive on account of its energy intensity and the high openness to trade.

The various model setups in JRC-GEM-E3 were used to assess three key issues: (1) the behaviour of firms with respect to the value of free ETS allowances; (2) the effectiveness of free ETS allowances in protecting EU-based companies; and (3) the use of carbon revenue by the authorities.

Industrial firms exposed to international competition frequently indicate that they cannot include the opportunity cost of free ETS allowances in their price setting behaviour, which thus implies that they maximise volumes (market shares) rather than profit. Under such a market share maximisation behaviour, the negative impact of the 55% fragmented scenario on gross value added is indeed lower than under profit maximisation. The impact amounts to about 1 percentage point (p.p.) for ferrous metals and is more limited for other sectors (Table 49).

The same market share maximisation setup (at 55% ambition and under fragmented action) also indicates that free allocations can be effective in shielding energy intensive industries from losses of competitiveness, at least according to these macro-economic modelling tools that take into account historic trade statistics to assess their elasticities. The loss of output relative to baseline in ferrous metals and non-metallic minerals is about 3 p.p. and 2 p.p. lower by 2030, respectively, under free allocations than under full auctioning. Similarly, the use of carbon revenues to lower labour taxation (when also factoring labour market imperfections in the model) generates a positive effect on the output of energy intensive industries because the tax shift reduces distortions in the economy. The net impact on gross value added in energy intensive industries by 2030 under such tax-shift policies is therefore significantly reduced.

Finally, the model was extended to apply carbon pricing across the economy. Under such a setup, the significantly higher level of carbon revenue enables a bigger shift away from labour taxation, which further reduces distortions and reduce labour costs. This largely mitigates the negative impact on gross value added in 2030 of fragmented action in the EU at a 55% level of ambition.

Table 49: Impact of policies and company behaviour on output in ETS sectors (55% fragmented action, deviation from baseline)

Output vs. baseline, 2030	Profit maximisation	Market share maximisation			
	Perfect labour markets			Imperfect labour markets	
	Lump sum transfers to consumers			Tax recycling to lower labour tax	
EII sectors (power sector always auctioning)	Free allocation		Auctioning	Free allocation	
Carbon pricing non-ETS	No				Yes
Ferrous metals	-1.3	-0.9	-4.0	-0.6	-0.6
Non-ferrous metals	-1.6	-1.4	-2.7	-1.0	-0.8
Chemical products	-0.6	-0.4	-0.9	-0.3	-0.3
Non-metallic minerals	-0.6	-0.3	-2.1	-0.1	-0.1

Source: JRC-GEM-E3 model

The assessment of impacts on skills needs due employment shifts across sectors in section 6.5.1 builds on a linking results from the JRC-GEM-E3 model and the Skills Forecast 2020 of the European Centre for the Development of Vocational Training[163] (CEDEFOP). The 66 sectors for which CEDEFOP makes projections on occupation and skills are mapped to the more limited number of sectors represented in JRC-GEM-E3, leaving a total of 20 sectors represented. It is then possible to assess the impact of climate and energy policy on occupations and skills requirements in the economy. Such a method enables to measure the impact of changes in employment patterns across sectors, but it does not capture impacts related to changes in skills and occupations needs due to climate and energy policy within a given sector and thus results should be treated with care, likely not showing the full dynamics related to the transition to a decarbonised economy.

From the PRIMES modelling results, it can be clearly seen that across all policy scenarios households spend a slightly higher share of their income on energy related equipment

[163] The CEDEFOP Skills Forecast provides comprehensive information on future labour market trends in Europe. It forecast trends in skill supply and demand for Europe every two years, with a dataset that includes projections on occupational and skill breakdowns (41 occupations and 3 skill levels) for 66 sectors out to 2030. The forecast acts as an early warning mechanism to help alleviating potential labour market imbalances.

expenditures and renovations and (with exception of CPRICE and ALLBNK) a smaller share on energy purchase expenditure compared to BSL. The strong emphasis on energy efficiency policies in REG increases the spending on energy related equipment in 2030 compared to BSL by about 45 € and in investments in house insulation by about 218 €, partly balanced by almost 76 € reduced energy purchase expenditure.

Table 50: Energy Related Expenditure per Household (excluding transport) (€'15/household)

	2015	BSL	MIX-50	REG	MIX	*MIX-nonCO2 variant*	CPRICE	ALLBNK
Energy related expenditure per household (excl transport) (in €'15)	2575	3099	3168	3286	3261	3229	3256	3308
- energy equipment	725	1168	1209	1213	1202	1201	1240	1214
- energy purchases	1773	1557	1556	1481	1549	1525	1616	1583
- direct efficiency investments (renovations)	78	374	403	592	510	504	399	511
Share of energy purchase expenditure in energy expenditure	69%	50%	49%	45%	47%	47%	50%	48%
Energy related expenditure (excl transport) as % of household income	7.0%	7.2%	7.5%	7.6%	7.7%	7.6%	7.8%	7.9%

Source: PRIMES model

These changes in relative costs affect households in contrasted manners that depend on their expenditure structure, level and sources of incomes, wealth and the very composition of the household. Given that macro-economic models typically represent one or a limited number of representative households, detailed distributional impacts need to be assessed with the support of micro-level data.

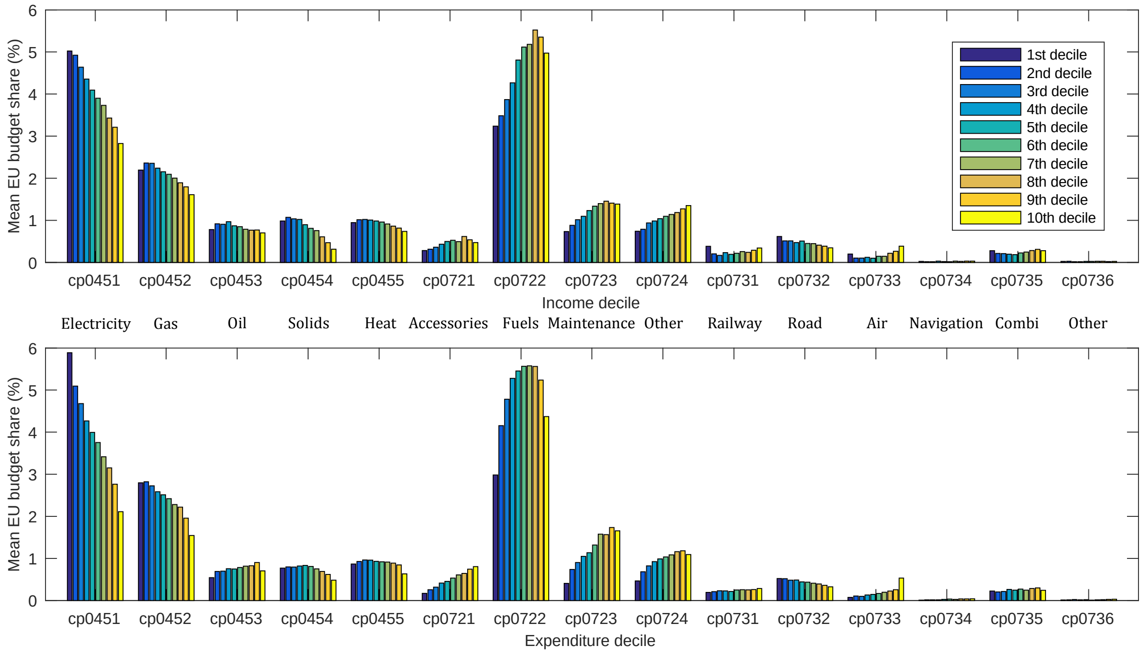
The JRC-GEM-E3 model includes a single representative household and as such cannot be used directly to assess distributional impact. For the assessment of distributional impacts on households in section 6.5.2, the JRC therefore linked its JRC-GEM-E3 model with the household budget survey (HBS) of 2010, which contains detailed data on consumption expenditure. Applying the estimated changes in the relative prices of 14 consumption categories[164] resulting from higher climate ambition onto the micro-level data of the HBS therefore enables to assess distributional impacts at a high level of disaggregation. Such an approach has a number of limitations though. First, the application of changes in relative prices to the micro-data is an "accounting" exercise in that there is no behavioural modelling involved at the micro level. This implies that the analysis does not account for differences in behavioural responses across households with varying socio-economic characteristics. The structure of household expenditure is static by assumption and cannot adapt to the changes in relative prices. Second, the latest HBS dates back to 2010, and data for Austria and the Netherlands is lacking, while data for Italy is incomplete. The aggregate is nevertheless still representative of the EU population, and the

[164] Food beverages and tobacco; clothing and footwear; housing and water charges; fuels and power; household equipment and operation (excluding heating and cooking appliances); heating and cooking appliances; medical care and health; purchase of vehicles; operation of personal transport equipment; transport services; communication; recreational services; miscellaneous goods and services; and education.

analysis complements the results on distributional effects that occur via the labour market (section 6.5.1), and concentrates here on the expenditure side only.

In terms of expenditure on energy-related goods, the HBS indicate that households spend a decreasing share of their income (or consumption basket) on electricity as one moves from the bottom to the top deciles. This is also broadly the case for oil, gas, solid fossil fuels and heat, but an opposite trend (i.e. a rising share of income spent moving from lower to top deciles) is observed for transport fuels, maintenance or air transport.

*Figure 89: Expenditures for energy-related products by income decile in the EU**



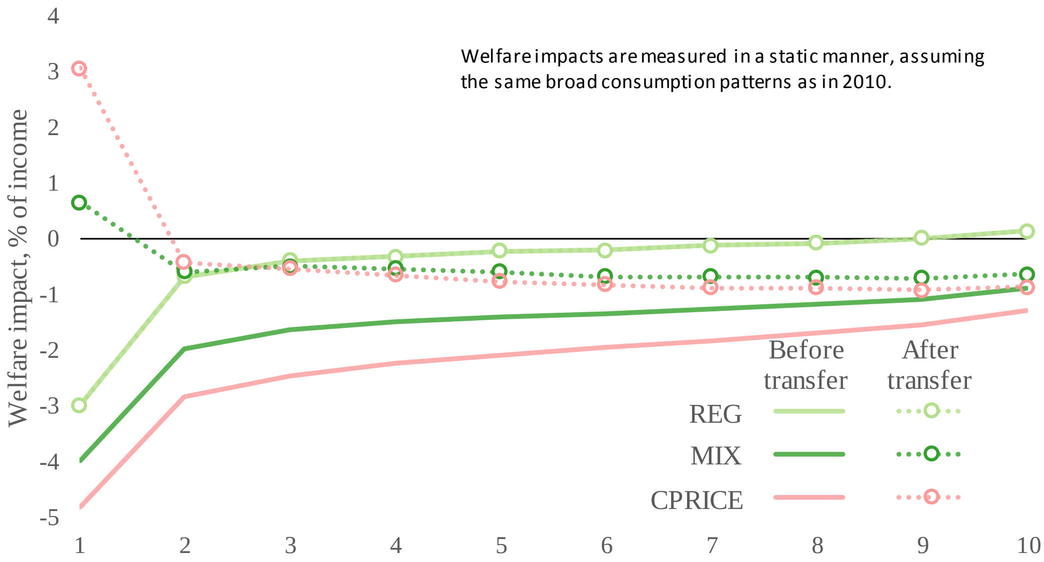
*Note: * Categories 45X represent residential energy use; categories 72X represent operation of personal transport; categories 73X represent transport services*

Source: JRC calculations based on HBS

A common measure of impact on household is the compensating variation, defined at the monetary transfer that a household would need to receive in order to maintain the same level of utility as under the previous set of relative prices. Abstracting from substitution effects, this can be simplified to the monetary transfer necessary to keep the expenditure pattern unchanged. In turn, households can be grouped in deciles either based on their level of expenditure or on their level of income. Both benchmarks are useful as expenditure data in the HBS are more robust than income data and are arguably a better proxy for lifetime consumption. In turn, income is more commonly used and reflects the fact that higher-income households spend only part of their budget on consumption. The monetary transfer can thus be expressed as a percentage of total expenditure or consumption, or relative welfare losses.

Section 6.5.2 shows the distributional impact on households before and after transfer of carbon revenues based on expenditure deciles. Similar results and conclusions can be drawn when assessing distributional impacts based on income deciles (using the same methodology as the one used for expenditure deciles), as shown in Figure 90.

Figure 90: Changes in relative welfare by income decile due to changes in relative prices (fragmented action REG, MIX and CPRICE scenarios with 55% level of ambition)



Source: JRC-GEM-E3 model

9.6 Future energy policy framework (including transport aspects)

While chapter 6.6 looks at the impacts of policy scenarios and derives on this basis conclusions on future policy framework, this annex complements this assessment with indication of future policy tools that could correspond to assumptions made in policy scenarios.

Importantly, the translation of the policy framework options into scenarios is stylised, as not all policies described below can be or are sufficiently well developed to be represented in the energy system model used for this exercise.

This exercise is without prejudging the IA for the revision of the EED that is scheduled for 2021.

Beyond the insights from modelling, it is important to assess the type of instruments that could be used to achieve the overall objectives. Both for renewables and energy efficiency, the bulk of the measures are designed and implemented at national level (with exception of eco-design standards and labelling, CO_2 standards for vehicles and renewable fuel obligations) in line with the subsidiarity principle. This enables better consistency with national circumstances and more flexibility but it is also more difficult to monitor and can lead to different implementation across MS and thus risk of cost inefficiencies at the EU scale[165].

It is not the purpose of this impact assessment to identify all specific EU measures for boosting energy efficiency or renewables deployment in the context of an increased climate ambition. These will be assessed in-depth in dedicated impact assessments accompanying the legislative proposals in 2021. However, this analysis on policy architecture aims to identify possible level of efforts in sectors where action is needed most, types of instruments that should be deployed to meet the challenges identified and interactions between different policies. The current situation indicates that the building sector, where the level and depth of renovations is well below what is needed, would be an area where additional efforts and supportive measures should be aimed at. While regulatory measures of the existing legal framework would need to be reinforced, the financing and enabling conditions would be critical, especially for higher energy efficiency ambition.

9.6.1 Energy efficiency policy framework

The current 2030 framework for energy efficiency[166] introduces powers to the Commission to verify Member States progress and envisages EU action in case of insufficient ambition and progress, while still giving Member State a lot of freedom where to place their energy efficiency efforts. The higher GHG ambition, however, will require an increased ambition of the energy-efficiency framework both at EU and national level. At EU level, such increased ambition would require more targeted EU measures in specific areas, in particular in the buildings and transport sector, given that the efforts proposed so far by Member States seem to fall short of the ambition of the EU target, as exemplified by the collective ambition gap of the NECPs energy efficiency

[165] The Governance Regulation, however, requires that the Commission proposes EU level measures in case of the insufficient ambition or progress of Member States towards the 2030 EU targets in order to ensure that these targets could be met.

[166] The energy efficiency framework has been adjusted, with the 2018 review of the EED and EPBD and the adoption of the Governance regulation. For the period up to 2020 Member States had substantial autonomy in the way they set their level of ambition and proposing measures to reach it.

contributions. Still, it is important to keep in mind that the main barriers to energy efficiency are linked to proper project implementation and financing, so the regulatory changes would need to be coupled with better enabling conditions. These could cover various aspects, such as removing barriers to the full functioning of energy performance contracting, overcoming 'split incentives' barriers, scaling up one stop shops, ensuring that state aid rules support energy efficiency solutions, developing necessary skills for buildings modernisation, enabling access to available funds, raising awareness about the multiple, non-energy benefits of energy efficiency or increasing data availability on products and system performance.

The level of granularity offered by the modelling tools used in this impact assessment to illustrate Options EE_2 and EE_3 offers both insights on regulatory measures and on ones based on economic incentives to energy end-users, with soft measures being the hardest to assess. However, since such instruments often work in parallel, it is difficult to disentangle the effects of one specific instrument. In that respect, MIX and REG approximate the stimuli and additional rules and measures under the EU law needed for a higher GHG ambition, clearly showing that the current set of EU energy efficiency policies (combining measures under EED, EPBD, and Ecodesign/Energy Labelling) would not be sufficient. The policies and measures listed below indicate where energy efficiency policy framework could be strengthened. Their modalities of implementation are yet to be defined, so they were taken into account in a schematic manner by the modelling used for this exercise and will be subject to dedicated impact assessments which will look in more details at their impacts and exact shape.

Buildings

The intensification of efforts for the buildings sector under the MIX scenario (Option EE_2) could lead to the reinforcement of several EPBD measures as compared to the BSL scenario.[167]

One such measure could be the energy performance certificates (EPCs) which inform building owners and users about cost of heating and cooling, savings that investments would bring, are a precondition to regulate the worst performing buildings out of the market and are needed to link preferential financing conditions to quality renovations. Under the existing EU regulatory framework, EPCs are compulsory for a large category of buildings[168] but their implementation at national level varies greatly. The role of EPCs could be further improved (e.g. as a verification element of the energy performance gains achieved through renovation).

The take-up of technical building systems and further penetration of building automation and control systems (BACS) and more generally of smart technologies in buildings could also be accelerated thanks to strengthening of the EPBD measures to facilitate the diffusion of demand response and energy storage, boost of technological innovation and the deployment of highly efficient appliances and smart-ready building systems and digital solutions.

[167] The highest ranked options in the public consultation are encouraging better urban planning and construction of sustainable buildings and green infrastructure, encouraging the construction sector to apply circular approaches, and providing better education and training of architects, engineers, and workforce to provide quality renovation. Respondents in professional capacity also viewed the removal of administrative barriers, raising awareness of the benefits of sustainable building and financial mechanisms as important which were less important for respondents in individual capacity. The public consultation also provides insights in the public's view how renovation could be incentivised.

[168] Those being built, sold and rented and for buildings over 250 m^2 occupied by a public authority and frequently visited by the public.

The minimum energy performance requirements are gradually tightened[169]. Both cost-optimal minimum requirements and targets for Near Zero Energy Buildings (NZEBs) differ significantly across Member States, with saving potential in at least some of them. This policy option explores further reinforcement of minimum energy performance requirements, which could be achieved through different regulatory measures[170].

Moreover, several EED measures supporting the renovation of buildings and closely interlinked with the measures in the EPBD could also be reinforced:

- increased scope and the level of renovation rate under Article 5 on exemplary role of public bodies' buildings,
- strengthening of provisions under Article 6 on public procurement,
- increasing the level of ambition of energy savings obligation under Article 7 on energy savings obligation,
- extension of the requirements under Article 16 on certification and qualification schemes,
- further addressing barriers linked to energy performance contracting under Article 18 on energy services,
- stricter requirements under Article 19 on split incentives,
- further changes in budgeting rules and more guidance on energy efficiency financing under Article 20 on financing mechanisms,
- specific policy options to increase the efficiency in heating and cooling consumption, together with the use of renewable sources. As the current EED framework does not sufficiently incentivise the uptake of efficient heating and cooling technologies, including efficient district heating, nor the utilisation of waste heat, it could be strengthened for instance by introducing a requirement to incentivise the development of regional/municipal efficient heating and cooling plans.

Finally, as regards the intensification of products legislation measures (Energy Labelling Regulation and Ecodesign Directive), given that the product groups with the highest energy savings potential are already covered by existing regulations, following measures could be explored:

- increasing the ambition of the new Ecodesign working plan in 2020, including possible extension to new product groups and tightening the requirements, where applicable;
- improving compliance levels through better enforcement by Member States' market surveillance authorities (e.g. by improving coordination at EU level and financing joint surveillance actions);
- strengthening the systematic inclusion of circular economy aspects (e.g. reparability, durability, upgradeability, recyclability);

[169] The cost-optimal minimum requirements for new buildings and for existing buildings undergoing major renovations are revised every five years by Member States in order to take into account technology and market uptake, cost variation of different measures as well as national economic and climate conditions. As of 2021 all new buildings have to be nearly zero-energy buildings (NZEB), meaning buildings with high energy performance (high performing envelope and technical building systems, combined with RES solutions).

[170] E.g. through specific requirements for the energy performance of the insulation, windows, heating systems, etc. or a minimum energy performance expressed in kWh/m2.y or a minimum energy performance class).

- extending the scope of products that can be regulated under the Ecodesign Directive, as considered under the Sustainable Product Policy Initiative in follow-up to the Circular Economy Action Plan.

Under the REG scenario (Option EE_3) the three legislative frameworks (EEPD, EED and the products legislation) would be strengthened further than in the MIX. This could be done through the reinforcement of the EPBD measures concerning mandatory renovation/minimum energy performance requirements for the worst performing buildings from the market[171]. Such policies could improve the average quality of the national building stock given priority to buildings most in need, or targeting specific segments as a priority. Owners and landlords would have to invest in upgrading their properties e.g. before selling or renting out, or by a certain date. This could have positive impact notably on low-income and energy poor households often inhabiting badly performing buildings. This measure also addresses fundamental barriers to building renovation like split incentives between owners and tenants, decision-making difficulties in multi-owner buildings, building value not fully reflecting energy performance and low awareness of the benefits of renovation.

The scope of Article 5 of the EED, which concerns the renovations of public buildings obligation, could be extended to all public authorities and to all public buildings, or reinforced by defining the scope of the obligation based on the "functions" or public use of the buildings in such a way to include also e.g. museums, theatres.

Furthermore, products legislation measures could be reinforced by:
- a more ambitious new Ecodesign working plan, including a larger set of new product groups and further tightening the requirements, where applicable;
- speeding up the regulatory process;
- Further increased ambition of the revision in the Ecodesign Directive;
- promoting higher minimum standards even if, for certain product categories, it implies *de facto* phasing out certain fossil fuel options.

Finally, with the adoption of the Recovery Plan, the Renovation Wave initiative and its action plan, accompanied by the rigorous enforcement of legislation on energy performance of buildings and a targeted review of the regulatory framework, the EU will be well equipped to address the main barriers to building renovation and deliver energy efficiency actions also in other sectors at a much larger scale.

Industry

The reinforced policy architecture for energy efficiency for industry could be based on several measures that are already covered by the EED. Further strengthening of the relevant eco-design requirements, coupled with further prioritisation of energy efficiency, could also be explored.

The intensification of efforts under the MIX scenario (Option EE_2) could include:

[171] E.g. dwellings rented out having to meet a minimum energy performance class.

- cross-cutting policy measures, such as energy savings obligation schemes (Article 7 of the EED),
- strengthening and extending the energy audits requirement (Article 8 of the EED),
- measures to promote the uptake audits recommendations (Article 8 of the EED),
- introduction of measures to address waste heat reuse potential (Article 14 of the EED),
- intensification of Ecodesign requirements for products applied in industry (e.g. motors, fans),
- application of the energy efficiency first principle in the energy infrastructure planning and promotion of demand side solutions.

The REG scenario (Option EE_3) would build on the strengthened Article 8 EED concerning energy audits for large companies under the MIX scenario. The provisions of this article could be further reinforced[172] through:

- an extension of scope of the mandatory requirement, covering more type of enterprises or different economic actors,
- financial and regulatory support to the implementation of energy efficiency measures identified in the audit,
- mandatory implementation of cost-effective energy efficiency measures.

ICT

There have been some energy efficiency improvements of data centres in the past, but there is no appropriate legislative framework and policies to limit the negative impact of data centres' energy consumption to CO_2 emissions. While this assessment was being performed, in 2020, the EU Digital Strategy announced a commitment to make data centres climate-neutral by 2030, with actions to be put in place in 2021-22. For the time being only a voluntary Code of Conduct for Energy Efficiency in Data Centres have been introduced since 2000. Intensification of policies in this area under MIX and REG scenario would be based on strengthening the existing legal framework and extending its scope to data centres. The areas to be explored when intensifying efforts under the MIX and REG scenario could look at new actions under EED measures:

- addressing the challenges (e.g. the 'hidden' energy consumption of datacentres) and opportunities (e.g. self-reporting of product energy use) of product digitalisation,
- ensuring energy performance standards by newly constructed data centres,
- introducing provisions to address waste heat re-use in data centres (Art. 14),
- strengthening the market for energy efficiency ICT products through targeted public procurement measures (Art. 6 on Public Procurement).

On the top of all these measures, the energy efficiency targets for 2030 and the way they are defined could also be adapted to reflect the new level of efforts needed, so that the targets provide

[172] It requires the Member States to ensure that large companies carry out an energy audit every four years, but it does not require implementing energy efficiency improvement measures identified in the audits, and thus the impact of the current measure is limited unless it is required by national law. In addition, Member States have high flexibility in relation to the uptake of energy audits by small and medium-sized enterprises and households.

a clear signal on the EU and Member States commitment in energy efficiency and push all parties concerned to do more. To this end the ongoing evaluation of the EED should help identify the elements in the existing policy framework that do not sufficiently address persisting barriers to energy efficiency as well as policy design that could ensure scaling up the efforts.

9.6.2 CO_2 emission standards for vehicles and other transport system efficiency related policies

Looking at the entire transport sector, it is projected that energy demand will decrease in all scenarios by 2030. The differences in terms of impact on final energy demand are not significant between the REG, MIX and CPRICE scenario. The comprehensive policy mix of REG scenario combing taxation, CO_2 standards, renewable fuels mandates and overall energy efficiency improvements in the transport system leads to slightly bigger reduction in transport emissions than in other scenarios. In all scenarios, intensification of CO_2 standards for vehicles is an effective and important driver for higher efficiency and switch toward zero-emission vehicles and in this way ultimately to deeper greenhouse gas emissions reductions, with benefits for consumers in terms of lower fuels bills, contributing to energy security and stimulating investments into the technologies needed for the transition towards zero-emission mobility. Intensification of CO_2 standards has a key role in the longer term perspective, thanks to gradual impact due to the pace of overall fleet renewal. In all the scenarios, stricter standards as compared to the baseline in 2030 lead to significant environmental benefits in the period after 2030.

Strengthening of the CO_2 standards for vehicles is a critical instrument for road transport. In addition there is a plethora of other policies that are in place and could be strengthened or expanded in order to further reduce energy consumption and emissions. These have also been to some degree reflected in the policy scenarios which intensify efforts in transport policies. The possible actions to be explored in this context cover:

- incentives for intermodal freight transport and further efforts to improve the functioning of the transport system via support to multimodal mobility and intermodal freight transport by rail, inland waterways and short sea shipping;
- initiatives to increase and better manage the capacity of railways, inland waterways and short sea shipping, supported by the TEN-T infrastructure and CEF funding;
- gradual internalisation of external costs (“smart” pricing);
- incentives to improve the performance of air navigation service providers in terms of efficiency and to improve the utilisation of air traffic management capacity;
- revision of roadworthiness checks;
- deployment of the necessary recharging and refuelling infrastructure, smart traffic management systems, transport digitalisation and fostering connected and automated mobility;
- further actions on clean airports and ports to drive reductions in energy use and emissions;
- additional measures to reduce GHG emissions and air pollution in urban areas;
- pricing measures such as infrastructure charging;
- other measures incentivising behavioural change;
- further measures related to intelligent transport systems, digitalisation, connectivity and automation of transport - supported by the TEN-T infrastructure;
- additional measures to improve the efficiency of road freight transport;

- incentives for low and zero emissions vehicles in vehicle taxation;
- increasing the accepted load/length for road in case of zero-emission High Capacity Vehicles;

Finally, these policies would be combined with intensification of policies that impact the carbon intensity of fuels (as discussed in the section on renewable policies below).

9.6.3 Renewable energy policy framework

Renewable energy is crucial to deliver on a climate-neutral economy. It is also a key component of the EU long-term energy strategy and a core dimension in the NECPs regarding 2030. RED II was recently reviewed and provides a stable platform to build a stronger and forward looking regulatory framework for the development of the renewable energy in Europe in line with higher GHG reductions in 2030. The aggregated Member States contributions show that renewable energy will grow at a faster pace in the years up to 2030 and if the Member States' fulfil and exceed their renewable energy contributions the overall share of renewable energy in the EU27 would exceed the 32% target in 2030. In this regard, the comprehensive and updated regulatory framework under the Clean Energy Package has already proved to be a key driver for renewable energy deployment plans beyond the target that the EU has set itself in the context of the climate and energy policy architecture at the time.

However, to reach an increased GHG target the measures contained in the Renewable Energy Directive will require an increased ambition as carbon pricing alone would not overcome some market barriers that still exist for the uptake and integration of renewable energy. As foreseen in the European Green Deal, there is a need to review the existing framework to deliver on the increased climate ambition, flanked with additional measures and related key actions foreseen on the already adopted Energy System Integration and Hydrogen Strategies and future strategies such as the one on Offshore Renewable Energy. The translation of these measures into legislation would lead to a more integrated, resilient and renewables-based energy system paving the way for a faster and more cost-effective transition of the energy system towards climate neutrality.

In all policy scenarios, electricity generated from renewable sources and its use increase across all sectors when compared to the BSL scenario. In this light and building on the RED II, the revised framework needs to assess how to increase coherence of energy infrastructure planning, supportive licensing procedures while introducing options for green public procurement and requirements across Member States. Specific analysis will be also needed to facilitate the roll out of offshore renewable energy, foster regional cooperation in renewable electricity including accelerating the opening of support schemes to cross-border participation and possible fast track permitting process. Such policy options go beyond Option RES_1, and would enhance regional cooperation, decrease the need for financial support and expedite the permitting process for energy consumers that could lead to increased public acceptance.

For transport, scenarios show the predominant role of the fuel switch. In all scenarios it is visible that electrification is a key avenue for decarbonisation in transport, however, it is challenging in sectors, which heavily depend on high energy density fuels, such as the aviation and maritime sectors and consequently renewable and low carbon fuels will have an important role to play to decarbonise these sectors as acknowledged in the Energy System Integration and Hydrogen Strategies. Current renewable fuels used in transport are predominantly biomass based, but the feedstock base for the types of renewable fuels used today is limited. It is therefore paramount to develop new technologies, which are scalable and allow broadening the feedstock base such as advanced biofuels as well as renewable and low-carbon fuels, including RFNBOs (such as hydrogen-derived synthetic fuels). These fuels are currently not commercially competitive with fossil fuels and mature types of biomass based fuels, and therefore could require more targeted support. In this regard, policy options RES_2 and RES_3 from Section 5.2.2.4, could provide an enhanced and stable policy framework that would ensure the development and commercial deployment of renewable- and low-carbon fuels increasing investor certainty, scaling up technologies and bringing costs down. All scenario results, including the BSL scenario, indicate that based on the current RES-T[173] methodology, the EU is set to overshoot the 14% target agreed in REDII by at least 4.7 percentage points (p.p.). This could be partly due to the existing incentives (multipliers) that might be higher in some transport sub sectors compared to others and in this regard the revision of the Renewable Energy Directive will also explore options to simplify and adjust as appropriate the methodology. Furthermore, the regulatory framework, including the Renewable Energy Directive as well as other legal instruments, need to be adjusted or defined as appropriate, for incentivising not only the production of these fuels but also their consumption in the most appropriate transport sub sector, while limiting and developing unnecessarily additional administrative costs.

The Renewable Energy Directive sets for the first time a coherent and dedicated EU legal framework for the heating and cooling sector including a specific renewable heating and cooling target[174] and a renewable sub-target for district heating and cooling. This would allow raising the share of renewables by 2030[175] and further mainstreaming of local renewable energy solutions to contribute for additional renewable energy deployment. Although in their NECPs over half of the Member States provided an at least indicative 1.1 p.p. yearly increase, these targets are indicative and Member States have a best endeavour obligation to reach them. Furthermore, MS trajectories and the target level is close to business-as-usual and would be insufficient to deliver on the ambition that is being showed in Section 6.2.1.3. More deployment of RES in H&C was analysed in all scenarios. Re-enforcing the current framework and updating the accounting framework, could stimulate further the integration of an EU market for renewables in heating and cooling. Within this context, measures devoted to foster the electrification of the sector are especially important to consider as a cost-effective vehicle to decarbonise the sector, as included in the Energy System Integration Strategy. Assessment of these policy options would aim to remove uncertainty while providing sufficient impetus for Member States to implement the required annual increase to reach the 2030 target and future increases to pave the way for climate neutrality by 2050.

Building on Policy options RES_2 and RES_3 from Section 5.2.2.2, a strengthened overall RES heating and cooling target would require the strengthening of the target and other provisions for district heating and cooling which would need much more granular assessment. For example, a

[173] The methodology is set out in Article 27 of recast Renewable Energy Directive (Directive (EU) 2018/2001)

[174] 1.3% point yearly increase requirement in the share of renewable heating and cooling in the period of 2021-2030. The target can be fulfilled up to 40% with waste heat/cold sources. If a Member States chooses not to use waste heat/cold, the target can be reduced to 1,1% point, can be averaged over two five-year periods of 2021-2025 and 2026-2030 and to be fulfilled fully with renewables.

[175] 1% point yearly increase in the period of 2021-2030. This target is also indicative and can be fulfil with the use of waste heat/cold up to 100%.

possible strengthening of the rules on third party access for renewable and waste heat/cold suppliers could allow for more informed decisions about the performance and transformation of district heating and cooling to support higher shares of renewable energy, making it an effective instrument for faster and more cost-effectively delivery of renewable and low carbon[176]. In addition, the design of the reinforced targets, measures and flanking instruments would address specific barriers and enable the use of sector integration solutions, such as the linking of heating and cooling and district heating and cooling systems with the electricity grids and the use of renewable gases and waste heat sources from industry and services. With regard to thermal and other energy storage in buildings, district heating systems will need to be incentivised and co-operation between electricity distribution network and district heating and cooling operators intensified to better exploit demand response and flexibility solutions, including from building renovation and energy network investment, in line with the Energy System Integration Strategy and the Renovation Wave.

Furthermore, to decarbonise heating and cooling sector, it is paramount to replace fossil fuels in buildings' heating systems to a more efficient and renewable systems. However, consumers need the know-how and find highly skilled installers to choose the best renewable and efficient heating systems that would be appropriately sized for their needs, while significantly minimise the costs if the right decision is taken. A coordination of heating system replacement with improvement of the building envelope is paramount to reduce costs and ensure the most cost-effective and high quality, optimised solutions. Building regulations and codes, urban and infrastructure planning must be conducive to also integrate decentralised renewable energy solutions in buildings and communities to supply their energy needs.

These improvements require amending the current relevant provisions; therefore, they go beyond option RES_1, which focuses on implementation via non-legislative guidance and best practice exchanges. Thus the RED II would help to design such regulatory framework and reduce the risk of lock in at low RES H&C levels in buildings, industry and district heating for their heating and cooling requirements.

9.6.4 Consistency between energy efficiency and renewables legislation

In the design and implementation of future energy policy, it is of utmost importance to exploit synergies, seek consistency and the mutually supportive nature of the reviews of the Renewable Energy Directive, the Energy Efficiency Directive, the Energy Performance of Buildings Directive and the EU Ecodesign and Energy Labelling Framework. Such streamlining would foster synergies between different energy carriers, such as between electricity and heating (direct and indirect use of renewable electricity), that would be also more also in line with the vision outlines in the Energy System Integration and Hydrogen Strategies, the Renovation Wave communication together with other relevant policies pointing to the same directions, such as the review of the TEN-E regulation, sustainable product policy, the Circular Economy Action Plan and biodiversity strategies, etc.

[176] The capacity of district heating to supply renewable and low-carbon heat at high efficiency has been underpinned by ENER/C1/2018-494 (on-going), which models technology specific heat of primary energy factors.

9.7 Extended analysis of impacts of ETS extension and interaction with the ESR

This section takes an increased ambition as starting point and extends the analysis of the impacts on the current key cross-sectoral climate policy instruments, the EU Emissions Trading System (ETS) and the Effort Sharing Regulation (ESR) summarised in section 6.7. The analysis focuses on a GHG ambition level of -55% as this would have larger implications, but extends also to relevant differences in case of a -50% ambition.

9.7.1 Environmental impacts of policy aspects: impact on ETS and ESR

The increase in climate ambition to -50 to -55% below 1990 would lead to significantly higher GHG emission reductions both in the ETS and ESR sectors. Overall the ETS sectors, even with a changed scope, are still projected to reduce emission more compared to 2005 than the ESR sectors, in the current scope -63 to -64% for -55% and -58% for -50%. For the current ESR sectors, the reductions would be -39 to -40% for -55% GHG and -36% for -50% GHG.

What is clear is that beside the higher reduction in the existing ETS and ESR scope, the ETS and ESR would see different levels of projected emission reductions depending on which sectors are included or not, driven by the difference in reductions achieved per sector (see Table 26 for the full results). For instance if the scope of the ETS were to be extended with buildings only, the projected emission decrease for this ETS scope (-65% in the -55% scenarios) would numerically not significantly differ from the current scope's (-63 to -64% for -55% GHG). However, if the scope of the ETS were to be extended with road transport only, the projected emission decrease in the ETS is typically much lower (-53%) than the one reflecting the current ETS scope. The opposite is of course the case for the ESR, which sees higher percentage reductions of -45 to -47% compared to 2005 if one excludes road transport from its scope (-42% with -50% GHG reduction), and lower percentage reductions of -34% to -36% if buildings and transport are excluded (-30% with -50% GHG reduction) and -29 to -31% compared to 2005 if one excludes buildings from its scope (-27% with -50% reduction). Similarly the extension of the ETS to maritime navigation and return to full scope for aviation under the ETS would result in lower projected emission reductions, with both international aviation and navigation making emissions relatively higher, and the other sectors in the ETS having to reduce even more.

Impacts on the EU ETS for its current scope

The outcome of the ETS in terms of the emissions ambition level is determined by its cap on the total number of allowances and the functioning of the MSR. In option ETS_1, the current ETS scope, the BSL scenario would achieve a 2030 emission reduction of -54% compared to 2005 while the policy scenario with -55% GHG ambition reductions combined with an increased ambition in EE and RES policies up to 2030 (REG) would achieve emission reductions in the ETS of -63% by 2030 compared to 2005[177].

The ETS Directive (Article 9) determines that the ETS cap for stationary installations decreases linearly, by an annual amount equal to a percentage of the average annual allocation during phase 2 (2008-2012, excluding aviation), referred to as the linear reduction factor (LRF). The LRF is applied to the mid-point of the period from 2008 to 2012 and for phase 3 (2013-2020) was 1.74%, coherent with the then 2020 overall economy-wide GHG reduction target of 20%

[177] ETS ambition based on current ETS scope (including only intra-EU aviation).

compared to 1990. For phase 4 (2021-2030), it was set at 2.2% coherent with the current 2030 -40% GHG target.

Arriving at a cap in 2030 in line with the emission projections under option ETS_1 for 50% to 55% GHG reductions economy wide would require a change of the ETS linear reduction factor, an update overall recognised as needed by stakeholders[178]. A revised linear reduction factor is dependent not only on the 2030 ETS ambition but also on other elements including:

- Starting year: the year from which the cap is to be revised, i.e. the start year from when the new LRF will apply[179]. The later the LRF is revised the higher the LRF (steeper curve) is needed to achieve the same 2030 ambition[180];
- Rebasing: the baseline level from which the LRF is applied for stationary sources follows a linear approach starting from a historical figure, the midpoint of the period from 2008 to 2012. To ensure an appropriate annual cap, the baseline starting reference level could be adjusted downwards to better reflect the actual development of emissions[181,182];
- Scope: depending on a possible ETS scope extension and how such an extension is designed, elements such as cap stringency/ambition will impact the extended ETS LRF

See also section 6.7.1, Figure 17 for an example of how simply changing the LRF (in 2026 in this example) compares to rebasing of the cap for stationary installations (using 2025 emission projections as a starting point on which the LRF is applied from 2026 onwards), as well as the impact of the scope, with ALLBNK resulting in the tightest cap for stationary installations.

Regarding scope, for policy purposes, the definition of the cap and LRF setting requires a robust and verified emissions data reference point. For the current ETS scope, the ETS Monitoring, Reporting and Verification (MRV) system ensures the data robustness for the covered sectors, and for a possible scope extension a comparable system is required.

Therefore, for this exercise no representative LRF has been established for the ETS options with extended scope. This impact and the consistency with the overall framework will have to be assessed in the subsequent policy review. But overall it is clear that options that include additional sectors that reduce less than the current ETS sectors and thus result in lower percentage GHG reductions (see Table 26), may allow for a less stringent increase in the overall LRF. The installations covered by the ETS today are emitting less than the total cap. This gap between the cap and the actual emissions was estimated for 2018 equivalent for 134 million allowances. This has significantly widened to around 250 million allowances in 2019 due to the large reduction of emissions. However, the Market Stability Reserve, in operation since 2019 to

[178] E.g. Eurelectric response to the consultation

[179] Based on the current ETS framework with its two five-yearly allocation periods 2021-25 and 2026-30, for the purpose of this analysis, all results are presented for a start in 2026. However, earlier start as of 2023 is also possible. This envisaged start will be assessed in the possible review of the ETS.

[180] As per the ETS Directive, the LRF does not have an end date and the current analysis focuses on reaching the increased 2030 ambition level. A LRF beyond 2030 in line with the 2050 climate neutrality objective will be assessed in the possible review of the ETS.

[181] Further assessment of the LRF options and their interaction with the Market Stability Reserve will be performed in the possible review of the ETS and the MSR review in 2021, this interaction and review is supported by both industry and academic stakeholders.

[182] Rebasing is a in Sitra's consultation reply – 2019 study by the Oeko institute "The role of the EU ETS in increasing EU climate ambition: Assessment of policy options"

tackle structural supply-demand imbalances, ensures that much fewer allowances than the annual cap come to the market.

In the BSL scenario, this difference between the nominal cap and the annual emissions, is projected to continue into the next decade (on average estimated to be 17% below the yearly cap), despite a more ambitious 2.2% LRF. Accordingly, the surplus of allowances in the system would not see sufficient reductions and continue, thereby potentially preventing the EU ETS from delivering the necessary investment signal to reduce GHG emissions in a cost-efficient manner and from being a driver of low-carbon innovation contributing to economic growth and jobs. Hence, this may only be addressed, if the Market Stability Reserve is strengthened as part of its first review in 2021.

Impacts on the ESR for its current scope

The ESR currently sets binding national minimum contributions for 2030 that for EU27 add up to a 29% reduction compared to 2005. The BSL scenario as well as the EU-NECP variant achieves a 2030 emission reduction of 32%. In line with the current ESR architecture and scope (option ETS_1), the REG policy scenario sees emissions reduced mainly through increased EE, RES, transport and some non-CO_2 policies, resulting for -55% GHG in an ESR reduction of 39% compared to 2005 (-36% for -50% GHG). Ensuring achievement of this emission reduction in the current policy architecture would imply translating this ambition level into more ambitious national 2030 targets, requiring a step up on average of 10 to 11 percentage points (p.p.) for -55%, 7 p.p. for -50% and 12 p.p. for ALLBNK.

Another impact would be a change of the target trajectories. Based on the current ESR framework with its two five-yearly compliance cycles 2021-25 and 2026-30, this could be implemented for the second cycle. The starting point of the target trajectories in the current ESR has been set in a way avoiding a significant EU surplus at the start of the period. Therefore, this was done based on most recent available emissions. For 2021 this has been 2016-18 emissions. The implication of the continuation of this logic[183] for the average steepness of the trajectories can be illustrated at EU level by using EU average emissions between 2020 and 2025 as proxy. For -38% ESR to achieve -55% GHG, this would increase the steepness of the trajectory over the five years 2026-30 from annually 1.8% compared to 2005 under the current ESR to 4.1%. Starting the trajectory calculation for the 2026-30 change instead from 2025 ESR allocations would lead to a steepness of -3.9%. If the 2026-30 trajectory calculation would start from 2021 ESR allocations, then the trajectory steepness would decrease to 3.1% compared to 2005.

Contrary to this balanced approach, some Member States and stakeholders have indicated that they want a focus on higher emission reductions in the ETS sectors instead of tightening further current ESR targets for increasing ambition. The realisation of some of the reduction potentials, e.g. in existing buildings and agriculture, is seen as more uncertain due to specific barriers. In the modelling results, the ETS sectors are already expected to reduce more, compared to 2005, than the ESR sectors, with e.g. -63% vs. -39% reductions for -55% GHG and -58% vs. -36% for -50% GHG (see Table 26). A 5 p.p. additional ambition in the ETS sectors alone would imply for the 55% ambition level, at current ETS scope, a further increase of the ETS target to 70% and in turn a high linear reduction factor.

[183] These illustrative calculations should not be read as prejudging the ESR revision. This issue will be dealt with as part of the legal proposal planned for 2021.

If the binding minimum targets under the existing ESR were not to be changed at all, as some Member States argue, but the overall GHG target is kept, the ETS target would need to cover for all additional reductions or, alternatively, the LULUCF objectives would have to be raised. The former would result in the current ETS scope in an ETS reduction target well above –70% compared to 2005 to achieve respectively an overall economy wide GHG target of -55% GHG compared to 1990[184].

Turning to the environmental impacts of the other policy options, with changed climate policy architecture and different ETS and ESR scopes, Table 51 presents as an additional element an overview of the respective relative sizes of the systems for relevant scenarios.

Table 51: Current and 2030 ETS and ESR shares for different scenarios and sectoral coverages

Current and 2030 ETS and ESR shares in % of total GHG	**Current emissions**		**BSL**		**REG**		**MIX - nonCO2**		**CPRICE**	
	ETS	ESR	ETS	ESR	ETS	ESR	ETS	ESR	ETS	ESR
(Options ETS)	Fully separate ETS and ESR scopes									
(1) (4) No change scope[185]	42	58	37	63	34	66	34	66	33	67
(2.1) Buildings + road transport in ETS	74	26	69	31	67	33	68	32	67	33
	Increase scope ETS but maintain these sectors in ESR									
(2.2) Buildings + road transport in ETS	74	58	69	63	67	66	68	66	67	67
	Create separate ETS for some sectors while maintaining them in ESR									
(3) buildings + road transport	42	32 | 58	37	32 | 63	34	33 | 66	34	33 | 66	33	34 | 67
(3) buildings	42	12 | 58	37	9 | 63	34	8 | 66	34	8 | 66	33	8 | 67
(3) road transport	42	20 | 58	37	23 | 63	34	25 | 66	34	26 | 66	33	26 | 67
(3) all remaining energy CO_2	42	39 | 58	37	37 | 63	34	39 | 66	34	39 | 66	33	39 | 67

Source: own calculations, EU GHG inventory 2020, PRIMES model, GAINS model

Impacts of changes of sectoral ETS coverage illustrated for -55% GHG reduction

If additional sectors were to be covered by the ETS as in options ETS_2, ETS_3 and to a certain extent ETS_4, this would increase the likelihood of achieving the emission reductions in these sectors, and hence the EU's GHG target for 2030. With the resulting carbon prices, firms and households would have an additional economic incentive to reduce their emissions in the sectors newly covered by an ETS, and this incentive would rise the lower the estimated achieved emission reductions are in the current setup, even countering possible rebound effects from

[184] For a 50% reduction, the corresponding value would be well above 60%.
[185] The ETS scope starting point used in the calculations in this table corresponds to the current EU ETS scope, i.e. covering stationary installations covered by the ETS directive and intra-EU aviation.

efficiency improvements and resulting cost reductions. It would also help in diffusing decarbonisation technologies more quickly. With buildings and road transport CO_2 emissions included in the ETS, around three quarters of the current total emissions (around two thirds in 2030) would be covered by an EU wide cap. This compares to one third in 2030 in the current architecture.

Examples of building technologies, which could be implemented profitably at carbon prices in the range of the modelling results (assuming the absence of the additional energy efficiency and renewable policy intensification measures analysed in section 6.6), are early furnace replacements, integrated heating and domestic hot water, certain elements of insulation, high efficiency ventilators, water heater replacements, ground source heat pumps for the commercial sector, biomass heating or electric heating. Examples of transport technologies are improved aerodynamics, engine efficiency, tyre resistance, light-weighting of vehicles, more blending of biofuels as well as to a certain extent the switch to electric vehicles.[186]

ETS emissions in the main variants of options ETS_2 and ETS_3, that include the building and road transport sectors into the ETS or create (at least temporarily) a separate trading system for these sectors, reduce by 56% compared to 2005, which is less than in option ETS_1 without buildings and the road transport sector in the ETS. The carbon pricing scenarios show clearly that building emissions are expected to respond significantly stronger to carbon prices than transport emissions, with additional reductions between 2015 and 2030 compared to the baseline of 14 to 15 p.p. for residential and 9 to 12 p.p. for services, compared to 3 p.p. for road transport. One reason is that in the transport sector there are currently already often high explicit or implicit carbon prices through national carbon or energy taxation, unlike in the buildings sector, and therefore the additional incentive is smaller. For example for motor fuels, the EU27 unweighted average of implicit carbon prices of current MS nominal energy and carbon tax rates reported in the Taxes in Europe database amounts to around EUR 240 for petrol and around EUR 160 for diesel.

If heating related emissions of buildings were fully included into the ETS, ETS emissions reduce therefore stronger, by -65% compared to 2005. Most of the additional carbon price-induced emission reductions would be realised through fuel switching and electrification. If only transport were included in the ETS, the ETS emission reductions would be -53% compared to 2005, lower than with buildings only.

If all energy-related CO_2 emissions were to be included, as it is proposed, for example, in the German national ETS, ETS emissions would reduce by -55%. Then also abatement options in non-road machinery and equipment, including in the agricultural sector, would be incentivised.

A strong point of options ETS_2 and ETS_3 is that the ETS has strong enforcement. It thus scores high on certainty to deliver the environmental outcome. The enforcement mechanisms in case of non-compliance with the obligations through the financial penalties under the EU ETS apply directly to the emitting entity. In the ESR the compliance obligation is on each Member State, through additional emission factors[187] and standard infringement procedures. The incentive to comply for an emitting entity is therefore stronger under the EU ETS, although this also depends what measures each Member State puts in place for the sectors covered by the ESR.

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[186] Results from bottom-up modelling by ICF et al. (forthcoming), using carbon prices between €30 and €90.

[187] If a Member State misses its ESR target in year x by 1 million tonnes, it would have to over-achieve its ESR target in the subsequent year by 1.08 million tonnes.

The option ETS_2.1, which not only extends the scope of the EU ETS, but sees a commensurate reduction of the ESR scope, has some significant implications for the ESR. It would require a smaller numerical increase of Member State targets than in the current ESR scope, with emissions having to decrease by 34 to 36%[188] instead of 39 to 40%. However, the ESR would lose in this option around 55% of the current emission scope and the share of emissions covered by the ESR would decrease in 2030 from 66 to 67% in option ETS_1 to 32 to 33%. This would change the characteristics of the ESR very significantly.

This would leave agriculture as the main remaining sector (CO_2 and non-CO_2 together around half of the remaining ESR scope), followed by industry with around 20% and waste and energy with both around 10% of the remaining ESR emissions. Around 40% would stem from CH_4, around 30% from CO_2, around 20% from N_2O and around 5% from F-gases. This could further strengthen the visibility of the need for emission reductions and ambitious policies in the remaining ESR sectors. The major reduction in ESR scope could also lead to significant changes in Member State specific cost-efficiency gaps to achieve national targets based on fairness (GDP per capita) compared to the 2016 ESR impact assessment[189]. Hence if the current features of the ESR are maintained in this reduced scope, the target adjustment rules might need to be reconsidered. The increased role of agriculture in a reduced ESR would also invite to revisit the role of the LULUCF flexibility, which has been designed to compensate for the comparatively lower technical mitigation potential of agriculture.

If only buildings were to be shifted, the projected ESR emission reduction is only -29 to -31%, i.e. similar as the current numerical ESR reduction of -30%, thus raising less the prospect of an absolute need to review the ESR targets. If only transport were to be shifted, the opposite would apply, as the remaining ESR would reduce in this variant emissions by -45 to -47%.

The main variant of option ETS_3, which puts the buildings and road transport sector at least transitionally in a separate ETS, leads to two ETS systems of roughly similar size in 2030, each close to 35% of total emissions. If only transport is covered, the separate system would still cover around 25% of total emissions. A separate ETS covering only buildings would cover close to 10% of total emissions.

The environmental impacts would depend on the cap setting for the separate ETS. The presented reductions would only materialise if the separate cap is set in line with cost effective emission reductions. If initially set at a less ambitious level to test the impacts, the separate ETS would have lower impacts on additional national policies and not allow the sectors as a whole to achieve its cost-efficient GHG target ambition.

The reductions would also depend on the extent of flexibilities allowed between the existing EU ETS and new separate ETS for buildings and transport (as well as the flexibility between existing ETS and remaining ESR), and possibly with the LULUCF sector. Since one of the reasons for going for separate systems would be to first ensure the robustness of the new systems, with expected early challenges associated with lack of a robust and verified emissions data reference for the cap setting in the new ETS, limited or no linking at all could be foreseen in the first years of the system operating.

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[188] If all energy CO_2 is excluded from the ESR, the required reduction is with -29 to 32% still smaller, while the other impacts are similar.

[189] SWD(2016) 247 final

Maintaining ESR coverage in a transitional manner for some sectors newly covered by emissions trading, as foreseen in options ETS_2.2 and ETS_3, can lead to a situation where sectors in the ESR that are also in the ETS, reduce more than needed in the ESR as a whole, allowing sectors not covered by the ETS in the ESR to do less than what would be cost-efficient. Potentially, and with the assumption that the ESR target for these sectors is significantly lower than the ETS target for these sectors and lower than the cost-efficient ESR reduction, this could lead to a situation that both the ETS and ESR targets are met, but not the collective economy wide targets. Such as situation could happen if carbon pricing in the sector with overlap between the ETS and ESR, potentially in combination with other policies, is seen as strongly reducing emissions, resulting in less pressure on the Member State to achieve the ESR targets in the remaining sectors not covered by the ETS. This risk would be reduced in case the scope expansion covers a large part of ESR emissions or if ESR targets are set higher. This risk could also be limited by specific ambitious EU measures in these sectors, such as the F-gas regulation and EU circular economy and waste legislation, or a further greening of the CAP. Of course if the ETS would cover the whole of the ESR, the risk is reduced to zero assuming the ETS target is set at the corresponding level needed to achieve 50% or 55% GHG reductions economy wide. In addition to the need for mitigating such risks where relevant, maintaining ESR coverage with extended ETS (option ETS_2.2) would lead to the need to review the current ETS flexibility in the ESR in view of emerging interaction dynamics.

Impacts of additional national carbon pricing measures

In option ETS_4, the current ETS/ESR architecture continues, and related architectural impacts described under option ETS_1 also apply. However, it is complemented by an additional carbon price incentive to reduce emissions, in principle created by a national system. As currently and under option ETS_1, national environmental considerations and ambition levels would take precedent over EU internal market aspects in the covered sectors. An obligation to set up national trading systems would prioritise the certainty of the environmental impacts and counter rebound effects from cost reductions. National carbon taxation would have less certainty to achieve the targeted emission reductions, but more certainty on the level of the price signal. Furthermore, it might be a more practical alternative for MS with already existing carbon taxation or small MS.

The national emissions trading systems in option ETS_4 have the disadvantage that, if collectively the national caps are set at a level below the EU ambition for the sectors covered by these national systems, then this option will not achieve the required EU wide GHG reduction. If, even with caps set below the EU ambition, the sectors covered achieve the EU wide GHG ambition, then this means other policies or technology developments are driving this and the carbon price would be in a number of Member States, those with overachievement of the target under their trading system, weak and thus not serve as an incentive to take action to reduce emissions and hence defeat its purpose.

Finally the creation of a national trading system for a sector presently in the ESR could also be considered to facilitate convergence of carbon pricing systems and pave the way to an inclusion of more sectors into the EU ETS at a later stage[190].

[190] Already the current ETS legislation allows a Member State to ask for switching sectors from the ESR to the EU ETS, so called ETS opt-ins. Under option ETS_4, it could be considered to allow this possibility to comply with the obligation to establish an effective carbon price.

An interesting example illustrating option ETS_4 is the newly created German ETS system for energy-related CO_2 emissions not covered by the EU ETS, which combines a cap with a fixed price in the first years and minimum (and maximum) carbon prices later.

Setting explicit minimum carbon price levels for these sectors by a revision of the EU energy taxation could mitigate internal market challenges by ensuring the same minimum carbon prices across all EU Member States, but in itself is no guarantee for delivery of the required emission reduction. The extent of the incentive of a national taxation would depend on national choices and would normally be influenced by the extent of national gaps regarding national effort sharing targets. Member States would also have a direct national choice on the strength of the price incentive compared to other means to achieve their ESR targets.

9.7.2 Economic impacts

The general economic impacts of an increased ETS and ESR ambition and various scenarios are assessed in section 6.4. If the ESR and ETS targets are increased as in the current architecture and scope (option ETS_1), the flexibility between the ETS and ESR could be enlarged to increase cost-efficiency by allowing for more flexibility between the two systems reflecting Member State circumstances.

Options with an emissions trading system at the EU level (ETS_2 and ETS_3) can assist in first incentivising the cheapest reductions across Member States, improving cost-efficiency in the sectors covered and deliver increased environmental certainty at the emission reductions to be achieved. This is not the case with a variant of option ETS_4 with a national carbon tax, or where national trading system do not add up to the required overall ambition level.

An extension of the EU ETS to new sectors such as in option ETS_2 would not only represent a significant expansion in the availability of abatement options across the EU, but also sectors compared to the current situation. It would create a more integrated carbon market with a single carbon price, which could hence drive emission reductions where they are overall most cost-efficient. Hence, it would ensure the maximum cost-efficiency and not distort the single market. By contrast, options ETS_3 and ETS_4 could lead to different carbon prices for the buildings and road transport sectors, the current EU ETS sectors, or across Member States, and could therefore possibly be more adapted to diverse abatement potentials and ability to pay of different sectors and Member States.

This needs to be weighed against the problems, which the different national prices or different prices in different sectors, may create for the level playing field in the single market, in particular but not only in road transport. Variants of emissions trading options (ETS_2, ETS_3 and to an extent ETS_4) with inclusion of only one of the sectors would be comparatively less efficient than variants with both sectors, or with all energy-related emissions covered.

Covering building emissions fully by the current ETS (options ETS_2.1 and ETS_2.2) would provide a level playing field in terms of carbon pricing of domestic fossil-fuelled heating systems with district heating and electric heating already now covered by the ETS. There is no clear pattern regarding the relative size of attributable ETS and non-ETS emissions in the buildings sector across Member States. In 11 Member States the ETS based building emissions are larger than the ESR base, which can be explained by differences in the coverage of district heating systems and in electric heating and cooking in the Member States[191]. As such there may be suboptimal incentives presently, potentially creating an incentive of switching away from district heating due to inclusion in the EU ETS. Similarly, covering road transport emissions fully by the current ETS would provide a level playing field in terms of carbon pricing of fossil-fuelled road transport and rail with electric vehicles and electrified rail.

In principle it is difficult to argue for double EU regulation from an economic perspective, as for the same emissions two different parties would be obligated to reduce them, leading to potential inefficiencies. However, there is ample evidence that at least the short term price sensitivity in the buildings and transport sector is relatively low[192], hence prices either cannot overcome all barriers or might need to be very high to achieve the outcome, a risk which modelling and the resulting carbon price of EUR 60 in CPRICE can only reflect to a certain extent.

In option ETS_2.2 the economic rationale for keeping the sectors newly covered in the EU ETS also in the scope of the ESR is to limit the carbon price impact risks for the industry sector by continuing to make sure that important non-price-sensitive abatement potentials would be addressed by the Member States. To be efficient, Member States would need to take into account the development of the EU ETS price and its impact on their domestic emissions in these sectors when specifying their policies.

Option ETS_3 starts from the economic rationale to create an EU level carbon pricing instrument (while option ETS_4 fosters such instruments at national level) to facilitate the cost-efficient achievement of the ESR reductions, while acknowledging that there are externalities less amenable to be addressed by prices, for which targeted national policies (and/or some targeted intensification of EU wide energy efficiency and renewables policies) could be also economically useful.

The ESR transfer flexibility between Member States may mitigate the economic impacts as it could allow Member States to sell ESR surpluses achieved through the ETS to other Member States. The opposite can also happen, with private entities under the ETS fully complying with the ETS, if need be by buying allowances, and Member States still required to buy ESR allocations from other Member States to comply with their ESR target. This could in itself be driven by a continued national target setting in the ESR that is focussed on differentiation between Member States based on per capita GDP, if cost-efficiency adjustments remain as limited as in the current ESR.

To further mitigate the economic impacts of covering some sectors by ETS and transitionally maintaining them in the ESR, the ex-ante limits for such transfers set in the ESR of up to 10% of a seller’s annual emission allocation for a given year 2026 to 2030 as well as the limited flexibility between ETS and ESR might need to be reviewed.

As mentioned above, as the shifting of new sectors from the ESR to the EU ETS under option ETS_2.1 also shifts the responsibility for the reduction achievement from Member States to economic actors, it reduces ceteris paribus the incentive for ambitious national policies which address specific barriers. What the materialisation of this risk could mean is reflected in the significant carbon price differences between the CPRICE and the MIX scenario (EUR 60 vs. 44 in 2030). The complementary policies introduced in a scenario like MIX would address barriers

[191] ICF et al, forthcoming.
[192] Ibid.

like imperfect information, slow responses to prices incentives due to the relative long time horizon of individual investments in buildings and cars, split incentives between owners and renters, which in itself allow to achieve more mitigation action at certain carbon prices, thus lowering the required carbon price increases.

In option ETS_4, the variant with national carbon taxation has the economic advantage over emissions trading (ETS_2, 3 and variant of 4 with national emissions trading systems) that prices are more predictable (subject to political interventions). However, emissions trading enables emission reductions to take place where least costly. To note, in the relatively few countries that have an effective carbon taxation for buildings and transport, carbon tax levels are often higher than current EU ETS prices.

Notably in the building sector the introduction of the carbon pricing will have a material impact on the pricing of certain carbon intensive energy carriers and correspondingly increased end user prices. While this would exactly provide for the economic incentive to reduce emissions, it can also impact lower income households' spending (see also section 6.5.2 on the impacts for household spending).

Auctioning is the default method for allocating allowances in the EU ETS, because it is the most economically efficient and simplest system and avoids windfall profits. Free allocation of allowances is only continued as a safeguard for sectors at a significant risk of carbon leakage.

In the absence of an extension of the European Emissions Trading to the maritime sector, under options ETS_2-4, a possible reduction of road transport competitiveness compared to the maritime transport could result in an uneven playing field. In any case, it is expected that this would be rather limited as it is only a small proportion of routes where maritime transport competes with road transport.[193] Conversely, applying a carbon price to road transport could put it on an equal footing in competitive terms with rail freight transport.

An increase of fuel prices in road transport could also decrease the competitiveness of filling stations on the EU borders vis-à-vis filling stations just outside the EU borders, and thus regarding the impacts on end consumers, may encourage tank tourism. However, cross-border differences in fuel prices are already considerable and therefore the EU ETS is estimated to only have a modest impact on the scale of this. Figure 18 shows the sensitivity analysis for the effect of different carbon prices on fuel prices both in road transport and buildings in 2030.

The cost efficiency of the ETS at achieving additional emissions abatements might be limited by the current heterogeneity of the national fuel tax landscape. Indeed, current tax rates applied by Member States diverge quite widely, both in level and in structure. These differences distort the market and would therefore prevent EU cost-efficient emissions reduction[194]. This market distortion could be corrected by the integration of the transport sector in the ETS if the price increase from ETS inclusion was significant in relation to the energy tax levels[195]. A related dynamic that may impact is if Member States will leave their own taxation levels on transport fuels, to the extent that they are higher than the minimum requirements of the Energy Tax Directive, in place, or if they were tempted to lower any of these. This would of course distort the overall impact and require other sectors, also in other to reduce more. This should be avoided to

[193] CE Delft et al. (2014), *Analysis of the options to include transport and the built environment in the EU ETS*

[194] Öko-Institut, *Policy mix in the transport sector: What role can the EU ETS play for road transport* (2015). Available at https://www.oeko.de/oekodoc/2221/2015-006-en.pdf

[195] Ibid.

not end up in a run to the bottom where inclusion in the ETS provides for incentives to reduce energy taxation rather than maintain it.

Buildings do not meet the criteria that would deem them to be at a risk carbon leakage either.

Because both sectors have relatively small or non-existing competitive pressure from outside the EU or even within the EU, free allocation risks resulting in windfall profits, with those receiving the free allocation incorporating the opportunity cost in their own price setting. This was also empirically noted in the beginning of the EU ETS for the electricity sector, where evidence emerged that free allocation was not stopping the incorporation of the carbon price in the price of electricity sold[196]. This was one of the principal reasons to make the shift to auctioning for that sector.

As discussed in section 6.4.2 auctioning puts a price on an externality, and allows to recycle revenues. If used to reduce distorting taxes it decreases the overall economic impacts and can even spur growth. It can also be used to invest in exactly the low-carbon investment needed to decarbonise.

Hence, auctioning is applied as the allocation method in all options with emissions trading to eliminate the risk of windfall profits and improve overall economic performance.

9.7.3 Social and distributional impacts of policy aspects

Many of the policy aspects depend on the details of policy proposals, thus only a few policy related considerations can be provided at this stage.

For the buildings sector, the abatement potential varies by Member State, with the amount dependent on the building typology, the fuel mix, and the degree of market penetration of applicable abatement measures, purchasing power, and the relative levels of retail fuel prices. In the road transport sector, the abatement potential is related to the rate of vehicle fleet renewal in each Member State, baseline vehicle energy consumption, the degree of expected market penetration of applicable abatement measures and fuel prices. Hence the impacts of a uniform carbon price for these sectors under options ETS_2 and ETS_3 are expected to vary across Member States, depending also on the way ETS auctioning revenues are distributed.

The ESR has a relevant distributional impact on different Member States, mostly determined by the extent of gaps between emissions and targets[197]. A key distinction for several ESR elements is between higher income and lower income Member States. The scenarios indicate that additional emission reductions compared to baseline under the current ESR scope (option ETS_1) are roughly equally distributed between both groups.

Options ETS_2 and ETS_3 with ETS coverage of new sectors while maintaining them in the ESR could lead to additional distributional impacts between Member States depending on whether the national ESR targets would be significantly less or more stringent than ETS induced reductions.

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[196] See e.g. Sijm, J., Neuhoff, K. and Chen, Y. (2006), *CO_2 cost pass through and windfall profits in the power sector*, Working Paper 0639 and EPRG Working Paper 0617.

[197] See for details section 5.1 of the impact assessment of the Effort Sharing Regulation proposal, Commission SWD/2016/0247 final.

9.7.4 Administrative impacts

This section goes into the administrative costs and feasibility of the different options considered. If the current scope of ETS and ESR is maintained (option ETS_1), there would be no change of administrative impacts compared to the current ETS and ESR. Under the ESR, the administrative impact comprises annual emission reporting and five-yearly compliance checks, complemented by national action plans in case a Member State makes insufficient progress towards its national target including use of flexibilities. A higher ambition level could imply that such corrective action under Art. 8 of the ESR would need to be invoked more frequently than with the current targets. Considerations on stronger ESR enforcement mechanisms would be warranted, including if flexibilities with EU ETS are increased.

Presently inventories of ESR emissions are based on the economy wide GHG reporting by the EU and its Member States to the UNFCCC from which the verified ETS emissions data are subtracted for each Member State. If emissions trading is extended to new sectors (options ETS_2 and ETS_3), for such extension to be effective, it must be possible to measure and monitor emissions with high certainty and at reasonable cost and be able to attribute it to individual entities.

An extension will require a totally new monitoring, reporting and verification system for these new additional sectors. An extension to new sectors will trigger costs related to the setting in place and the operating of such a system, both for the regulated entities and public authorities, including in terms of IT infrastructure and human resources. Regulated entities' participation in the system would imply obtaining a permit, a registry account, putting in place a monitoring, reporting and verification system, obtaining and surrendering allowances. Public authorities would need to ensure the running of the system and compliance by regulated entities with its requirements.

Different competent authority structures in the EU ETS framework are encountered across Member States (see Table 52). In most Member States more than one competent authority is responsible for all activities of the ETS. Furthermore, in many Member States also involve regional or local authorities in the administration for granting permission of installations, inspection, monitoring, reporting and verification or other issues. For these reasons, and due to possible coordination of monitoring and reporting with already existing requirements for the purpose of excise duty, it is not possible to give quantitative figures on the administrative costs incurred by regulators in the various Member States. Moreover, these costs could at least to some extent be offset by the new auction revenues, depending on how they would be used.

Table 52: Competent authorities' structures across Member States in 2018 in the current EU ETS framework

Organisation	Number of countries
Centralised system in which one competent authority deals with all activities related to EU ETS	6
Centralised system in which one competent authority deals with all activities related to EU ETS for aviation	7
Centralised system for MRV activities and inspection/enforcement while the allocation and policy making, or auctioning are allocated to a different authority.	16

Organisation	Number of countries
Local or regional authorities responsible for permitting or inspection but one centralised competent authority for approving the monitoring plans, dealing with changes to the monitoring plan, reviewing emission reports and approving improvement reports.	5
Decentralised system where multiple local and regional authorities are involved in inspection and MRV activities	11
Competent authorities that are responsible for installation's MRV activities are organised differently than for aviation.	9

Source: ICF et al. assessment, European Commission, SQ Consult, UBA Vienna (2019), Application of the European Union emissions trading directive - Analysis of national responses under Article 21 of the EU ETS Directive in 2018

Looking at the setting in place of the system, the option whereby the existing ETS is extended (option ETS_2) has the advantage that the use of the existing infrastructure such as registry, auctioning arrangements or competent authorities' structures in the Member States for the new sectors may be more obvious than if the new sectors are included into a new separate emissions trading system (option ETS_3). Nevertheless, also for option ETS_3 it seems likely that existing ETS infrastructure could to a certain degree be used. Whether emissions trading is extended to only one or to two sectors would not affect the one-time costs for setting up the system significantly.

Looking at the costs associated with the operating of the system, both options ETS_2 and ETS_3 would trigger recurring administrative cost and burden for regulated entities and public authorities. The cost of monitoring, reporting and verification plays a crucial role in this respect: for participants in the current EU ETS, the MRV cost has been estimated to represent about 70% of the total transaction costs and average MRV costs per entity have been estimated at around 22,000 €/year and 0.07 €/tCO_2[198]. Furthermore, administrative costs include fees for the use of the registry – different across the Member States[199].

Because of the large number of small emitters (many of which are private persons) and their proportionally higher administrative burden and cost, a pure downstream approach such as in the current ETS whereby the emitters themselves are regulated does not seem feasible when extending emissions trading to the two sectors.

An upstream approach whereby not the emitters themselves but entities further up the supply chain would be regulated, could to some extent remedy challenges stemming from the large number of small emitters in the two sectors[200]. It must thereby be ensured that the chosen point of regulation is technically feasible (volumes can be monitored and reported, and end use known),

[198] Monitoring, reporting and verifying emissions in the climate economy, 25 March 2015, V.Bellassen, N.Stephan, I.Cochran, J.-P.Chang, M.Deheza, G.Jacquier, M.Afriat, E.Alberola, C.Chiquet, R.Morel, C.Dimopoulos, I.Shishlov, C.Foucherot, A.Barker, R.Robinson. Nature climate change, VOL 5, April 2015

[199] https://ec.europa.eu/clima/policies/ets/registry_en#tab-0-1

[200] For example, EDF have argued that a cost-efficient solution could be to place compliance obligations for small emissions sources higher up in the supply chain, e.g. on fuel suppliers and distributors.

that incentives to reduce emissions can be passed on to consumers, and that the administrative costs are proportional to the reduction effect.

An assessment against these elements shows that the regional distributors for gas[201], tax warehouses for oil[202] and distributors for coal could qualify for being upstream regulatory points. Gas supplies (gas being the most important fuel in the building sector and playing a very small role in transport) and oil supplies (oil being widely used in both transport and buildings) would need to be regulated regardless of whether both sectors are submitted to emissions trading, or only one of them. Coal supplies would only be relevant in case emissions trading is extended to buildings (coal playing only a minor role in buildings at the EU level but with variation between Member States).

While there are more than 2,300 regional distributors for gas, the cost of identifying supply streams to buildings and filling stations is expected to be moderate: data on volumes and fuel quality are already collected and since the delivery is done to end-customers, regional distributors should be able to clearly separate fuel for use in road transport and the built environment from fuel used for other purposes. On the basis of the individual consumption profile, gas distributers should also be able to distinguish supplies to residential buildings from supplies to commercial buildings. Though all of this will add additional transaction costs compared to a system that would include all gas use in the ETS.

With respect to oil, the number of regulated entities would be high (there are approximately 7,000 tax warehouses) but the administrative costs for these entities would be moderate since they are already heavily regulated and an administrative quantity metering system for monitoring and reporting already exists for the purpose of excise duty. Not all tax warehouses know the final user of their products and additional transaction costs will arise in the differentiation of fuels for heating, fuels for road transport and fuels for other purposes[203] or in design variants when only commercial buildings and freight transport are included.

With respect to coal there would be a relatively high number of regulated entities (there are about 3,000 coal distributors). In comparison to the markets for oil and gas, the administrative impacts would be significantly higher since there would be many smaller regulated entities which have hardly been regulated up to now and which would need to establish reliable monitoring and reporting systems. Coal distributors would be able to identify the supply stream to buildings, as they deliver to end customers but this clearly would increase transactional costs.

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[201] In principle also Transmission System Operators (TSO) could qualify as regulated entities, but given that TSOs are not the legal owner of the gas, possible legal obstacles at this level would need to be considered.

[202] Oil refineries could in principle also be chosen as point of regulation. In that case it would be necessary to also regulate imported and exported oil, which is not the case for tax warehouses.

[203] The CE Delft study noted with respect to transport fuels that "*Currently, not all tax warehouse keepers are able to distinguish to which transport mode fuels are delivered. However, since many tax warehouse keepers act also as excise duty points and since at these levels in many Member States different fuel tax rates are applied for road, rail and IWT transport (and also for agricultural and construction vehicles), it should be technically feasible to made this distinction at every tax warehouse. However, this may require an extension of the monitoring and reporting obligations set for tax warehouse keepers.*" With respect to heating fuels, the CE Delft study noted that "*Some countries use the same tariff for fuels used for heating purposes and fuels used in other sectors. In these countries the excise duty administration might not be sufficient to distinguish between fuel use in the built environment and fuel use elsewhere (…) and additional measures will have to be taken to include fuel use in the excise duty administration for the purpose of the ETS.*"

With more effort, it also seems possible to distinguish between the commercial and private buildings. Nevertheless, the monitoring of coal supplies can be expected to be less accurate than oil and gas supplies, with more room for error and fraud, because of the variation in coal quality, difficulties to identify all regulated entities and all of their deliveries, and because of difficulties to control import and export. Adequate measures would need to be put in place to mitigate this risk[204].

The above shows that as a result of the extension of emissions trading to the two sectors as foreseen in options ETS_2 and ETS_3, the number of regulated entities would more than double compared to the current number of regulated entities under the EU ETS. However, it can be expected that the monitoring and reporting rules that would be adopted for the upstream regulated entities would be not more complex as compared to the current EU ETS system. In the new sectors, only sales of largely standardised fuels for combustion purposes would be monitored. The calculation of emissions could continue to rely on emission factors, as in the current system. While tax warehouses and gas distributors are already heavily regulated entities which facilitates their identification and supervision, there would be more efforts for the regulators to identify and supervise the coal distributors.

The above also shows that limiting the upstream regulation to certain sectors can only be done with considerable effort, as from the upstream perspective, the tracking of fuels over the supply chain would be cumbersome and would give rise to complexities. This would be in particular the case for oil where tax warehouses often do not have a direct relationship with the end user of the supplied oil. Adopting an upstream approach when extending emissions trading to the two sectors as foreseen in options ETS_2 and ETS_3 would lead to a hybrid system whereby the sectors currently already covered under the well-established and well-functioning EU ETS would continue to be regulated downstream.

Any risk of double counting (e.g. upstream coverage of fuel being supplied to installations already covered by the EU ETS) or risk of loopholes (e.g. larger non-ETS gas consumers that do not purchase their gas from the distributors but have instead a direct connection to the gas TSO network) would need to be assessed and addressed appropriately. While this could in theory be done notably by providing for ex-ante exemptions when the regulated entity knows the status of the end consumer, and where necessary, compensation regimes to avoid double coverage or specific arrangements for firms that would otherwise not be captured by the regime, the practical design of such mechanisms would undoubtedly pose very complex challenges.[205] These challenges led Germany to include in its national ETS not only heating and transport fuels, but also fuels for small industry emitters not covered by the EU ETS, while foreseeing at the same time exemptions from the national ETS for EU ETS installations.

If all fossil fuels emissions were included into an emissions trading system, it would not be necessary to differentiate between individual sectors. This would address to a certain extent boundaries issues identified above and could reduce administrative impact. Still, the challenges

[204] This could include for example requiring coal suppliers to monitor both coal they purchase and coal supplied to end-users in a mass-balance approach, and an assumption that in principle all coal that passes through a supplier is intended for end-users in the built environment, unless proven otherwise.

[205] For a detailed analysis of the important practical challenges of an extension of emissions trading to sectors not covered by the EU ETS, see Felix Matthes, "Ein Emissionshandelssystem für die nicht vom EU ETS erfassten Bereiche", available at https://www.oeko.de/fileadmin/oekodoc/Emissionshandelssystem-fuer-nicht-vom-EU-ETS_-erfassten-Bereiche.pdf

coming from the combination of an upstream and downstream model (i.e. replacing the EU ETS with a new EU-wide-all-fossil-fuels upstream emissions trading system) and the risk of double counting would exist and need to be addressed. While a shift to a full upstream model may be seen to solve MRV issues, it would mean an overhaul of the ETS, which has proven to work well.

There may be also some administrative impacts resulting from the ETS coverage of certain sectors while maintaining them (transitionally) in the ESR under options ETS_2.2 and ETS_3. First, ESR administrative rules would continue to apply. However they are generic and the administrative costs related to ESR implementation are limited and are independent from the emission scope, as they always start from GHG inventory emissions deducting (or not) emissions covered by the EU ETS[206]. Second, there may be complexities resulting from differences in emission calculation methods under the EU ETS and under the GHG inventories. This would need to be further analysed as part of any legal proposal, however, there is ample experience from dealing with such issues and related risks for ESR compliance for the industry sector, where such calculation methods differ more strongly.

The administrative impact under option ETS_4 would depend on the sub-option chosen. To the extent that the sectors are included into an emissions trading system, similar considerations as those formulated above regarding the level of regulation, the need to identify sector fuel use and challenges coming from the combination of an upstream or downstream approach would apply. It is moreover likely that precise coverage and regulation in the different MS would differ leading to a heterogeneous design.

On the positive side, the systems could be more tailor-made in function of the existing situation in the MS (and take into account for example the country's existing excise duty regime). If an obligation for a carbon tax is put on MS (several of which have already adopted such carbon tax), the tax would most likely apply to the same entities as those that would be regulated under an emissions trading system.

Where necessary, measures would need to be taken to distinguish, where this is not yet the case, fuels covered by the carbon tax from those not covered (such as fuels supplied to current ETS systems). A tax is expected to have an advantage that has lower start-up costs and subsequent operation. The use of the existing tax infrastructure may be more obvious than with an emissions trading system. A revision of the Energy Taxation Directive, which is a possibility for implementation of this option, would require unanimity among MS. Future energy policy framework (including transport aspects).

[206] See for details section 5.6 of the impact assessment of the Effort Sharing Regulation proposal, Commission SWD/2016/0247 final.

9.8 Sector specific analysis of climate and energy policy interactions

This annex complements the analysis in section 6.8 on the interactions of climate and energy policy architecture and increased carbon pricing with sector specific considerations for the key relevant sectors, buildings/ heating and transport sectors.

Specific considerations for the buildings/ residential and services/ heating sector

Increasing the synergies between energy efficiency policies for buildings and policies fostering renewables deployment in heating & cooling and future more stringent energy efficiency standards for buildings, heating and cooking appliances and other equipment would require intensified policies to remove barriers and hassle related to renovations. Some previous EU attempts to introduce mandatory measures in this area have incurred in the past subsidiarity concerns. The EU financing has focused more on regions eligible under cohesion funding, although the instruments foreseen within the framework of the Recovery Plan could change the picture.

Only a limited number of Member States and countries in the world use the pricing of the carbon content of heating fuels through taxation or emissions trading as significant policy leverage. In the residential and commercial sector 78% of emissions of 42 OECD and G20 countries are not subject to a carbon price. Sixteen percent are priced between EUR 0 and EUR 30/tCO_2, and 6% above EUR 30/tCO_2[207]. Often there are economic and social reasons invoked for this, as the demand for heating fuels is also dependent on weather conditions and very inelastic to price in the short term. In the longer term household energy demand has been more price elastic, with values ranging from 0.23 to 0.5 in the EU and its MS[208]. Sweden is an example of a Member State which uses since long carbon taxation as key driver for reducing emissions and increasing the use of renewable energy, with recent tax rates set at EUR 110. It has been a key driver for large emission reductions in the building sector by reduced emissions from heating of homes and premises[209].

In the buildings sector, the interactions of carbon pricing instruments with the horizontal energy efficiency instruments are more complex and require a careful design of the policy architecture. One of the main instrument of the EED is set in Article 7 that requires achievement of a cumulative energy savings target by 2030. This requirement drives to a large extent measures in the buildings sector. According to the information submitted in the NECPs (Annex III), in the period from 2021 to 2030 at least 52% of the energy savings will be realised on buildings (the remaining 48% would come from cross-cutting measures which could also target buildings). These are to be achieved either via energy savings obligations scheme, which are currently in place in 15 EU MS, or alternative measures. Depending on the type of carbon pricing introduced, the implications for the functioning of Article 7 would be very different.

[207] OECD (2018): Effective Carbon Rates 2018: Pricing Carbon Emissions Through Taxes and Emissions Trading, OECD Publishing, Paris.

[208] ICF et al. forthcoming

[209] E.g. Nilsson, Lars J. et al., In the Light of the Future – Steering towards Zero Emissions in 2050 (in Swedish), Climate Research Programme LETS 2050 at Lund University, 2013, https://www.lth.se/fileadmin/lets2050/Rapporter_o_Abstracts/130522_I_Ljuset_av_LETS_2050_webb.pdf, Ricardo Energy and Environment, Sweden Energy and Carbon Tax Policy. 2018, https://es.catapult.org.uk/wp-content/uploads/2018/10/Sweden-Case-Study-FINAL.pdf

The introduction of a carbon taxation as in option ETS_4 would have direct impacts on the alternative measures provisions. Given that the alternative measures have to be additional to those set by the EU legislation, the introduction of EU (or EU mandated national) carbon pricing taxation as analysed would not be accounted as an alternative measure under the EED. Furthermore, given that minimum tax level would be set at the EU level, the existing national taxation measures could not be accounted for under Article 7 if they are not above the EU minimum. Assuming an unchanged EED this would limit the possibility for MS to use taxation as a measure to comply with Article 7 and therefore Member States would have to seek new energy efficiency measures to comply with Article 7 energy savings obligation, or the specifications would need to be adapted.

The example of France shows that carbon taxation could complement the energy savings obligation scheme (ESOS). The French carbon tax includes the building sector and co-exists with a white certificate scheme that obliges energy suppliers to promote energy efficiency measures among their customers through the trade of energy efficiency certificates. Both schemes create a price signal aimed at reducing demand for energy. The carbon tax of EUR 45/tCO_2 currently corresponds for natural gas used for heating purposes to EUR 8.45/MWh, while the ESOS price incentive corresponded in February 2019 to EUR 4.00/MWh. The instruments were found to complement each other, as they reinforce the incentives under each instrument. The energy efficiency schemes also mitigate against disproportionate impacts on low-income households, which may lack the capital to invest in energy efficiency in response to increased energy prices resulting from the carbon tax[210].

In case of an extension of the ETS system to buildings (therefore covering not only district heating and electric heating/ heat pumps, but also gas, oil and coal consumption for heating purposes) or of an equivalent carbon taxation instrument, a significant additional price incentive for heating fuel savings and the switch to renewable heating could be provided. The energy efficiency measures promoted by the EPBD and the EED would likely become more cost effective, due to higher costs for building heating as a consequence of ETS implementation. This could therefore accelerate progress towards achieving the targets in the EED and increasing renovation rates, depending, however, significantly on the level of the carbon price or taxation.

However, the functioning and effectiveness of the energy savings obligation schemes as key delivery instrument could be affected. The two instruments would most likely have to rely on the same regulated entities, which could not always be easy to implement, because the obligated parties under the Article 7 energy savings obligation schemes are defined differently depending on the country. Usually these cover energy suppliers, but can also be energy (network) distributors. This potential overlap is not for instance an issue in Germany, in which an ETS targeting the residential sector is under development, because Germany does not rely on ESOS to achieve the energy savings target but on alternative measures.

Furthermore, such extension of the ETS could limit the possibility to pass the extra costs to consumers and would reduce the options and the capacity of the obligated parties to deliver abatement measures, as a carbon price would incentivise end-users for the same actions as typically pursued under the obligation schemes. The impact on administrative burden would also need to be carefully considered.

[210] ICF et al. forthcoming

Concerning the Energy Performance of Buildings Directive, a possible extension of ETS to buildings will be confronted with existing market conditions as the majority of the barriers to energy renovation of buildings are local and often non-economic, whilst the ETS is primarily a tool to address economic barriers e.g. to fuel switching, even if it also makes energy services to address other barriers more profitable. The coverage of buildings by emissions trading could also influence the cost-optimal minimum requirements for new and existing buildings. Due to the impact on the cost-optimal balance between the investments involved and the energy performance improvements saved throughout the lifecycle of the building, Member States may need to revise their minimum requirements accordingly. Normally, these standards need to be revised every five years in any case under the EPBD to reflect market conditions and technological developments. Finally, there is a question to be addressed about interaction of the financial incentives that Member States are encouraged to put in place under Article 10 of the EPBD and the ETS market.

Similar considerations apply on the likelihood of interactions with the heating and cooling provisions under the Renewables Energy Directive, under an upstream approach in the ETS. There are already measures in the RED and the ETS being used complementarily tools in the electricity sector, so this administrative burden is likely to be manageable[211]. However an ETS alone would not address completely long entrenched barriers that still exist across the whole heating and cooling sector, such as the lack of information, lack of capacity to structure financing and projects, lack of skilled installers, lack of institutional capacity of heat planning, perceived risks and fragmented nature of renewable heating and cooling solutions. These barriers result in more limited price elasticity leading to suboptimal outcomes if using price signals alone, such as taxation or carbon pricing, but can benefit from specific measures and targets together with an overall adapted regulatory framework, through which such carbon price signals can fully exercise their impacts.

Specific considerations for the (road) transport sector

Already in the current EU policy set-up there are interactions between classic transport policies (i.e. regarding infrastructure, pricing and increasingly also connectivity) and energy and climate oriented transport policies, notably between the renewable fuel obligations under the recently adopted Renewable Energy Directive, the Fuel Quality Directive, the CO_2 standards for vehicles, Alternative Fuels Infrastructure Directive, Eurovignette Directive that aims at the gradual internalisation of external costs (also beyond GHG emissions) and the minimum taxation for motor fuels under the EU Energy Taxation Directive. In addition, the Alternative Fuels Infrastructure Directive, Energy Performance of Buildings Directive and electricity market legislation support the rollout of recharging and refuelling infrastructure for zero-emission vehicles. Legislative and other instruments in the field of transport are numerous and policy interactions are acknowledged.

Member States can, for example, express the renewable fuel obligation as a requirement to reduce the GHG emission intensity of fuels, providing the RES-T share targets are met. The recently adopted CO_2 standards for vehicles for 2025 and 2030, including further provisions incentivising the deployment of zero- and low-emission vehicles, are expected to be an effective driver for higher efficiency and switch toward zero-emission vehicles providing certainty for the

[211] ICF et al. forthcoming

roll-out of the related alternative fuels infrastructure, with benefits for consumers in terms of lower fuels bills, contributing to energy security and stimulating investments into the technologies needed for the transition towards zero-emission mobility. Altogether, these policies combined are projected to overachieve the minimum target set out for RES-T in 2030 in the Renewable Energy Directive by nearly 4 p.p. [212].

An intensification of these policies as indicated in section 5.2.2.2 and 5.2.2.4 and reflected in the REG and MIX scenarios would increase these policy interactions. A further mainstreaming of renewable and low carbon fuels, beyond the current obligation on Member States to set an obligation on fuel suppliers to achieve a share of at least 14% renewable energy in the transport sector in 2030, including at least 3.5% of advanced biofuels and biogases, would further decrease the GHG intensity of fuels and facilitate the market diffusion of zero or low emission vehicles. The changes are most pronounced in the road transport as here stricter vehicle CO_2 standards for 2030 further incentivising the deployment of zero- and low-emission vehicles would not only foster further specific emission reductions but also energy efficiency. For a quicker market uptake, a large-scale roll-out of recharging and refuelling infrastructure would be needed. A strengthening of minimum energy taxation (e.g. alignment of minima on energy content for diesel and petrol and mirroring the alignment in terms of energy content at MS level) could foster the wider uptake of more energy efficient vehicles but would not necessarily incentivise further emission reductions in the extent needed to achieve the GHG ambition. Here in addition minimum incentives for low and zero emissions vehicles in vehicle taxation would be needed if no carbon content element would be added.

This comprehensive policy mix, if highly intensified compared to current policies, which reduce emissions in road transport with 16% compared to 2015 by 2030, could increase road transport emission reductions by 5 p.p. to -21% (REG). It could lead to around 2 percentage points bigger reductions in transport emissions than using carbon pricing as main additional policy tool (CPRICE), to some extent also a result of a stronger reduction in transport energy demand, by 4% in REG compared to baseline instead of 2% in CPRICE.

Looking at all transport modes, there are already currently interactions of the analysed specific policies with carbon pricing instruments. Aviation emissions and emissions related to electrified rail and electric vehicles are covered by the EU ETS, amounting to less than 10% of total transport emissions. This share is expected to increase, notably through the increased use of electric vehicles. Inclusion of domestic and intra-EU maritime emissions under ETS as proposed by the European Green Deal is analysed in all policy scenarios.

Carbon pricing in road transport is also mentioned as an option to consider by the European Green Deal and there is already some experience of such policy. Several Member States (i.e. Denmark, Finland, France, Ireland, Luxembourg, Portugal, Slovenia and Sweden) apply specific carbon taxes for road transport as part of the fuel excise duties and electricity taxes, albeit with varying levels[213]. An OECD study on effective carbon pricing in 42 OECD and G20 countries found that in the road transport sector 34 of the 42 countries covered have already an implicit

[212] Based on the methodology set out in the Renewable Energy Directive, which applies multipliers for the calculation of the RES-T share.
[213] European Commission, *Transport taxes and charges in Europe – An overview study of economic internalization measures applied in Europe* (2019), p.27

effective carbon rate above €60/tCO_2, significantly stronger than in other sectors[214]. In the EU, the implicit carbon prices implied by the current nominal minimum energy taxation rates are around €150/tCO_2 per for unleaded petrol and around €120 for diesel. Current unweighted EU27 averages of implicit carbon prices resulting from adding national energy and carbon taxation rates are around €240/tCO_2 for petrol and €160/tCO_2 for diesel[215].

An EU carbon price of €60/tCO_2 in 2030 which adds to the national energy and carbon taxation, combined with a low intensification of CO_2 emission standards for vehicles and of the policies to improve the efficiency of the transport system and shift activity to more sustainable transport mode (as in CPRICE scenario) increase emission reductions below 2015 levels compared to baseline by 3 p.p. to 19%.

This policy combination with an EU carbon price would enhance electrification and create a more level playing field with fossil transport fuels and thus improve energy efficiency, reducing final energy demand in transport by 2% compared to baseline. It would incentivise an increase of the renewable energy share in transport by 45 p.p. compared to baseline, to 22% in 2030. While an additional €60 carbon price combined with CO_2 standards and other policies can deliver emissions reduction, carbon pricing alone would be less effective. For example, it has been estimated that for achieving a 2030 target of 60 g CO_2/km (measures according to the NEDC) without CO_2 standards and only via carbon pricing, the average EU ETS price would need to be significantly higher (in that study €218/tCO_2)[216].

In general terms the estimated low short term price elasticities of road transport, which limit the effectiveness of carbon pricing, are due to the long investment lead times of private car users. The relatively low price elasticities in general are due to the fact that private consumers typically severely discount future fuel savings, only taking these into account on average up to a time horizon of a few years[217]. The long-term elasticity of freight transport is higher than for passenger transport. For commercial users and freight companies, the barriers highlighted are information asymmetries of SMEs compared to suppliers, limited access to finance and for lorries often also split incentives as the drivers do not pay the full fuel costs[218].

The implementation of emissions trading for road transport could build on synergies with the Energy Taxation Directive. The transport fuels concerned are held in tax warehouses until they are released for consumption, at which point the excise duty must be paid. The amount of these fuels which is consumed for transport is therefore monitored and registered by tax warehouses. An upstream ETS inclusion for transport could likely rely on these mechanisms.

These considerations lead to the conclusion that in the transport sector the question is not about a regulation driven versus a carbon price driven policy mix, but about the extent and level where these different elements already present in the current policy mix are provided. For example, ETS

[214] OECD (2018): Effective Carbon Rates 2018: Pricing Carbon Emissions Through Taxes and Emissions Trading, OECD Publishing, Paris
[215] ICF et al. (forthcoming)
[216] Cambridge Econometrics, The Impact of Including the Road Transport Sector in the EU ETS, 2014. Available at https://www.ebb-eu.org/EBBpressreleases/Cambridge_ETS_transport_Study.pdf
[217] See e.g. Greene, D. L., Evans, D. H., Hiestand, J., *Survey evidence on the willingness of U.S. consumers to pay for automotive fuel economy (2013)*. In: Energy Policy. 61, pp. 1539–1550.
[218] European Commission, *impact assessment Accompanying the document Proposal for a Regulation of the European Parliament and of the Council setting CO2 emission performance standards for new heavy duty vehicles*, SWD(2018) 185 final, pages 12-16.

coverage together with existing tax levels and CO_2 standards for vehicles are complementary instruments, acting as incentives on the fuels use and on the introduction of technologies respectively. Just like higher carbon taxation or a revised Eurovignette along the lines of the Commission proposal, it would increase the price of every additional kilometre driven and increase the incorporation of externalities by the sector[219].

There is possible overlap between REDII, the Fuel Quality Directive[220] and ETS coverage of road transport, as both could incentivise the use of renewable and low carbon fuels. However, as the abatement costs of renewable and low carbon fuels are relatively high, it is unlikely that ETS inclusion would have a significant impact here[221].

In case of a further strengthening of the carbon pricing element next to a targeted intensification of specific regulatory energy and transport policies, it needs to be carefully weighed if this should better occur at EU level by introducing emissions trading (options ETS_2 and ETS_3 in section 6.7) or at the currently dominating national level, leaving a choice between national emissions trading and carbon taxation (or EU ETS opt-in, option ETS_ 4 analysed in section 6.7).

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[219] For an analysis to what extent transport has not yet incorporated all externalities, see also the Handbook on the external costs of transport Version 2019
https://ec.europa.eu/transport/sites/transport/files/studies/internalisation-handbook-isbn-978-92-79-96917-1.pdf

[220] "The Commission decided in 2016 to pursue renewable mainstreaming measures in the transport sector through the proposal recast of the Renewable Energy directive, finally adopted in 2018".

[221] CE Delft, *Analysis of the options to include transport and the built environment in the EU ETS* (2014), p. 60

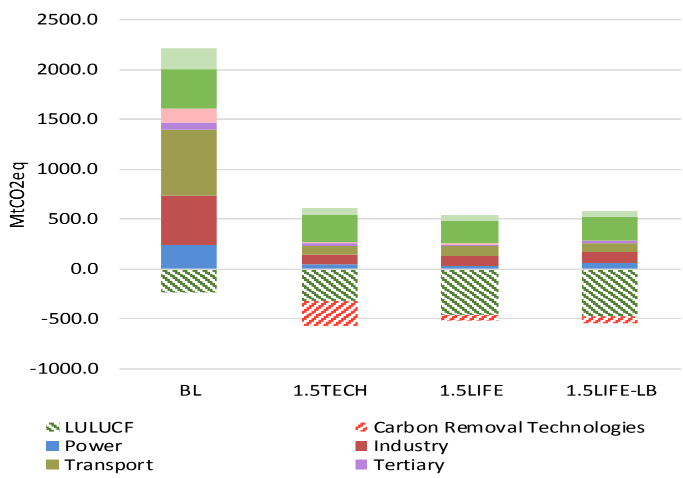
9.9 Extended analysis on the role of the LULUCF policy architecture in achieving increased ambition in GHG removals

Current policy (Baseline: Option LULUCF_1) is focussed on ensuring that Member States do not backslide in the LULUCF sector compared to the evolution of the sink under 'current practices'. This approach, however, places the commitment against the counterfactual of a decreasing forest sink, predicated on a reduced forest growth due to aging forests in the majority of zones in the EU27. By relating only to national greenhouse gas inventory results, the legislation also does not define any EU markets to internalise the positive impacts of carbon sequestration. It also still relies partly on data on carbon sinks that is incomplete or collated at a coarse level.

The decrease in reported sink is largely due to a reduction in forest sink (on managed forest lands) dominated by a handful of Member States with important divergence from historical trends in their forestry sectors, as well as natural hazards such as fires and pests.

Projections from modelling show a limited impact in the medium term (2030) – a consideration that remains one of the limiting factors in engaging in action with LULUCF. Conversely, the Long Term Strategy[222] showed that an increase of the net reported sink for the EU28 in the range of -300 to -500 $MtCO_2$-eq./year by 2050 should be favoured (Figure 91). Options to better prepare for expanding the sink in the decades that follow in preparation of the shift to a climate neutral bio-economy are therefore required.

Figure 91: Emissions profile by 2050 for selected climate-neutral scenarios of the in depth analysis supporting the EU Long Term Strategy



Source: PRIMES and GLOBIOM models

What can be the LULUCF sector's contribution to achieving the -50% to -55% GHG reductions?

The climate-neutral scenarios of the in-depth analysis underpinning the communication "A clean planet for all" are clear: to be climate neutral by 2050 and a net GHG remover thereafter, the EU will have to rely on a substantial amount of carbon removals, going beyond the current 264

[222] See In-depth analysis document: https://ec.europa.eu/knowledge4policy/publication/depth-analysis-support-com2018-773-clean-planet-all-european-strategic-long-term-vision_en

$MtCO_2$-eq/year LULUCF sink reported today. Both nature-based and technological solutions are required to offset around 500 $MtCO_2$ of residual fossil and non-biogenic emissions that are too difficult or costly to abate.

However, the immediate contribution of LULUCF in the shorter term is more nuanced. Acting on deforestation can have an immediate impact, whereas afforestation or fundamental adjustments to forest structure (species, age class distributions) to generate more sink will take decades (section 6.2.3). A renewed focus towards natural restoration and "old growth" forests requires stands to develop over centuries, so as to become "old" and develop substantive carbon stocks – although existing stocks are key factors in this equation, too. Soil carbon restoration may also take decades to be significantly improved. The long-term transition needs to be planned urgently and implementation started with a sense of urgency.

In the period up to 2030, therefore, the most promising mitigation measures relate to emission avoidance from agricultural land (histosols), perennial cropping, changes in harvest intensity, optimization of thinnings, and afforestation. Many of these actions are synergistic with action on biodiversity, if handled in a manner appropriate for the local context. Annual mitigation of 50 $MtCO_2$ to 80 $MtCO_2$ annually is considered technically feasible across EU27. However, there is an emerging mismatch between responsibility for action, incentives and governance, and actors and financing sources.

Along the pathway to a climate neutral bio-economy, it is of key importance to properly assess the interlinkages between the dynamic of the forest sink, the use of biomass in other sectors of EU economy and any associated environmental impact, including indirectly the impact on carbon stocks due to displacement of other land-based activities. Afforestation, reforestation[223] and reduced deforestation are obvious options to increase the coverage of EU forests potential, together with possible co-benefits of many other ecosystem services such as biodiversity and reduced risks of soil erosion, floods, and air and water pollution. Land is a finite resource and extending forest coverage may, if carried out over large scales[224], intensify the competition for land with other sectors of the economy. Afforestation for instance may displace agricultural production of food, feed, fibre or energy, and subsequently increase GHG emissions in other sectors.

Territorial imbalances

The current baseline deliberately restricts Member States from optimising LULUCF action (e.g. afforestation or land use restoration) at the best location in the Union. Instead, it requires the action to take place within a Member State's territory. Consequently, the first most significant conclusion of the baseline policy approach is that not only would the incentive for action be limited in geographic scope, but that also action in the sector would not be cost-efficient. This also partly explains the relatively limited uptake of action so far in the sector.

Furthermore, according to the IPCC[225], global land use will undergo very significant transitions over the next three decades. These changes are caused by shifting weather and climate patterns, as well as by increased demands on biomass, agricultural and forest feedstocks in general, and competing demands for land to produce them. This dynamic also translates at the level of the EU, and will have a significant impact on removals from forests, emissions from crop production,

[223] i.e. the re-planting of harvested forest land with better adapted mix of species
[224] IPCC Special report on Climate Change and Land https://www.ipcc.ch/srccl/
[225] Ibid.

livestock management etc. Long-term optimisation of sustainable land use will be a major challenge that starts already this decade.

The increased action to redress the loss of biodiversity experienced over the past decades on the EU's territory will also require substantial land management change. These can however become positive actions for climate, for example where protected areas underpin nature-based carbon storage and carbon sequestration. A similar response may be identified for climate adaptation actions, where these lead to the reduction of natural hazard effects created by drought, fire and pest.

What policy architecture could we use?

Based upon the Kyoto Protocol rules, the current regulation presents a potential mismatch between actors (individuals) directly managing land on the one hand, and state-level responsibility and interests on the other. For the latter, relatively weak definitions of global level rules and governance provide only a limited mandate to act; and for the former, only exceptionally direct incentives are tangible either via pricing or specific regulatory – and usually nationally focussed – frameworks. The currently adopted EU legislative framework, while respecting the EU's international commitment under its NDC, only acts as a floor against which Member States risk being penalised.

Instead, a better match between the actors and the (financial, cost-driven) incentives needs to be made to unlock the significant mitigation potential offered by land, thereby mobilising the necessary financial means to reward action. Such an architecture could build on the current LULUCF accounting framework, be it through eco-schemes or the Rural Development Programme in the Common Agriculture Policy through direct rewards to farmers and foresters. However, the CAP alone cannot be taken as sufficient to deliver the total carbon sequestration needed; the distribution of CAP financing is not indexed on this priority alone, and will also not relate to dynamic factors such as biomass pricing signals.

As a starting point, voluntary frameworks for trading additional action on land between private actors should be fostered; even if this approach would need to be correctly integrated into the national inventories reported at EU and MS level to be meaningful. The development, in due course, of a comprehensive regulatory framework for certification of carbon removals based on robust and transparent carbon accounting – as announced in the Circular Economy Action Plan[226] – would provide certainty to all actors and enable a larger deployment of carbon removal solutions. As set out in the Farm-to-Fork strategy[227], the Commission is piloting – together with local actors – "carbon farming" initiatives to provide financial incentives to farmers and foresters, financed by the means mentioned above or through EU programs such as LIFE[228] or in the framework of the recovery package.

The LULUCF regulation and related framework should therefore be developed to better enable such initiatives at the level of Member States or private market actors. This can be done through strengthening of existing rules, introducing LULUCF targets set at national level; or increasing existing flexibility for Member States to use their sink to compensate hard-to-abate emissions in

[226] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2020:98:FIN
[227] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0381
[228] https://ec.europa.eu/clima/policies/budget_en

other sectors of the economy; or through a combination of these approaches. The key issue is to ensure that the relative pricing of action and carbon sequestered is optimised to the extent possible, and to avoid that carbon is instead imported or emissions "leaked" through land use "displacement".

Increasing the flexibility of LULUCF credits towards the ESR and/or ETS

With regard to the flexibility towards the ESR, Member States are today the sole actors in terms of generating LULUCF credits and buying/selling LULUCF credit. This means every Member State has the sole responsibility to design national incentive schemes to transmit a carbon price signal to their farmers and foresters. However, few Member States have presented ambition to exploit this path, and very few programmes are being developed with significant ambition.

Instead, Member States have preferred to remain cautious over the enhancement of removals in the sector. Under this assessments baseline, removals slightly increase by 2030 and are in the medium term (2030-40) likely to remain stable (see section 6.2.3). A key part of a revision of the 2030 framework needs therefore to be directed towards removing the existing barriers in the current architecture, and increasing the incentives to take more action both at Member State level and (in contrast with the current LULUCF Regulation) at the level of farmers and foresters.

Raising ambition through more stringent rules

A further option to increase sink is to place more stringency in the accounting system. Such an approach may be justified in view of the risk of decreasing sink at EU level, and the competing complex demands on land and biomass, and the complexities in the existing system concerning the setting of the Forest Reference Level benchmarks for each Member State. Introducing a more stringent sectoral LULUCF target would theoretically require Member States to introduce incentives to generate more sink than under current policies and plans.

However, unless the existing flexibility from the ESR – which also serves as the last resort compliance mechanism for the whole of the non-ETS including LULUCF – is closed, such extra 'sink' may be delivered by sectors other than LULUCF, or by action outside the national territory. The governance of the two sectors would therefore need to undergo revision, possibly also including reciprocal adaptations of the current LULUCF flexibility under the ESR.

In the long-term, the optimal level of the forest benchmark would need to be determined, such that the foresters have sufficient and adequate financial and regulatory incentives for additional action. Land managers could be encouraged to engage in win-win actions for climate and biodiversity, such as the rewetting of organic soils and peatlands as well as afforestation projects in line with the Biodiversity Strategy (also including agroforestry). These areas offer good opportunities to spearhead the development of carbon removal credits and to develop reliable MRV rules.

On the one hand, a framework should emerge such that the other sectors do not transfer windfall profits from decarbonisation (for example, through the low-cost access to biomass) to actors, for forest growth and harvesting that would happen in any case. On the other hand, the framework should also avoid an overloading of the use of imported biomass, for which the climate mitigation credibility may be called into question. The necessary regulatory mechanisms to achieve this balance should be examined in future impact assessment work, upon the selection of the overall policy architecture, and be based upon a much more economically oriented discussion on the optimal pricing incentives.

The pathway to a 2050 climate neutral bioeconomy

In the case that the sectors included in the ESR would be considerably changed, e.g. all energy CO_2 emissions would be included in the EU ETS and taken out of the scope of the ESR (see section 6.7), or when they are reduced to marginal size, agricultural emissions would become relatively isolated. These may become the dominant component of what is today the ESR, and hence be assigned a *de facto* sectoral target in accordance with the legislative framework agreed in 2018. The non-ETS sectors – including LULUCF – would in effect be an extended form of the IPCC's combined Agriculture, Forestry and Other Land Use (AFOLU) configuration[229] [230]. Given that biomass related emissions in other sectors are conceptually set to zero by the IPCC, the removal and emissions scope of these sectors also corresponds to the biomass related emissions of the bioeconomy.

Such a configuration would imply that flexibility to offset non-CO_2 emissions from agriculture with LULUCF carbon removals is widely available. Member States' sectoral targets would likely be based on their (very heterogeneous) potential for carbon removals and emission reductions. Thus, these targets differ widely: while in some Member States the combined sectors will have to become a net sink, in others it may still remain a source.

The EU-wide market for carbon removals (discussed above) may again prove a useful instrument to address this geographic heterogeneity. New digital technologies and governance models would facilitate the individual certification of carbon removals, making them robust and trustworthy. For instance, livestock farmers or biomass users could compensate their emissions by buying carbon removals from forest or wetland owners geographically distant and within the EU. Again, national accounting registries would be adjusted to cater for traded emissions and removals. Finally, this provides scope for larger operators, for example dairy producers under the ETS, to link with credits or specialised allowances under the EU ETS (of course, depending on the ETS ambition and scope).

Overall, even if such LULUCF sectoral targets were achieved by Member States, the EU net sink as reported in the inventory is not guaranteed to increase across the EU. In summary, the setting of the Member State level target may require:

- A detailed individual sub-sector analysis (cropland, managed forest land, etc.), to help determine the fair and cost effective effort beyond the (accounting rule) baseline; or
- The re-adjustment of the LULUCF Regulation accounting rules to a more stringent level: most obviously the simplification of the forest related benchmark. The international risks for the EU, should a move away from long established conventions be selected, must be considered.
- The redesign of the governance and target compliance framework, separate from the ESR, that is currently absent in the LULUCF Regulation (and would also require fundamental adjustments to the ESR legislation too)
- The redesign of the internal LULUCF flexibility rules, to oblige sink increase (target compliance) in each individual Member State before flexibility and trading of the benefit of the sink elsewhere (geographically) or in other sectors.

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[229] See 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4. Agriculture, Forestry, and Other Land Use, https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

[230] For reporting, Agriculture and LULUCF are still reported separately, consistently with the Paris Agreement rulebook (decision 18/CMA 1).

Box: Incorporating LULUCF into the target metric

The current 2030 climate legislation uses a metric showing reductions of fossil emissions compared to a base year, ignoring the reported information from LULUCF. However, the move to a future paradigm under the Climate Law proposal - where fossil emissions are marginal, and the key to "climate neutrality" is the correct accounting of biogenic emissions and balancing of any residual non-biogenic emissions – means that at some point a move to a new metric to describe the advancement towards climate neutrality is required.

A decision therefore needs to be taken as to when the accounting framework should move from 'accounted' LULUCF to 'reported' LULUCF metrics. The re-framing of the EU baseline would place it in line with the Paris Agreement and Climate Law proposals, where reported GHG anthropogenic emissions and removals are aggregated each reporting year to determine the achievement of climate neutrality. In this sense, the direction of assessing the achievement is clearly towards the reported (rather than accounted) GHG inventories.

While attractively simplifying the EU target framework, the application of LULUCF reporting values in the computation of a pathway/reduction compared to a base year (e.g. 1990) raises a number of considerations:

- Total GHG emissions including the full reported LULUCF sink (though excluding international maritime and aviation emissions) have reduced by 1.3% more over the period 1990-2018 than the conventional computation excluding LULUCF. Redefining the baseline by including the full reported LULUCF sink may be perceived as a "windfall" use of the sector, even though it would also fully capture any potential negative impacts on the performance of the overall LULUCF sink, including increased harvesting, forest stand ageing or natural hazards such as forest fires.
- If LULUCF sink is assumed constant at 2018 levels - and other emissions decline – the difference in relative achieved reduction with or without inclusion of the LULUCF grows. This is a crucial feature of the transition to climate neutrality. If the EU manages to enhance its sink to around 500 $MtCO_2$, the EU would achieve climate neutrality when non-LULUCF emissions are reduced by 90%, compared to 1990.
- Reliability of LULUCF data – which have shown variability and uncertainty – from 1990 is certainly questionable, especially if broken down to Member State level; indeed, such uncertainties (particularly bias of estimates of significant carbon pools) has led to the development of a complex set of accounting rules to minimise these effects. Agreeing which verified data would be used may be difficult[231]. The current LULUCF regulation, for example, has selected a period (2005-2009) as an average to help address such concerns.
- Inter-member state variability: some of the 27 Member States will present already significant LULUCF emission/removal profiles that lead to national climate neutrality (or even sinks), sooner than others, whereas others will be sources (emissions).
- The change may remove policy action incentive through the elimination of "mere presence" of sinks due to legacy land use: for example, where forest land delivers a very significant reported sink in the 1990 base year. The incentive for action in other sectors must be maintained, for example by stepping up overall ambition of EU climate policy.

The application of a LULUCF report-based target frame, while being the intended destination of a climate neutral bioeconomy assessed the balancing of greenhouse gases, needs careful application to the

[231] However, this issue does not apply to the climate neutrality assessment, which is based upon reporting in the time period around 2050.

determination of the trajectory milestones.

9.10 Context of the 2030 Climate Target Plan

9.10.1 Current policies and progress achieved

9.10.1.1 2020 targets: progress to date and trends for the European energy system

In 2007, the European Union proposed the first dedicated energy and climate policy package to address at the same time emissions reduction and energy sector reform. The package set national energy and climate targets for the year 2020; improvements and extension of the EU Emissions Trading System (EU ETS)[232]; a legislative scheme for renewable energy (the Renewable Energy Directive); energy efficiency (the Energy Efficiency Directive) as well as the 3rd package of energy market liberalisation. The implementation of the legislation that emerged clearly facilitated a faster transition to a decarbonised energy sector.

The EU28 set for itself the target to reduce greenhouse gas emissions by 20% by 2020 compared to 1990. In Europe, economic growth decoupled from GHG emissions several decades ago. Between 1990 and 2018 total emissions[233] in the EU28 decreased by 22%, while the EU's combined GDP grew by 58%. In the period from 2014 to 2018, emissions stagnated but emissions fell again in 2019.

Higher carbon prices in the ETS, high generation from renewable producers and historically low gas prices reduced generation from coal in 2019. Emission under the EU ETS decreased by 8.7% year on year. Electricity generation from solid fossil fuels (coal and lignite) in the European Union fell by 26% on a year-on-year basis in 2019[234] and was the single largest contributor to the drop in emissions in EU. The power sector has made the most progress towards decarbonisation. In 2018, nearly 59% of all EU electricity was generated from emissions free sources compared to under half in 2010[235].

This shift away from coal foretells deeper structural changes. As the aging fleet of European coal fired power plants nears the end of economic lifetime, 14 Member States have announced a phase-out of coal power generation.

In the short term, coal-to-gas switch in power generation can lead to significant year-to-year emissions reduction. In the medium term, gas-fired power plants may provide the flexibility needed to integrate increasing shares of variable renewables. However, unabated emissions from natural gas are incompatible with the European decarbonisation ambition. Therefore, overall its consumption needs to decrease in a transition to a climate neutral economy.

For sectors not covered by the EU Emissions Trading System (excluding LULUCF), the EU 2020 target is an 8% reduction compared to 2005[236]. The target is implemented through binding Member State targets under the Effort Sharing Decision[237]. In 2018, EU emissions reached the

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[232] 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

[233] Including all outgoing international aviation and excluding emissions from LULUCF.

[234] European Commission, Quarterly Report on the European Electricity Market, Q4 2019.

[235] https://ec.europa.eu/energy/data-analysis/energy-statistical-pocketbook_en

[236] For the EU28 the target was a 10% reduction compared to 2005.

[237] Decision No 406/2009/EC of the European Parliament and of the Council of 23 April 2009 on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020

reduction target, with the majority of Member States having emissions below their national targets.

Since 1990, GHG emissions have decreased in all sectors of the European economy, except for transport. Greenhouse gas emissions from transport saw a strong increase in the period 1990 – 2007. Emissions decreased between 2007 and 2014 but saw an increase again since 2014, following the sharp drop on oil prices in 2014. In 2018 emissions of the transport sector in the EU (excluding international aviation and maritime navigation) were 23% higher than in 1990. Abating transport emissions remains challenging and, notably in urban environments, the impact of air pollution from fuel combustion, from transport as well as other sectors, is often a major concern. To reverse this trend, by 2021 new cars sold in the EU will have to emit, on average, no more than 95 gCO_2/km. The average CO_2 emissions of new cars sold in the EU28 in 2018 was around 121 gCO_2/km[238]. In 2018, transport emissions excluding international aviation and maritime navigation represented 22% of the total EU emissions[239]. Adding international aviation and international maritime navigation would increase these total emissions by 3.4% and 3.6% respectively[240].

In 2018, manufacturing activities and construction contributed to about 21% of total GHG emissions. In the period between 1990 and 2018, the sector reduced emissions by 33%[241]. This is the second largest contribution to the EU's emissions reduction after the power sector.

The EU's balance of emissions and removals for the land[242] sector results in net removals of CO_2 from the atmosphere. In 1990 the EU net sink resulted in 255 $MtCO_2$ net removals. This increased in the period up to 2009 by over 70 $MtCO_2$, but has since seen a reversal. In 2018 the net removal by land (mostly forest) was 263 $MtCO_2$-eq.

Overall, the EU is thus on track to overachieve its target under the UN Framework Convention on Climate Change (UNFCCC) of reducing GHG emissions by 20% by 2020. In 2018 EU greenhouse gas emissions, excluding the UK and including emissions of all outgoing aviation were 20.7% below 1990 levels[243]. Including emissions and removals of the EU's Land-Use, Land-Use Change and Forestry sector, net emissions have reduced by around 24% compared to 1990.

The EU has also set a 20% energy efficiency target for 2020. Final energy consumption in the EU28[244] fell by 5.8%, from 1194 Mtoe in 2005 to 1124 Mtoe in 2018. It decreased at an annual average rate of 0.42% between 2005 and 2018. However, the trend reversed in recent years and energy consumption kept rising since 2014 (which was an exceptionally warm winter with low heating demand). Amid continued economic growth, energy consumption rose by 5.3% in the period from 2014 to 2018. This is 3.5 percentage points (p.p.) above the 2020 final energy consumption target of 1086 Mtoe. In 2018, energy consumption increased by only 0.1% compared to the previous year.

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[238] https://www.eea.europa.eu/highlights/new-cars-and-vans-sold

[239] Within this sector, road transport is by far the biggest emitter accounting for more than 70% of all GHG emissions.

[240] EEA Greenhouse Data viewer, EU27 emissions (Convention basis), https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer

[241] A decreasing share of manufacturing in total GDP also contributed to this trend.

[242] Refers to Land Use, Land Use Change & Forestry (LULUCF)

[243] EEA Greenhouse Data viewer, EU27 emissions (Convention basis), https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer

[244] Energy efficiency target for 2020 are set for the EU28 using FEC2020-2030 and PEC2020-2030 indicators.

Primary energy consumption in the EU28 decreased from 1721 Mtoe in 2005 to 1552 Mtoe in 2018 – a 9.8% drop. This is 4.65 p.p. above the 2020 target of 1483 Mtoe. Following three years of increase, a 0.7 % drop in primary energy consumption was recorded in 2018. Overall, without taking into account the impact of the COVID-19 crisis, both primary and final energy consumption were just above the trajectory towards the 2020 energy efficiency target. Clearly, over the long term, decoupling of energy consumption from economic growth is evident. Energy intensity of GDP decreased 38% between 1990 and 2018. Final energy consumption in 2018 is 3.3% higher than in 1990 while GDP grew by 61%.

The third target for 2020 aims at a 20% share of renewable energy in gross final energy consumption. Renewable energy has been increasing continuously in the EU. Helped by Member States support policies, the share of renewable energy in gross final energy consumption grew from 9.6% to 18.9% in the period between 2004 and 2018. This result put the Union on track to reach its target for 2020[245]. Over this period, direct and indirect employments in renewable energy in the EU28 more than doubled, increasing from 660 000 to 1.51 million jobs[246].

Policies implemented by both the European Union and Member States were instrumental in bringing about the remarkable cost reduction experienced by renewable energy sources – in particular solar PV and wind energy – in the past decade.

As a result, in a majority of Member States, new-built renewable power generation is now cheaper than gas and coal power plants[247]. In the EU, electricity generated by wind energy increased more than 3 times between 2010 and 2018 and electricity generated by solar PV increased almost 5 times[248]. Cost reductions in offshore wind technology, pioneered by developments in the North Sea, are opening vast additional renewable energy resources. Offshore wind capacity in the European Union[249] increased from 1.6 GW in 2010 to 12.2 GW in 2019[250].

Considering the magnitude and rate of the changes, the European power networks have coped well with the rise of variable renewables. Policy and regulatory measures have been instrumental in developing interconnected and integrated trans-European electricity markets. Forty projects – of which 30 related to power networks – have been implemented under the TEN-E policy framework aimed at improving cross-border exchange.

Investments in renewable energy are increasingly driven by market decisions. Member States increasingly grant support for renewable energy through competitive tenders and ensure that renewable energy installations are integrated in the electricity market, as required by State aid rules. Power markets in Europe are adapting to these changes. The volume of renewable electricity sold with power purchase agreements (PPAs) is increasing rapidly. At the beginning of 2020, corporations worldwide signed contracts to purchase almost 60 GW of green power under PPAs with renewable producers (6 GW of which were in the EU). The market tripled since 2017[251]. New business models are emerging for energy communities and demand response schemes. A flexible, decentralised power market will have to be complemented by smart

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[245] With some Member States overachieving and some underachieving their national targets.
[246] https://www.eurobserv-er.org/, Data for the EU28. Excluding the UK 1,38 million jobs in 2018 in the renewables sector.
[247] Estimates from Bloomberg New Energy Finance.
[248] IEA Data and Statistics.
[249] Following the withdrawal of the UK from the European Union, Data related to the European Union exclude the UK.
[250] Wind Europe, Offshore Wind in Europe, key Trends and Statistics 2019.
[251] Bloomberg Corporate PPA Deal Tracker, March 2020.

distribution and transmission networks. To this aim, 29 interconnection projects have been identified aimed at developing electricity and smart grids and are expected to be implemented by 2022.

Over the period from 2004 to 2018, the renewables share in the heating and cooling in the EU almost doubled from 11.7% to 21.1%. Helped by increased penetration of renewables, CO_2 emissions in the EU residential sector in 2018 were almost 29% below 1990 levels. However, increased energy use meant that emissions increased by 3% between 2014 and 2018.

The share of renewables in transport reached 8.3% in 2018 for the EU compared to only 2% in 2005. This provides a solid ground to reach the 10% target in the Renewable Energy Directive. Battery electric vehicles and plug-in hybrids represent only 3.3% of the new vehicles sold in 2019, but new models are coming to the market.[252]

9.10.1.2 Current 2030 climate and energy framework

In October 2014, the European Council concluded that the EU set a target of an at least -40% reduction in domestic economy-wide emissions of greenhouse gases by 2030 compared to 1990. The European Council also agreed on a target of at least 27% renewable energy consumption and on a target of 27% for energy efficiency. The GHG target was incorporated in the EU Nationally Determined Contribution (NDC) to the Paris Agreement. It was implemented in three main pieces of legislation: The first legislative deliverable under the Energy Union to implement the 2030 targets was the revised ETS directive[253], which regulates GHG emissions from large point sources (mainly power sector and industry) and aviation. The annual ETS cap reduction was increased with a view of achieving 43% reductions by 2030 compared to 2005, while the Market Stability Reserve was strengthened to address the surplus of EU allowances that has built up historically. A second set of legislation under the 2030 climate and energy framework, (the Effort Sharing Regulation[254] and the LULUCF Regulation[255] on the inclusion land use, land use change and forestry) regulates emissions and removals of the sectors outside the EU-ETS. It does so by setting binding emission trajectories and reduction objectives per Member State, taking into account their different capabilities to reduce GHG emissions, and including rules to ensure that greenhouse gas emissions from the LULUCF sector are offset by at least an equivalent removal of CO_2 from the atmosphere.

In 2018 and 2019, the EU adopted a comprehensive update of its energy policy framework to facilitate the energy transition and to deliver on the EU's commitments under the Paris Agreement. The Clean Energy for All Europeans consists of eight legislative acts setting the European energy targets for 2030 and paving the way for their achievement. The new legal framework set an EU binding target of at least 32% for renewable energy sources in the EU's energy mix and of at least 32.5% energy efficiency by 2030. It also includes legislation to adapt

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[252] https://www.eafo.eu/vehicles-and-fleet/m1

[253] Directive (EU) 2018/410 amending Directive 2003/87/EC to enhance cost-effective emission reductions and low-carbon investments, and Decision (EU) 2015/1814

[254] Regulation (EU) 2018/842 of the European Parliament and of the Council of 30 May 2018 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement and amending Regulation (EU) No 525/2013

[255] Regulation (EU) 2018/841 of the European Parliament and of the Council of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework, and amending Regulation (EU) No 525/2013 and Decision No 529/2013/EU

the electricity market design to increasing shares of decentralised and variable generation assets.[256]

The binding 32% renewable energy target to be achieved collectively by the EU in 2030 moved away from national binding targets agreed for the 2020 framework as Member States have set their contributions to the Union target in their National Energy and Climate Plans. In addition, a renewable energy target for transport of 14% has been set with a sub-target to promote advanced biofuels. A specific indicative target to increase the share of renewables by 1.3 p.p. a year has been defined for the heating and cooling sector. Further, the agreement includes measures to facilitate the participation of citizens in the energy transition through self-consumption and energy communities and to enhance the sustainability of bioenergy.

The combined impact of these energy targets if fully implemented is a significant reduction in energy related emissions, which taking into account expected development in non-energy related GHG emissions is projected to lead to more than 40% GHG reductions in the EU by 2030 compared to 1990 levels. The results of the combined impacts of the greenhouse gas emissions, renewable energy sources and energy efficiency, have been modelled for the purpose of this impact assessment and confirm the findings of earlier simulations of the existing policy framework, that combined, the existing 2030 targets would reduce emissions by more than 40% in the EU. For more detail see annex 9.3.3.2.

In the transport area, the Commission adopted a European strategy for low-emission mobility in 2016.[257] It acknowledged that achieving deep emissions reductions will require an integrated system approach that includes promoting (i) overall vehicle efficiency, low- and zero emission vehicles and infrastructure; (ii) a long-term switch to alternative and net-zero carbon fuels for transport; (iii) increased efficiency of the transport system – by making the most of digital technologies and smart pricing and by further encouraging multi-modal integration and shifts towards more sustainable transport modes such as inland waterways, short-sea shipping and rail. Changes in behaviour and consumer choice to shift from private transportation to low-carbon public transport, shared mobility and zero-carbon mobility (biking, walking) were also acknowledged as key. The low-emission mobility strategy framed the policy initiatives that were adopted by the Commission in the three 2017-2018 Mobility Packages.[258]

In addition, the new Regulation of the Governance of the Energy Union and Climate Action has established an integrated energy and climate planning, monitoring and reporting framework[259]. It has created a unique system of energy and climate governance ensuring that the Union and its Member States can plan together and fulfil collectively the 2030 targets. In 2018, all Member States have, for the first time, prepared draft integrated National Energy and Climate Plans (NECPs). The Commission published a Communication assessing the 28 draft NECPs in June

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[257] https://ec.europa.eu/transport/themes/strategies/news/2016-07-20-decarbonisation_en

[258] https://ec.europa.eu/transport/modes/road/road-initiatives_en

[259] Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action, amending Regulations (EC) No 663/2009 and (EC) No 715/2009 of the European Parliament and of the Council, Directives 94/22/EC, 98/70/EC, 2009/31/EC, 2009/73/EC, 2010/31/EU, 2012/27/EU and 2013/30/EU of the European Parliament and of the Council, Council Directives 2009/119/EC and (EU) 2015/652 and repealing Regulation (EU) No 525/2013 of the European Parliament and of the Council

2019 (COM/2019/285), together with specific recommendations and a detailed "Staff Working Document" for each Member State. Member States were to submit final NECPs by 31 December 2019. All Member States have done so.

In the 2020 State of the Energy Union report, the Commission will assess the final plans against current EU-level energy efficiency and renewable energy targets and identify policies and measures to achieve the Union's 2030 targets if there is a gap.

A similar process of preparing National Forestry Accounting Plans was also followed for the establishment of key benchmarks for forestry accounting, under the LULUCF Regulation[260]. The governance process also provides an opportunity to update the plans by 2024 to reflect experience and to take advantage of new opportunities for the remainder of the decade. The EU Forest Strategy to be adopted in 2021 will contribute to these goals.

9.10.1.3 The COVID-19 crisis – unfolding impact on the energy system and economy wide GHG emissions

The COVID-19 pandemic has affected countries across the globe. No region has been spared and the worldwide count of confirmed cases continued to rise rapidly through August, with around 21 million confirmed cases globally in the middle of the month[261]. Economies have been particularly affected both from the health and economic perspectives. Lockdowns have been enforced across the EU and in countries around the world. At their peak, emissions in individual countries decreased by 26% on average, while for 2020 as a whole global CO_2 emissions are expected to fall by 4-7%[262].

The disruptions in economic value chains related to the lockdowns have triggered sharp declines in economic activity across the globe, with a high degree of uncertainty regarding future developments that are relevant for this impact assessment.

At the global level, the IMF's June World Economic Outlook[263] projects world economic output to shrink by 4.9% in 2020 while the World Bank's Global Economic Prospects[264] shows a similar figure of -5.2%. Although both anticipate a rebound in 2021 (respectively +5.4% and +4.2%), the global GDP level projected for 2021 is markedly below pre-COVID estimates. Advanced economies are projected to be affected significantly more than emerging markets and developing economies, whose output is projected to decline by 2-3% in 2020 before growing 4.9-5.9% in 2021. Both the IMF and the World Bank stress the extreme uncertainty surrounding these projections and that risks remain on the downside, including a longer duration of the current outbreak or its resurgence at a later stage.

The Commission's Spring Economic Forecast[265] was the basis for the macro-economic assumptions underpinning the COVID-BSL and COVID-MIX scenarios. It projects the EU economy to contract by 7.4% in 2020, followed by a recovery of around 6% in 2021. While this

[260] SWD(2019) 213 final, COMMISSION STAFF WORKING DOCUMENT, ASSESSMENT OF THE NATIONAL FORESTRY ACCOUNTING PLANS https://europa.eu/!yp46uj
[261] Based on data from the Johns Hopkins University, Coronavirus Resource Center.
[262] Le Quéré *et al*. (2020) Temporary reduction in daily global CO_2 emissions during the COVID-19 forced confinement. https://doi.org/10.1038/s41558-020-0797-x
[263] World Economic Outlook Update, June 2020: A Crisis Like No Other, An Uncertain Recovery
[264] World Bank, Global Economic Prospects, June 2020
[265] European Commission, DG ECFIN, European Economic Forecast, Institutional Paper 125, May 2020

supposes a relatively quick rebound in economic activity and the absence of a second wave of the pandemic, it would still leave real GDP in 2021 2.3% lower than would have been the case under the autumn forecast 2019. The Commission also indicated at the time that risks were mainly on the downside and highlighted the unprecedented level of uncertainty regarding the projections as the full scale and duration of the pandemic remain uncertain.[266] Furthermore, Member States themselves are projected to be affected to varying degrees by the crisis, with the Commission's spring forecast indicating contractions in real GDP in 2020 ranging from -4.3% to -9.7%.

The European Central Bank's June macro-economic projections are along the same lines, with euro-area GDP expected to shrink by 8.7% in 2020 before growing 5.2% and 3.3% in 2021 and 2022, respectively[267]. This would still leave euro-area real GDP 4.2% below its previously projected level in 2022.

The slump in economic activity has also triggered sharp increases in temporary lay-offs and unemployment and to massive cuts in hours worked across the EU. The Commission's Spring Economic Forecast projects that 5 million jobs would be lost in 2020 compared to a year earlier (a 2.4% drop) and that employment would remain 2.1 million under that level in 2021. Similarly, the ECB projects a 2.8% fall in employment in 2020, followed by a modest 0.4% increase in 2021.

Workers in certain services sectors, including retail, hospitality, tourism or leisure have been particularly hit. The rise in unemployment and the differentiated distribution of impacts across sectors and skills levels therefore could potentially exacerbate existing social inequality within Member States. It could also generate lasting effects on private consumption as households increase precautionary saving.

The lockdowns have affected sectoral activity to very different degrees. Passenger air travel has been cut down to a fraction of normal activity rates, with the IATA reporting 4.5 million flight cancellations worldwide until June 2020. Revenue passenger kilometres fell 94.3% year-on-year in April 2020[268], while cargo tonne kilometres declined 27.7%[269]. At the European level, Eurocontrol indicates that airline traffic fell to nearly 90% below the previous year's level in April before recovering slowly[270].

Road transport has also been significantly affected, both in terms of passengers and freight. This is evidenced by sharp declines in congestion indices in major cities and by lower levels of NO_2 concentrations[271]. Road freight was significantly disrupted within the EU at the onset of the

[266] DG ECFIN's Summer Economic Forecast 2020, which came out too late to be used in this impact assessment, projects EU GDP to contract by 8.3% in 2020 and grow by 5.8% in 2021. The t+10 projections were also not updated as part of this forecast.
[267] https://www.ecb.europa.eu/pub/projections/html/index.en.html
[268] https://www.iata.org/en/iata-repository/publications/economic-reports/air-passenger-monthly-analysis---apr-20202/
[269] https://www.iata.org/en/iata-repository/publications/economic-reports/air-cargo-market-analysis---march-2020/
[270] https://www.eurocontrol.int/covid19
[271] For example, the Tomtom congestion index in Madrid fell from a typical weekday morning peak of around 60% in late April 2019 to around 5% in April 2020. Under the lockdown, the congestion index has remained relatively stable throughout the day, with much less significant morning and evening peaks. The same phenomenon is observed in London, Milan, Paris or Rome. (https://www.tomtom.com/covid-19/). The European Environment Agency similarly reports significantly lower levels of NO_2 concentrations in major cities across the EU. (https://www.eea.europa.eu/themes/air/air-quality-and-covid19/air-quality-and-covid19).

pandemic, which created issues in terms of border crossings[272]. Rail passenger traffic has been heavily disrupted, by the significant reduction in domestic services offered and in many cases the stop of international connections.

The reduction of economic activity has sharply decreased energy demand since the onset of the crisis. Electricity demand in the EU decreased between 10% and 33% from March 9 to May 25, depending on Member State[273]. This has translated into much lower electricity day-ahead prices (up to -70%[274]). In the context of a robust contribution of renewables[275], which reached 49% of the EU power production, this situation put pressure on other generators[276], notably coal (which reduced by 30% year-on-year in the first quarter of 2020[277]), gas in Southern Europe and nuclear that reached record lows in France (300 TWh expected in 2020, versus 413 TWh produced in 2018[278]). The EU energy sector had to implement exceptional arrangements to ensure continuity of operations of critical infrastructure.

In the context of a rift among oil producing countries, lower transport activity has led to a rapid contraction of oil demand and consequently to a sharp decline in international fuel prices. In response, oil producers have cut output, bringing crude oil spot prices to US$35-US$40 per barrel in June, after having reached in April a record low of US$20 per barrel[279]. This is still markedly lower than the US$50-65 of 2019[280] [281]. Natural gas prices fell significantly as well, in the first quarter about 40-50% year-on-year on European hub prices[282]. Energy prices are expected to bounce back progressively with the recovery of the global economic activity, although the pace, the degree and the level of stabilisation of international energy markets are still uncertain.

Low energy demand and prices combined with the supply chain disruptions (EU and international) have created turmoil with energy industry investment and growth plans. Global investment in the energy sector is expected to fall 20% compared to 2019, mostly driven by a reduction in the oil and gas industry (-32%), followed by coal (-15%), energy efficiency (-12%), the power system (-10%) and renewables (-10%)[283].

Merchant renewable electricity projects and corporate PPAs, dependent on the wholesale prices, have also been affected. Auctions to subsidise new projects have been cancelled or delayed[284].

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[272] The European Commission's Green Lanes initiative helped improved the situation and road freight appears to have stabilised after the initial sharp decline.

[273] Sources: ENTSO-E; Power in Europe, Issue 823, May 18, 2020 and European Power Daily, May 22, 2020 as analysed in JRC120950 - Impact of COVID-19 on European energy value chains and the operation of our energy system: Bulletin No. 5: 2 June 2020.

[274] Sources: ENTSO-E and Power in Europe, Issue 823, May 18, 2020 as analysed in JRC120950 - Impact of COVID-19 on European energy value chains and the operation of our energy system: Bulletin No. 5: 2 June 2020.

[275] The contribution of renewables can be explained, in a context of lower demand, by lower short run marginal costs of production than other generators, notably solar and wind, as well as by the priority rule dispatch under Regulation (EU) 2019/943 of 5 June 2019 on the internal market for electricity (Article 12).

[276] Sources: Power in Europe, issue 821, April 20, 2020 and issue 822, May 4, 2020 as analysed in JRC120807 - Impact of COVID-19 on European energy value chains and the operation of our energy system: Bulletin No. 4: 15 May 2020.

[277] European Commission, Quarterly Report on European Electricity Markets, July 2020

[278] https://ec.europa.eu/energy/data-analysis/energy-statistical-pocketbook_en

[279] The Brent crude oil price had not been as low as US$20/bl (nominal price) since February 2002.

[280] https://www.eia.gov/dnav/pet/PET_PRI_SPT_S1_D.htm

[281] West Texas Intermediate crude oil even briefly traded Futures contracts at negative prices at the end of April.

[282] European Commission, Quarterly Report on European Gas Markets, July 2020

[283] IEA, World Energy Investment 2020

[284] For instance in Portugal, France, Italy

Beyond renewables, the crisis has weakened the financial solidity and capacity to invest for the whole energy sector, including for the electricity sector where the logistical and supply chains for grid technologies, storage and nuclear technologies have also been disrupted. Overall, the clean energy transition industries are facing a significant slowdown, even if to a lesser extent than fossil fuel ones. One of Europe's fastest growing sectors, necessary for reaching climate neutrality as well as contributing to our energy security of supply, risks stagnation and the loss of its leading international position.

The European Union and Member States, similarly to other major economies, rapidly put in place emergency measures in order to address the socio-economic impact of the pandemic. In part, this has taken the form of income support to households. In part, this has also involved the provision of State aid to avoid a wave of bankruptcies, as facilitated by the Temporary Framework for State Aid Measures to Support the Economy in the Current COVID-19 Outbreak[285]. Based on policy measures adopted up to late-April 2020, the Commission's Economic Spring 2020 Forecast projected all Member States to run general government deficits ranging from 2.8% to 11.1% of GDP in 2020, with an average of 8.3% for the EU. Facing an unstable context and highly uncertain prospects, gross fixed capital formation is expected to fall 13.2% in 2020. Compared to the levels projected in the autumn 2019 forecast, the cumulated shortfall in investment in the EU is expected to amount to 6% of EU GDP.

Beyond the need for emergency measures, the EU needs to invest in sectors and activities that will make its economy more resilient and sustainable over time. It has also become evident that ensuring a strong and sustained recovery will require additional support from public finances as well as securing productive private investments aligned with the Green Deal objectives. A significant part of the long-term recovery measures will be implemented at the national level and will be shaped by policy choices by Member States. At the EU level, the Commission has proposed a Recovery plan in order to address the recession (annex 9.11.1).

Overall, major uncertainties remain about the evolution of the pandemic itself and economic developments in the short and medium term. First, the sharp downturn in economic activity may result in a temporary increase in bankruptcies and accelerate structural change. More vulnerable and less productive firms would likely be more affected and this could free up resources (labour and capital) and redirect them towards firms operating with improved technologies and production processes. The pandemic could also potentially lead to structural social and economic shifts, including as a result of behavioural changes by consumers and new business strategies by producers. The following broad trends could emerge, in part reinforced by policy developments:

- A global trend towards somewhat less globalised value chains, which would affect international trade flows and demand for international air and maritime transport, driven by:
  - enterprises, particularly in industrial sectors viewed as strategic, in the EU and elsewhere, seeking to address the potential vulnerabilities that the pandemic has evidenced;
  - policy measures as governments aim at reducing reliance on imports in certain sectors;
  - increased consumer preferences for locally produced goods.
- Changed mobility patterns:

[285] https://ec.europa.eu/commission/presscorner/detail/en/ip_20_496

  - increased recourse to teleworking practices, with associated impacts on commuting needs and urban congestion;
  - increased recourse to tele-conferencing in services sectors, with reduced demand for international business travel;
  - increased substitution of long-distance tourism with shorter-distance tourism.
- A faster development of digitalisation of the economy, including e-services (e.g. tele-medicine or other services), e-commerce and teleworking, and the related productivity changes (gains in a number of sectors, but also possible losses associated to teleworking).

A higher awareness of both businesses and consumers of the positive environmental impacts of lower pollution, especially in cities as experienced during the lock down, leading to higher willingness to change habits.

The assessment of the impact of the COVID crisis in this document builds upon the BSL and MIX scenarios on which a sensitivity analysis was conducted to assess the potential impacts of the current COVID-19 crisis. Using the E3Modelling GEM-E3 computable general equilibrium model[286], the associated downward revision in real GDP growth was disaggregated to sectoral impacts, including resulting impacts on transport, energy and industrial demand between 2020 and 2030. This resulted in projections with significant negative impacts first and foremost in transport, including road and air. Construction is also expected to suffer from a double-digit fall in gross value added in 2020, which has repercussions on providers of inputs to the sector, including cement and other non-metallic minerals. Other energy intensive industries are expected to be somewhat less negatively affected, even though they are likely to also take a significant hit in 2020. Market services, in turn, are expected to contract more than overall GDP, while output in agriculture is unlikely to be fall to any major extent.

It is projected that the share in total gross value added of transport, industry and to some extent construction would decline somewhat by 2030 compared to the pre-COVID projections, due to structural shifts as well as reduced investments due to lower economic growth. This would be compensated by a moderate increase in the share of less energy intensive market and non-market services. The share of the energy sector in total gross value added is expected to remain broadly unchanged as the substitution from imported fossil-fuels to higher-valued added domestic electricity production is expected to continue regardless.

These post-COVID macro-economic projections have been used to conduct a sensitivity analysis (COVID-BSL and COVID-MIX) with the PRIMES energy system model applied on the MIX scenario achieving 55% GHG reductions. As for the BSL and other policy scenarios developed for this impact assessment, the sensitivity analysis therefore relies on a fully coherent system and set of assumptions.

In 2020, gross inland energy consumption and final energy consumption[287] in the COVID-MIX scenario are estimated respectively at 7.7% and 6.2% below the MIX scenario. By 2025, this gap is projected to decrease to 1.9% and 0.4% for GIC and FEC respectively. The gap in energy demand between the COVID-MIX and MIX scenarios in 2030 decreases further to 1.5% for GIC and 0.3% for FEC.

[286] https://e3modelling.com/modelling-tools/gem-e3/

[287] Final energy consumption does not include international aviation. If the latter is included, FEC under COVID-MIX is 9.1% below MIX in 2020 and 1.5% lower in 2025 and 2030.

Compared to MIX, FEC in COVID-MIX in 2030 is projected to be lower in services (-3.7%) and nearly unchanged in industry (-0.3%) and transport (+0.8%), but higher in the residential sector (+1.6%) because of lower renovation rates following the economic crisis. Demand for electricity is also lower by 2.1%.

In 2030 the cost of ETS allowances is €35/tCO_2-eq in the COVID-MIX scenario compared to €44/tCO_2-eq in MIX. Over the period 2021-2030, the sensitivity analysis shows that annual energy system investment needs (excluding transport) would be affected only marginally, at EUR 409.8 billion (constant prices of 2015) under COVID-MIX and EUR 417.8 billion under MIX. While the fall could be somewhat larger on the demand side than on the supply side, the differences are small in both instances.

The modelling confirms that even with COVID, investment in the energy system would need to increase at rates almost identical to a situation without the COVID-crisis. This while presently the economy is rather confronted with an investment drop. This contributes to the investment gap, as identified in the analysis accompanying the Communication ‘Europe's moment: Repair and Prepare for the Next Generation’.

9.10.1.4 The priorities of the current Commission and the European Green Deal

The President of the European Commission has made the European Green Deal[288] a priority for her mandate from the start. It strengthens and consolidates the Commission’s commitment to tackling climate and environmental-related challenges. It is a new growth strategy that aims to transform the EU into a sustainable, fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use. This strategy also aims to protect, conserve and enhance the EU's natural capital, and protect the health and well-being of citizens from environment-related risks and impacts, and includes the green oath to “not do harm”. The European Green Deal includes a dedicated roadmap[289] with key policies and measures to further this transformation. The main building blocks of the European Green Deal are illustrated in Figure 92.

[288] COM(2019) 640 final
[289] COM(2019) 640 final

Figure 92: Representation of the main building blocks of the European Green Deal

Source: European Commission

The European Green Deal brings together an important set of policy initiatives, such as:

- European Green Deal Investment Plan (Sustainable Europe Investment Plan) that will mobilise at least €1 trillion of investment over the next decade;[290]
- Just Transition Mechanism including a Just Transition Fund to ensure a fair transition and leaving no one behind;[291]
- European Climate Law to enshrine climate neutrality of the EU by 2050;[292]
- European Climate Pact bringing together regions, communities, and businesses[293];
- European Industrial Strategy to jump-start the green and digital transition while setting global standards;[294]
- Circular Economy Action Plan to decouple economic growth from resource use;[295]
- Farm to Fork Strategy to make food systems more sustainable;[296]
- EU Biodiversity Strategy for 2030 to bring nature back on a path to recovery;[297]
- Strategy for sustainable and smart mobility planned by the end of 2020,
- Proposal for a Revision of the Energy Taxation Directive planned in 2021
- Proposal for a Carbon Border Adjustment mechanism for specific sectors planned in 2021

[290] COM(2020) 21 final
[291] COM(2020) 22 final
[292] COM(2020) 80 final
[293] https://ec.europa.eu/clima/policies/eu-climate-action/pact_en
[294] COM(2020) 102 final
[295] COM(2020) 98 final
[296] COM(2020) 381 final
[297] COM(2020) 380 final

- Zero Pollution Action Plan due in 2021.
- Proposal for extending the EU ETS to the Maritime sector, due in 2021
- New EU Strategy on Adaptation to climate change in 2021

These initiatives all matter to achieve the transition towards climate neutrality.[298] They will be reinforced and accelerated by the massive investment towards a green recovery from the COVID-19 crisis that the EU is putting forward (see annex 9.11.1)

9.10.2 Key elements to improve the further coherence when developing energy, climate and transport policies

Renewable energy policy and offshore renewable energy strategy

Having in mind EU's climate neutrality objective, there is currently an unused potential contrasted with a need for further very significant deployment of renewable energy across all sectors: electricity (centralised and decentralised), heating & cooling as well as transport. Renewable electricity can also serve to produce renewable and low-carbon fuels such as hydrogen or biomethane from waste and residues. The role of policy initiatives which aim at facilitating deployment and more Europeanised approach[299] in development of renewable power is not sufficiently scaled up.

More specifically, relatively new renewable energy such as offshore wind will be playing an increasingly important role in the European electricity system. The already strong growth is set to accelerate and NECPs envisage a strong increase of capacity by 2030. Offshore wind projects and accompanying infrastructure have been developed in the context of the Member States' policies. However, this national approach will not suffice to foster the scale-up in a coherent manner and further measures, as proposed by the offshore renewable energy strategy[300] will be needed[301].

Heating and cooling is key to Europe's energy sector decarbonisation[302]. Due to its fragmented nature, however, renewable heat solutions face challenges in their competition with gas. Renewable heat is addressed in several EU legal and policy instruments in a fragmented manner[303]. Without more effective policies in support of renewables in this sector, its full decarbonisation potential will not be exploited.

Given that the transport sector is a major emitter, the RED II aims to promote the use of renewable and low-carbon fuels (e.g. advanced biofuels, e-fuels and hydrogen) by obliging each EU Member State to set out a supply obligation promoting the use of renewable fuels, designed to ensure the achievement of the 14% renewable energy target as well as a 3.5% sub-target for

[298] Research and innovation are also part of the Green Deal with, e.g. Horizon Europe strictly linking its missions to the European Green Deal objectives.
[299] Notably via different regional cooperation groups.
[300] Announced in the European Green Deal and scheduled for adoption in 2020 according to the Commission Work programme for 2020.
[301] The massive deployment of offshore wind requires a sound and prudent planning. While offshore wind parks can be beneficial for biodiversity (e.g. construction of artificial reefs), planning needs to address environmental problems and ensure that different uses and biodiversity can co-exist.
[302] As a sector contributes to 50% of EU energy consumption.
[303] The measures for increasing the share of renewable energy in heating and cooling in a sustainable and coherent manner have been included for the first time in the Renewable Energy Directive (RED II) recast.

advanced biofuels[304]. While RED II already includes special incentives for the deployment of such fuels in the aviation and maritime sector, the efficiency of these measures needs to be reviewed. Additional measures for uptake of renewable and other sustainable alternative fuels in these modes will be assessed in ReFuelEU Aviation[305] and FuelEU Maritime[306] initiatives. In addition, the FQD sets an obligation to reduce the greenhouse gas intensity of transport fuel by 6% at the latest by 2020 compared to 2010, expected to be fulfilled mostly with renewable fuels.

Given increased climate ambition, further acceleration and deployment of renewable and low-carbon fuels (e.g. advanced biofuels, e-fuels and hydrogen), in particular in those transport modes that are hard to decarbonise with other technologies, at Member State and EU level is necessary in the context of the climate neutrality objective. It is notably clear that the increased use of renewable energy in transport, for those part of the sector that have limited other mitigation options, will rely in the medium and long term on a significant uptake of renewable and low-carbon fuels, which will require significant increase in the generation of renewable electricity. Similarly, better waste treatment and valorisation will need to mobilise sufficient amount of feedstock for the production of advanced biofuels[307]. Still, any fuel policy must be accompanied by measures to improve efficiency. Deployment of renewable and low-carbon fuels therefore needs to be combined with efficiency measures that also comprise modal shift towards more sustainable transport modes.

Finally, re-enforcing measures such as streamlined permitting and administrative arrangements would encourage local and regional administrative bodies to include heating and cooling from renewable sources in the planning of city infrastructure as well as uptake for renewables self-consumption and renewable energy communities.

Energy efficiency legislation and the 'Renovation Wave' initiative

The EU policies have led to substantial energy savings and GHG emission reductions. However, market failures and barriers persist and prevent us from tapping the full potential of energy efficiency. In some sectors, notably ICT, emerging trends of increase in energy consumption would require to be addressed rapidly. Current barriers and market failures prevent investments, lead to high perceived risks, inefficient use of public funding, and lack of mobilisation of private financial resources.

The overall 2030 ambition for energy efficiency, the measures to achieve it and the scope of action might not be sufficient in the light of an increased 2030 climate target. In this context, the energy efficiency legislation, including the EED, EPBD, Ecodesign and energy labelling legislation targeting the energy efficiency of products, equipment and appliances should be more effectively implemented and can play a stronger role. The EED has an unused potential to provide for enhanced and expanded measures that could deliver higher savings contributing to climate ambition, especially that several articles have not been revised in 2018 and could offer a significant contribution to reducing GHG and air pollutant emissions. The energy efficiency first principle, recently included in the energy legislation, would need to be full exploited too. Beyond EED, the full energy efficiency legislation, including the EPBD, Ecodesign and energy labelling

[304] Replacing the current 10% renewable energy target in transport to be achieved by 2020.
[305] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12303-ReFuelEU-Aviation-Sustainable-Aviation-Fuels
[306] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12312-FuelEU-Maritime-
[307] The Commission will regularly assess whether the positive list of feedstock that can be used for the production of advanced biofuels can be extended in line with the RED.

legislation targeting the energy efficiency of products, equipment and appliances should be more effectively implemented and can play a stronger role.

75% share of building stock has a poor energy performance and thus contributes significantly to emissions. The current renovation rates are not sufficient even to meet the current targets and should be scaled up[308]. This problem will be addressed by the upcoming Renovation wave initiative. Particularly, deep renovations – achieving significant energy savings – need to increase in number, floor area and depth. Cost-effective approaches with the right financing and investment tools as well as green criteria[309] applied to procurement policy in the public sector will be necessary.

Energy system integration and hydrogen strategy

Today's energy system is built on parallel vertical energy value chains, which rigidly link specific energy resources with specific end-use sectors[310]. Market rules largely follow this setup. This separation is technically and economically inefficient and produces substantial losses in the form of waste heat and low energy efficiency, which in turn affect GHG emissions and pollution levels.

Scarce integration of the energy system hinders decarbonisation of electricity. Insufficient coordination and synchronisation across Member States does not ensure proper functioning of the internal market. Storage capabilities are not adequate to support a larger, more renewables-based power system. The network infrastructure[311] requires development enabling efficient low and zero carbon solutions at both the supply and demand side (higher RES, GHG neutral hydrogen, heat pumps, demand response, e-mobility etc.) and hence lower cost of decarbonisation.

In order to meet increased climate ambition, further deployment of renewable gaseous fuels[312] and, more broadly low-carbon gases will be needed which will be hindered without a suitable policy framework for their market uptake increasing tradability of renewable gases and allowing decentralised renewable gas producers to play an adequate role in the energy system.

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[308] The circularity principle should be fundamental for buildings and smart technologies (using full potential of digitalisation) can help achieving it. Nature-based solutions like green walls and green roofs can also help making buildings more sustainable.

[309] For instance related to energy and materials efficiency,

[310] For instance, petroleum products are predominant in the transport sector and as feedstock for industry. In turn, coal and natural gas are mainly used to produce electricity and heating. Electricity and gas networks are planned and managed independently from each other.

[311] Including smart grids, hydrogen infrastructure, CCS infrastructure and charging & hydrogen fuelling stations for transport.

[312] The most significant renewable gases in the EU are biogas and biomethane producing today some 17 bcm annually. There were more than 17000 biogas installations and around 450 biomethane installations in the EU in 2015[312]. Biogas is mainly used for producing electricity and heat supported by subsidy schemes. Once support schemes end, existing biogas plants may decide to invest into upgrading biogas to biomethane to inject it into the gas grid. Investments in new plants are expected to increase biogas and biomethane production.
The study "Optimal use of biogas from waste streams" (CE Deflt, 2016) performed for the European Commission found that until 2030 the production of renewable gases could be doubled. One of the main recommendations of this study for EU regulation was to ensure EU-wide harmonisation and enable biomethane cross-border trade.

While GHG neutral hydrogen is generally envisaged[313] as a promising energy carrier and feedstock to support the EU's climate neutrality objective, no supply and no market for clean hydrogen exist in Europe, due to high uncertainties.

The EU strategies on Energy System Integration and on hydrogen shed light on how to efficiently integrate decarbonised supply of electricity and hydrogen with transport, heating and cooling for buildings or industrial processes in order to maximise the synergies between the sectors. This integration could be facilitated by increasing consistency between the sectoral policies.

Sustainable and smart mobility strategy and transport investments

Transport (excluding international aviation and maritime navigation) accounts for around 22% of the EU27's greenhouse gas emissions (in 2018 emissions from transport were still 23% higher than in 1990). Meanwhile, international aviation emissions have grown by 140% since 1990 and international navigation emissions by 38%. Transport is also a major contributor to air pollution and noise. Road, rail, aviation and waterborne transport are making efforts to decarbonise but these efforts must be increased and sustained. The European Green Deal has set the key objective to deliver a 90% reduction in transport-related greenhouse gas emissions by 2050 to support the EU's aim to become the first climate neutral economy.

To accelerate the shift to sustainable and smart mobility, the transport sector will require important investments in the coming decade as regards the networks use, the infrastructure and the fleets.

For passenger transport, the completion of the TEN-T Core Network is needed by 2030 to radically change the transport offer in Europe with new high-speed rail links, good connections to all major airports allowing to offer alternatives to short-haul flights, the development of multimodal passenger hubs in urban nodes and accessibility to all users.

For freight transport, the completion of key cross-border sections and missing links, the upgrade of major interoperable freight routes fit for 740m trains, the upgrade of connections to ports and logistics centres, the massive increase of capacity in terminals and rolling motorways is necessary for the rail sector to attract significantly larger volumes of freight. Investments in inland waterways and short-sea-shipping, notably serving the hinterland of maritime ports, need to accompany this change. The smart component of the TEN-T related to traffic data and traffic management[314] should be boosted, to get more out of the existing capacity, fast[315].

The deployment of alternative fuels and smart European-wide systems is necessary for environmental improvements and efficiency gains. This will require the deployment of recharging/refuelling infrastructure for cars and light-duty vehicles, the deployment of recharging and refuelling for long distance / heavy duty vehicles, further electrification of rail tracks, modernisation and (renewable) electrification of rail fleet as well as enhanced clean public transport in urban areas. It will also require investments to accelerate the development and roll-out of renewable and low carbon technological solutions and fuels for the maritime and inland

[313] All Long Term Strategy decarbonisation scenarios show that clean hydrogen will play an important role in reaching climate neutrality by 2050 – it is thus not a question of whether but a question on when precisely this will happen.

[314] European Rail Traffic Management System, Intelligent Transport Systems, Air Traffic Management Systems, Vessel Traffic Monitoring and Information Systems, e-Maritime services, River Information Service.

[315] In the light of long duration of work related projects, this is the fastest way of enhancing the quality of transport and making a visible difference.

waterways sector and to support the production and use of advanced biofuels and e-fuels for the aviation sector, as well as the greening of ports and airports.

Digitalisation, automation, the emergence of shared, collaborative economy, and innovative mobility platforms are all disruptive trends challenging the current mobility and transport landscape, while also offering great possibilities for its enhancement. Investments in 5G, artificial intelligence, block-chain and common databases can also benefit the transport sector.

To boost the resilience of the transport system to future pandemic and other crises, it must also secure under all circumstances the smooth cross-border flow of citizens and goods. A fair and functioning internal market for transport is still not a reality. Obstacles remain to free mobility of persons, goods and services, including their accessibility, and to competition that is needed to boost innovation, service quality and ensure affordable mobility for all.

The price of transport must reflect the impact it has on the environment and on health, requiring a look at current tax exemptions and subsidies and extension of ETS to maritime navigation.

The comprehensive strategy on 'Sustainable and Smart Mobility' will build on the other Green Deal initiatives and actions that the Commission already deployed for the recovery of the sector, with a view to contributing to the increased EU 2030 climate target, clean energy transition and climate neutrality by 2050.

9.10.3 Climate change and its impact, how to increase resilience and adaptation

Climate change is already occurring and its impacts felt across the world. Europe has warmed faster than any other continent over recent decades with European temperature almost 2°C above temperatures of the latter half of the 19th century[316], with impacts and adaptation needs that we are feeling already now and that are expected to grow.

The past five years were the warmest on record[317], with global average temperature reaching 1.1°C above pre-industrial levels in 2019. Human-induced global warming is presently increasing at a rate of 0.2°C per decade[318]. However, temperature increase is not the same everywhere. Regions for example the Arctic regions are warming faster and if current trends continue, there is a risk for cascading tipping points.

The effects of rising temperatures and greenhouse gas emissions are being felt in Europe and around the world. Heatwaves were the deadliest meteorological hazard in the 2015–2019 period[319] and are becoming more intense in Europe. In summer 2019 they led to more deaths than the seasonal average in parts of Europe as temperatures broke records in several countries, including a new record of over 34°C above the Arctic Circle. In Europe almost all years since 2000 show above-average fire danger, with a number of associated disastrous events in the recent past, such as Pedrógão Grande wildfires (Portugal) in 2017 and the Scandinavian fire season in 2018.

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[316] Copernicus Climate Change Service (2019). European State of the Climate, 2019. https://climate.copernicus.eu/ESOTC/2019/surface-temperature
Note that land has warmed more rapidly than the ocean. Therefore, most populated regions of the world have experienced warming above the global average. However, Europe has warmed more than other regions.
[317] WMO Statement on the State of the Climate in 2019
[318] IPCC Special Report on Global Warming of 1.5°C (2018). Section 1.1
[319] United in Science (2019), High-level synthesis report of latest climate science information convened by the Science Advisory Group of the UN Climate Action Summit 2019. https://public.wmo.int/en/resources/united_in_science

There is a strong possibility that global warming will reach and overshoot 1.5°C, at least temporarily, before temperatures can be reduced again, raising the question of what it means for warming to cross the global 1.5°C threshold, and how impacts and the adaptation challenge in Europe will evolve. In examining these issues, this section builds upon section 5.9 of the in-depth analysis in support of the Commission Communication on the EU long term strategy[320] and updates findings since 2018.

The Commission announced in the *Communication on the European Green Deal*, COM(2019) 640 final, that the Commission will adopt a new, more ambitious EU strategy on adaptation to climate change. This is essential, as climate change will continue to create significant stress in Europe in spite of the mitigation efforts. Strengthening the efforts on climate-proofing, resilience building, prevention and preparedness is crucial. Work on climate adaptation should continue to influence public and private investments, including on nature-based solutions. It will be important to ensure that across the EU, investors, insurers, businesses, cities and citizens are able to access data and to develop instruments to integrate climate change into their risk management practices. The *Adjusted Commission Work Programme 2020*, COM(2020) 440 final, Annex I, includes the New EU Strategy on Adaptation to Climate Change for adoption in Q1 2021.

9.10.3.1 Global impacts due to climate change

The recent reports of the IPCC[321] find that robust differences in climate characteristics are projected between the present-day and global warming of 1.5°C, and between 1.5°C and 2°C. The main differences in impacts between these warming levels are examined systematically in SR1.5. These are summarised in Table 53 and Table 54. Further detail is provided in the subsequent IPCC reports on climate change and land (SRCCL) and on ocean and cryosphere in a changing climate (SROCC). SRCCL finds that risks associated with permafrost degradation, wildfire, coastal degradation and stability of food systems are high at 1.5°C, while risks associated with soil erosion, vegetation loss, and change in nutrition become high at higher temperature thresholds due to increased possibility for adaptation. SROCC focuses largely on differences in impacts between a below 2°C scenario and a high emissions scenario[322] and shows that keeping warming below 2°C will lead to multi-metre differences in sea-level rise beyond 2100. Limiting warming will also slow ice loss and reduce impacts on the ocean (such as marine heatwaves and acidification due to the ocean's absorption of CO_2) which in turn harm marine life and fisheries. Limiting warming to 1.5°C therefore increases the chances of ecosystem-based adaptation measures (such as wetland preservation and restoration) proving effective.

On the issue of Earth system tipping points, such as slowdown of the Atlantic Meridional Overturning Circulation (Gulf Stream) or instability of the Greenland and West Antarctic ice sheets, SR1.5 finds greater risks at lower temperatures compared to the previous (fifth) assessment report of IPCC, with moderate risk at 1°C of warming and high risk at 2.5°C of warming. While the IPCC does not explicitly label global warming of 1.5°C as an Earth system tipping point, there appears to be abundant evidence that impacts and risks are greater at higher

[320] https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf

[321] Special Report on Global Warming of 1.5°C – SR15 (2018), Special Report on Climate Change and Land – SRCCL (2019) and Special Report on Ocean and Cryosphere in a Changing Climate – SROCC (2019)

[322] These are scenarios RCP2.6 and RCP8.5 respectively. Warming under RCP8.5 is widely considered to be greater than current business-as-usual scenarios.

temperatures (every tenth of a degree matters). Articles such as Lenton et al. (2019)[323] make a precautionary case for keeping global warming as low as possible on the basis that while low probability, high impact events are little understood, science has progressively assessed them as being more likely at lower temperatures as knowledge has improved.

The Council conclusions on Climate Diplomacy[324] underlines that climate change multiplies threats to international stability and security in particular affecting those in most fragile and vulnerable situations, reinforcing environmental pressures and disaster risk, contributing to the loss of livelihoods and forcing the displacement of people.

[323] Lenton, M., et al. (2019). Climate tipping points — too risky to bet against. Nature | Vol 575 | 28 November 2019.
[324] Council conclusions on Climate Diplomacy, ST-5033-2020 of 20 January 2020, https://data.consilium.europa.eu/doc/document/ST-5033-2020-INIT/en/pdf

Table 53: Selected Climate Change Impacts to Natural Systems at 1.5°C & 2°C

	At 2°C	**At 1.5°C**
Extreme hot days	4°C hotter	3°C hotter
Sea level rise by 2100	around 0.1m more than at 1.5°C (less time to adapt)	0.26-0.77m
Ecosystems	13% of global land area changes from one ecosystem type to another	area at risk ~50% lower than at 2°C
Habitat Loss	18% of insects, 16% of plants and 8% of vertebrates lose over half their climatically determined geographic range	6% of insects, 8% of plants and 4% of vertebrates lose over half their climatically determined geographic range
Permafrost thawing	1.5 – 2.5 million km^2 greater than at 1.5°C	Woody shrubs encroaching into the tundra already at 1°C
Arctic Ocean	At least one sea ice-free summer per decade	One sea ice-free summer per century
Coral reefs	largely disappear (>99% loss)	decline by 70-90%
Fisheries Global annual marine catch (one model)	over 3 million tonnes lower	1.5 million tonnes lower

Greater risk at 2°C than 1.5°C is specified but not quantified[325]

- Droughts and precipitation deficits;
- Heavy precipitation events;
- Heavy precipitation associated with tropical cyclones;
- Larger area affected by flood hazards due to precipitation;
- Spread of invasive species
- Forest fires
- Marine ice sheet instability in Antarctica and/or irreversible loss of the Greenland ice sheet could be triggered around 1.5°C to 2°C of global warming
- Oceans (greater risk at 2°C spanning several impacts including species range shift and impacts of ocean acidification on marine species)

Note: Impacts above are attributed a confidence level of at least medium in the IPCC report's Summary for Policymakers

Source: IPCC Special Report on global warming of 1.5°C

[325] Some of these impacts are regional rather than global, though regions in this context are large. E.g. heavy precipitation events are projected to be higher in northern hemisphere high latitude/high elevation regions, eastern Asia and eastern North America. More specific phenomena within these categories may be quantified in the underlying IPCC report.

Table 54: Selected Climate Change Impacts to Human Systems at 1.5°C & 2°C

	At 2°C	At 1.5°C
Populations exposed to climate-related risks and susceptible to poverty	Numbers affected expected to increase	Several hundred million fewer people affected than at 2°C by 2050.
Water stress	Additional 8% of world's population affected (based on year 2000 population)	Affects up to 50% less of the world's population compared to 2°C
Greater risk at 2°C than 1.5°C is specified but not quantified • Human health: heat-related morbidity & mortality, ozone-related mortality • Vector-borne diseases (e.g. malaria, dengue): increased risk, shifting geographic range • Crops (cereals, rice): reductions in yields and/or nutritional quality • Reductions in projected food availability • Risks to global aggregated economic growth • Exposure to multiple, compound climate-related risks • Greater adaptation needs		

Note: Impacts above are attributed a confidence level of at least medium in the IPCC report's Summary for Policymakers

Source: IPCC Special Report on global warming of 1.5°C

9.10.3.2 The need to adapt in the EU

Successful mitigation action is the first necessary step to reduce the risk of climate change. However, in parallel, the EU economy as a whole must adapt to the risks that will result from already committed emissions. These risks grow as we lag behind schedule in stabilising global temperatures. Limiting global warming to 1.5°C, compared with 2°C, could reduce the number of people susceptible to poverty globally[326] by up to several hundred million by 2050. Each 0.5ºC of warming avoided can be significant, increasing the chances of achieving SDGs related to poverty, hunger, health, water, cities and ecosystems. Among others, EU agricultural, Arctic and coastal dependent communities would benefit significantly; adaptation of fragile ecosystems and the services they provide (e.g. coral reefs, wetlands, and mangrove forests) would be more effective. In general, overshooting the 1.5ºC limit will make climate-resilient development pathways (CRDPs) more elusive and impacts on water-energy-food-biodiversity links more difficult to manage.

Conventional and incremental approaches to adaptation that do not consider long-term sustainable development or consider adaptation and mitigation separately will not deliver the Paris Agreement. More emphasis on 'transformational' adaptation measures as a complement to 'incremental' adaptation may be required[327]. These adaptation measures and options may include not only "hard" structural and physical measures (e.g. coastal protection, infrastructure) but also

[326] Summary for Policymakers, IPCC Special Report, Global Warming of 1.5°C, B.5.1

[327] Transformational adaptation, according to the IPCC (2014 AR5, Chapter 14: https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-Chap14_FINAL.pdf) "seeks to change the fundamental attributes of systems in response to actual or expected climate and its effects, often at a scale and ambition greater than incremental activities. It includes changes in activities, such as changing livelihoods from cropping to livestock or by migrating to take up a livelihood elsewhere, and also changes in our perceptions and paradigms about the nature of climate change, adaptation, and their relationship to other natural and human systems". See also EEA 2017 climate, impacts and vulnerability report and 2016 EEA report on Urban adaptation to CC in Europe.

“soft” social policies (e.g. awareness, health services) and governance improvements (e.g. implementation, cross-sector coordination, mainstreaming). A combination of both “hard” and “soft” adaptation may produce best results[328], and joining efforts from several EU Member States may also improve protection, e.g. monitoring and mapping jointly coastal areas for a more reliable early warning of extreme weather[329].

It is necessary to better integrate long-term planning of emissions reduction and adaptation because:

a) **Adaptation provides opportunities and economic and social stability** – climate change will interact with other socio-economic developments[330]. It can be expected that climate change adaptation projects or the impact of climate extremes will involve a higher level of public intervention than today[331], which calls for effective and efficient adaptation strategies, particularly at local scale. Public resources may be severely drained if the climate reaches certain tipping points[332]. On the other hand, both public and private investments in adaptation provide opportunities and risk management opportunities that can spur the creation of market niches: e.g. for climate services or green infrastructure. In addition, supporting adaptation in developing countries may also bring stability and security within the EU's borders. The New EU Strategy on Adaptation to Climate Change will have a prominent international dimension.

b) **There are co-benefits and, if done incorrectly, trade-offs between mitigation and adaptation** – so both policies must be developed together as components of any credible long-term climate action. Early integration of both adaptation and mitigation in coherent climate-resilient development pathways entails that specific vulnerabilities are factored in when a given economic sectors starts implementing a decarbonisation strategy. For instance, adaptation must ensure that low-emission agricultural techniques withstand higher temperatures, it must lead to renewable electricity networks that are climate-resilient and protect forests so that they keep functioning as carbon sinks. Transformative climate action in cities, in particular, depends on the right mix of mitigation and adaptation actions to both protect citizens against climate impacts and enable emissions reduction within stringent legal and budgetary boundaries.

(c) **Adaptation improves the functionality and resilience of human and natural systems**. Effective adaptation action reduces both the vulnerability and exposure of natural ecosystems and communities to the risks associated with climate extreme events (floods, wildfires, hurricanes, etc.), and improves their capacity to recover and re-establish after a climate-related perturbation. These aspects ensure that the functionality of ecosystems (e.g. absorption of CO_2) is maintained over the long-term, or at least that such functionality is recovered shortly after an extreme event.

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[328] OECD (2015), Climate Change Risk and Adaptation - Linking Policy and Economics, http://dx.doi.org/10.1787/9789264234611-en

[329] For example, a new European seabed map stitched together from surveys originally made for navigation has improved storm surge forecasts in the North Sea. See: http://www.emodnet.eu/improving-storm-surge-modelling-north-sea

[330] EEA (2017), Climate change, impacts and vulnerabilities in Europe 2016, https://www.eea.europa.eu/publications/climate-change-impacts-and-vulnerability-2016

[331] Daniel Bailey (2015), The Environmental Paradox of the Welfare State: The Dynamics of Sustainability, New Political Economy, 20:6, 793-811, DOI: 10.1080/13563467.2015.1079169

[332] Steffen et al. (2018), Trajectories of the Earth System in the Anthropocene, Proceedings of the National Academy of Sciences Aug 2018, 115 (33) 8252-8259; DOI: 10.1073/pnas.1810141115

In 2013, the European Commission adopted an EU Adaptation Strategy to tackle climate change risks to the EU economy and society. The 2013 Adaptation Strategy – which will be updated with the New EU Strategy on Adaptation to Climate Change in Q1 2021 – focuses on developing better knowledge and understanding of climate impacts, climate proofing of specific sectoral policies and the promotion of action by Member States and cities through non-legislative means. The recent evaluation of the Strategy highlighted the urgency for action because of the important risks facing the EU in certain economic areas[333]. For instance:

- By the end of the century, under a high emissions scenario[334] and without specific adaptation measures undertaken, the EU could experience a welfare loss of around 2% of GDP per year by 2100, i.e. EUR 240 billion per year from only six impact sectors assessed[335]:
    - Weather-related disasters could affect about two-thirds of the European population annually (351 million people per year)[336], compared with 5% of the population between 1981-2010. This would increase the related fatalities per year by fifty times by the year 2100 (from 3 000 deaths per year presently, to 152 000 deaths per year by 2100)[337];
    - Flooding alone may cost EU countries up to EUR 1 trillion per year in damages by the end of the century. Most of this would be due to coastal flooding (up to EUR 961 billion). Damages from river flooding could also rise to up to EUR 112 billion compared to EUR 5 billion today, and there is considerable increase in river flood risk for Europe even under a 1.5º C warming scenario[338]. This could also affect transport infrastructure. By the end of the century, under a high warming scenario, about 200 airports and 850 seaports of different size across the EU could face the risk of inundation due to higher sea levels and extreme weather events.
- Climate change is already affecting agriculture production both in direct and indirect ways: through temperature and precipitation changes, increasing variability, and extremes. It is also affecting the long-term perspective of agriculture through slow on-setting events such as soil salinization, land degradation and desertification, and sea-level rise. This has a direct impact on production and yields, income and livelihoods, as well as the processing industry altogether accounting for high economic impacts. In a 2°C scenario before 2100, irrigated crop yields are projected to decline in most regions of Europe, with rain-fed yields depending on changes in water availability[339]. At EU level, the prolonged drought of 2018 has triggered

[333] Report from the Commission to the European Parliament and the Council on the implementation of the EU Strategy on adaptation to climate change.
[334] In this section, the term "high emissions scenario", unless specified otherwise, refers to the IPCC's Representative Concentration Pathway (RCP) 8.5. In the RCP 8.5 scenario, greenhouse gas emissions continue to rise throughout the 21st century.
[335] JRC (2018), Climate Impacts in Europe, Final report of the JRC PESETA III project. doi:10.2760/93257. https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/climate-impacts-europe
[336] Forzieri et al. (2017), Increasing risk over time of weather-related hazards to the European population: a data-driven prognostic study, https://doi.org/10.1016/S2542-5196(17)30082-7
[337] High emissions scenario, in this particular case, means scenario SRES A1B.
[338] Alfieri et al. (2018). Multi-Model Projections of River Flood Risk in Europe under Global Warming. Climate, 2018 6, 16; doi:10.3390/cli6010016: https://www.mdpi.com/2225-1154/6/1/6/pdf
[339] Commission Staff Working Document: Evaluation of the EU Strategy on Adaptation to Climate Change SWD(2018)461final.

higher CAP advanced payments and derogations from greening requirements.[340] Repeated droughts in Europe will have repercussions for climate mitigation policies: the water and carbon cycles are interlinked because CO_2 rates in the atmosphere increase when terrestrial water storage diminishes: major droughts may cause drastic regional reductions in land carbon sinks[341]. Drought is already ravaging Europe's soils, whose moisture shows a marked decreasing trend over the 1979-2017 period[342]. Furthermore, moisture decrease is a crucial factor in the ferocity and expanded reach of recent forest fires (that would jeopardise viability of forests as carbon sink).

- As regards the building sector, new and renovated buildings need to prepare for climate change impacts as they, together with most of the remaining built environment, are particularly vulnerable to: (1) Extreme temperatures affect the comfort of the occupants and building energy efficiency; (2) Climatic conditions (humidity, temperatures) can affect the structural integrity of the constructions; (3) More frequent and intense flooding events can do more harm to more buildings; and (4) Water scarcity could in the future make domestic water supply more expensive. Adaptation may for instance include: (i) Green roofs and walls contribute to reducing the heat island effect and enhance water retention in towns; and (ii) Domestic rain water cisterns contribute to urban water retention.

The PESETA[343] project analysed climate change projections for 2050 considering the Representative Concentration Pathway (RCP) of 8.5 W/m2 (with corresponding global warming levels ranging between 1.6°C and 2.7°C compared to pre-industrial levels), as well as for 1.5°C and 2°C warming conditions. Results show that climate change will pose a threat to global food production in the medium to long term, and that Europe will also be affected. Forced by the projected changes in daily temperature, precipitation, wind, relative humidity, and global radiation, grain maize yields in the EU will decline between 1% and 22%. In addition, wheat yields in Southern Europe are expected to decrease by up to 49%.

The vulnerability of forests and ecosystems to climate change has been highlighted in a number of studies and reports from the European Environmental Agency (EEA)[344] and the Joint Research Centre (JRC)[345].

In addition, climate-change related risks can also have implications on the assessment of medium-term inflation outlook by central banks. Recently, the European Central Bank (ECB) stated that catastrophic climate change could force the ECB to rethink its current monetary policy framework[346]. The EIB will end financing for fossil fuel energy projects from the end of 2021[347]

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340 Commission Press release – "Commission offers further support to European farmers dealing with droughts", Brussels, 2 August 2018. http://europa.eu/rapid/press-release_IP-18-4801_en.htm

341 Humphrey et al. (2018), Sensitivity of atmospheric CO_2 growth rate to observed changes in terrestrial water storage, https://doi.org/10.1038/s41586-018-0424-4

342 Copernicus Climate Services (C3S): European State of the Climate 2017: https://climate.copernicus.eu/climate-2017-european-wet-and-dry-indicators

343 PESETA: https://ec.europa.eu/jrc/en/peseta-iv

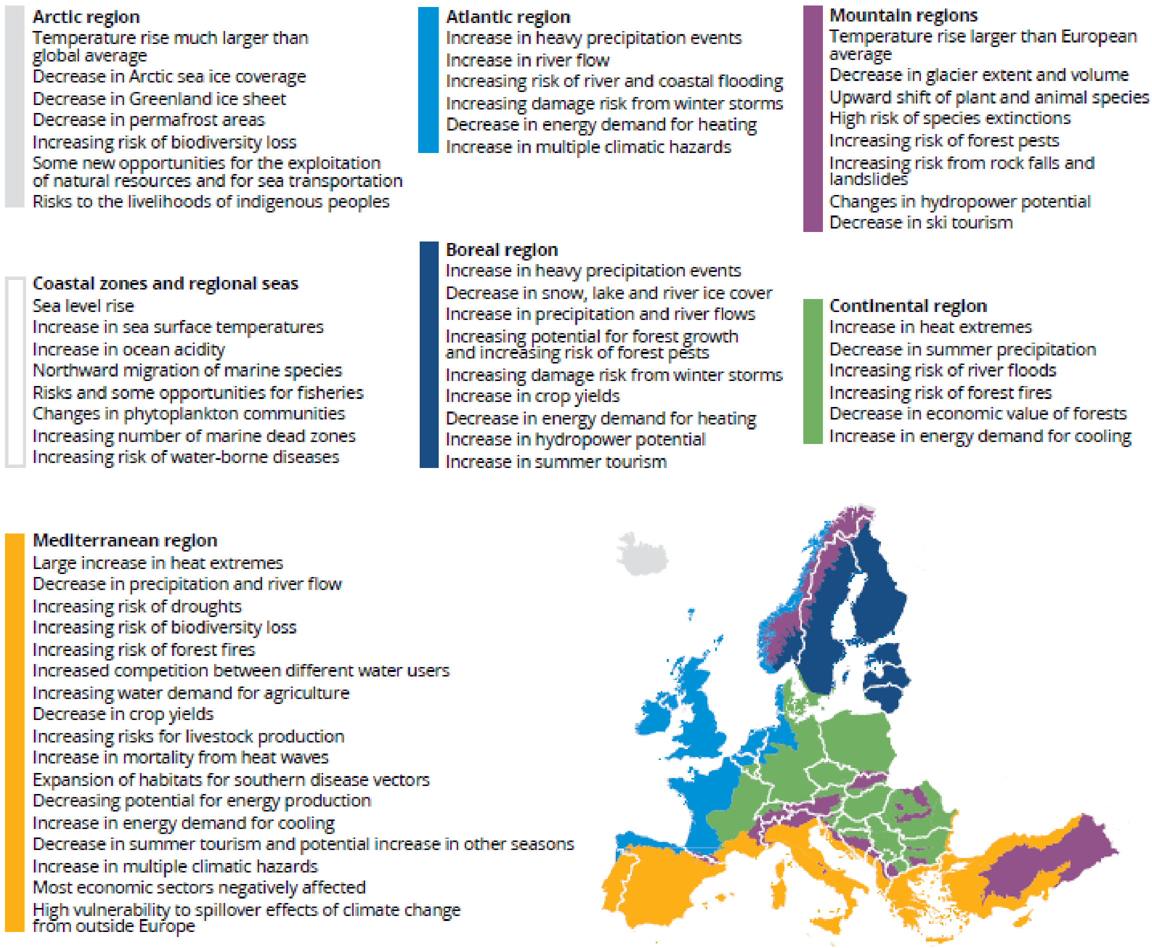
344 https://www.eea.europa.eu/publications/climate-change-impacts-and-vulnerability-2016

345 https://ec.europa.eu/jrc/en/peseta-iii ; https://ec.europa.eu/jrc/en/peseta-iv

346 Speech by Benoît Cœuré, Member of the Executive Board of the ECB, at a conference on "Scaling up Green Finance: The Role of Central Banks", organised by the Network for Greening the Financial System, the Deutsche Bundesbank and the Council on Economic Policies, Berlin, 8 November 2018

Looking at risks from a more territorial angle, evidence is mounting on the distributional effects of climate impacts across Europe. Impacts and opportunities will not be equally spread across the EU territory, as shown in the map below:

Figure 93: Risk of climate change impacts across Europe



Source: European Environmental Agency

There are specific climate risks that are of major concern to some EU regions and communities. In the absence of adaptation, for instance[348]:

- While Europe as a whole will be more prone to flood risk (with mean annual river flow set to increase), water stress will be more pronounced in Southern European regions[534], and may well cause tensions between different users of dwindling reservoirs and aquifers. Under 2°C warming, median river flows in Mediterranean regions are expected to fall in all four seasons.

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347 https://www.eib.org/en/press/all/2019-313-eu-bank-launches-ambitious-new-climate-strategy-and-energy-lending-policy.htm#

348 Where not otherwise specified, information provided comes from Commission Staff Working Document: Evaluation of the EU Strategy on Adaptation to Climate Change SWD(2018)461final.

- Higher temperatures by the end of the century are expected to have various impacts such as a 10-15% loss in outdoor labour productivity in several Southern European countries as well as increases in heat-related mortality.

- Habitat loss and forest fires are also serious risks. 16% of the present Mediterranean climate zone (an area half the size of Italy) could become arid by the end of the century. Drier soils in the Mediterranean also increase the area prone to forest fires.

- Loss of Alpine tundra, even at 2°C could have important impacts on water regulation (including for human consumption), as well as economic impacts including in the tourism sector.

- Specific risks (e.g. hurricanes, sea level rise, extreme heat) threaten to unravel EU efforts to support its nine Outermost Regions, most of them small and isolated islands. The impacts of hurricanes Irma and Maria on the Caribbean in 2017, and notably on St-Martin, Guadeloupe and Martinique (three of the EU's outermost regions) came as a stark warning of the potential impacts such regions face.

- Transport: From road and rail networks to ports, airports and inland waterways, critical transport resources are facing unprecedented threats from a climate, which is already changing. Spain, for example, has just suffered the most powerful storms experienced in decades, destroying bridges, cutting off roads and railway lines and submerging entire towns in coastal areas. Flooding from high precipitation and extreme storms, in possible association with related impacts including landslides and slope failures, will bring major risks across the region for all modes of transport (road - and airport - infrastructure, railway and inland waterways). Rising sea levels and greater wave activity causing erosion put vital coastal transport infrastructure (i.e. coastal roads, railways, seaports and airports) at risk. Over 60% of EU seaports[349] may be under high inundation risk by 2100, causing disruptions to operations and damages to port infrastructure and vessels, especially along the North Sea coast, where the traffic of over 500 ports accounts for up to 15% of the world's cargo transport. Rising temperatures linked to increased heat waves and drier and hotter summers will affect roads, where pavement damages, damages to bridges and increased landslides in mountainous areas are among key risks. Areas considered particularly worthy of more detailed analysis include E-Roads in Southern Europe (South-Eastern France, Italy, Western Balkans, Portugal, Spain, Greece, and Turkey) as well as in Nordic countries (Norway, Sweden and Finland). Climate proofing not only individual infrastructure investment projects, but also existing transport corridors, networks and systems will be increasingly relevant, as the majority of the existing infrastructure is built for the past climatic conditions.

- On major rail networks – where potential impacts include buckling of tracks, slope failures and speed restrictions – infrastructure in the Mediterranean (Spain, Italy, France), northern Europe, and Croatia are among those that could warrant more in-depth review.

- Warming is also associated with increased navigational risks on inland waterways, with significant implications for the transport of goods and people, which is already problematic in parts of central Europe.

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[349] UNECE: https://www.unece.org/info/media/presscurrent-press-h/transport/2020/unece-study-maps-transport-infrastructure-at-high-risk-due-to-climate-change-in-pan-european-region-and-canada/doc.html

- Cities as well as rural areas are directly and indirectly impacted by the impacts of climate change. As the level of governance closest to citizens, they are often at the forefront of responding to natural disasters and taking action on mitigate emissions and adapt to climate change. Through their concentration of people and assets, cities are the major consumers of energy and emitters of greenhouse gas emissions, but have also pioneered actions to reduce emissions and adapt to climate. Including through initiatives such as the EU and Global Covenant of Mayors, committing to reduce emissions by at least 40% by 2030, and taking action to adapt to climate change".

The EU Taxonomy on sustainable finance will also address climate related risks.

9.10.3.3 Mitigation and adaptation: co-benefits and trade-offs

Measures to cut emissions can undermine resilience to climate change in certain contexts, and vice versa. On the other hand, there are adaptation measures that are also beneficial for decarbonisation (e.g. protection of certain coastal ecosystems that both tackle sea level rise and remove CO_2). A recent OECD report[350] highlights that climate investments and projects must consider the links between adaptation and mitigation to minimise climate risk: the greater the perceived risks of a project, the higher the returns investors will demand, and the higher the costs passed onto end users and government sources of funding. The report provides a summary of potential synergies and trade-offs between adaptation and mitigation measures:

[350] OECD (2017), Investing in Climate, Investing in Growth, OECD Publishing, Paris. http://dx.doi.org/10.1787/9789264273528-en

Table 55: Co-benefits and trade-offs between adaptation and mitigation

	Positive for mitigation	**Potential trade-off with mitigation**
Positive for adaptation	Reduced deforestation: sequesters carbon and provides ecosystems services Agricultural practices (e.g. no till) that can sequester carbon while boosting farmers income Wetland restoration: carbon sequestration and reduced flood risk Renewable energy – wind and solar: lower water use than thermal generation	Desalination: addresses water shortage but is energy intensive Increased irrigation: helps farmers manage variable precipitation but can be energy intensive Construction of hard defences: reduces the risk of extreme events, but the construction may in some cases lead to substantial greenhouse gas emissions Air-conditioning: reduces the impact of high temperatures, but is energy intensive. However, redesign of buildings to enable passive cooling and natural ventilation in buildings is a better and more sustainable solution.
Potential trade-off with adaptation	Inappropriate expansion of biofuels: could exacerbate food price shocks if biofuels displace crops Hydropower: could increase the complexity of managing water resources	N/A

In some areas, the potential to maximise the mutual reinforcement between adaptation and mitigation should guide long-term EU efforts to decarbonise and climate-proof the economy. Examples for ecosystems, energy and cities are mentioned below.

<u>Land and coastal ecosystems</u>

Terrestrial and marine ecosystems globally absorb around 50% of anthropogenic emissions[351]. The rest remains for prolonged times in the atmosphere, increasing greenhouse gas concentrations and causing climate change.

Climate change is affecting ecosystems, modifying species range and prompting natural vegetation changes. Global warming has led to shifts of climate zones in many world regions, including expansion of arid climate zones and contraction of polar climate zones. As a consequence, many plant and animal species have experienced changes in their ranges, abundances, and shifts in their seasonal activities. 7.5% of global land area will change from one ecosystem type to another at 1.5°C, and 13% at 2°C.

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[351] Around 50% globally, according to A. P. Ballantyne, C. B. Alden, J. B. Miller, P. P. Tans, J. W. C. White. Increase in observed net carbon dioxide uptake by land and oceans during the past 50 years. Nature, 2012; 488 (7409): 70 DOI: 10.1038/nature11299

This absorption capacity has its own limits. In case of oceans this uptake is associated with increased acidification, having negative impacts on marine biodiversity. In case of terrestrial ecosystems, ecosystem degradation and deforestation actually result in significant greenhouse gas emissions, while being detrimental for biodiversity. Preserving and restoring terrestrial and marine ecosystems contribute both to mitigation and adaptation (for example, they contribute to water retention, control floods and protect against erosion or air quality).

In general, the joint implementation of adaptation and mitigation strategies contribute to the health, functionality and resilience of ecosystems, and therefore improve the availability and delivering of goods and services to EU citizens. Many environmental, welfare and climate objectives may be reached simultaneously through ecosystem-based initiatives[352]. For example, marine vegetated habitats (seagrasses, salt-marshes, mangroves and others) contribute 50% of carbon storage in marine sediments despite occupying only 0.2% of the ocean surface globally. They reduce wave energy and raise the seafloor, and as such moderate the impacts of sea level rise and contribute to safeguard people, infrastructure, and property along coastlines[353].

Land restoration, reforestation and reduced and avoided degradation in forests, as well as rehabilitation of wetlands, contributes to and increased land use sink. Forests offer a good example of the co-benefits that can arise from coordinated adaptation and mitigation. Indeed, EU forests absorb the equivalent of just over 400 MtCO_2, or almost 10% of total EU greenhouse gas emissions each year. At the same time, they lower temperatures, act as a buffer for hydrological extremes and purify water, which means they are also crucial in adapting to climate change. Recent case-studies in Ireland, Spain and the Czech Republic have shown that adaptation measures and good forestry practices enhance the role of forests as carbon sinks[354]. It is important to act with a long-term perspective because aging and degraded forests, agro-forestry systems and more recent forest plantations all require adaptation planning today in order to withstand a changing climate.

Energy

Due to climate change alone, and in the absence of adaptation, annual damage to Europe's critical infrastructure could increase ten-fold by the end of the century under business-and-usual scenarios[355], from the current EUR 3.4 billion to EUR 34 billion. Losses would be highest for the industry, transport, and energy. One of the greatest challenges is how to assess impacts on energy production which may occur as a consequence of the projected increase in the intensity of extreme weather events, as research gaps include economic modelling of extreme events and vulnerabilities of transmission infrastructure[356].

Impacts on renewable energy sources are of specific concern, given their critical contribution to emissions reduction. There is some evidence on impacts on hydropower production due to water

[352] Faivre et al. 2018; https://doi.org/10.1016/j.ijdrr.2017.12.015

[353] Duarte, C.M., Losada, I.J., Hendriks, I.E., Mazarrasa, I., Marbà, N. The role of coastal plant communities for climate change mitigation and adaptation. Nature Climate Change, 3 (11), pp. 961-968 (2013).

[354] European Forest Institute – 2018 https://www.efi.int/publications-bank/climate-smart-forestry-mitigation-impacts-three-european-regions

[355] Forzieri et al. (2018), Escalating impacts of climate extremes on critical infrastructures in Europe, Global Environmental Change 48, 97–107,

[356] Chandramowli et Felder (2014), Impact of climate change on electricity systems and markets – A review of models and forecasts, https://doi.org/10.1016/j.seta.2013.11.003

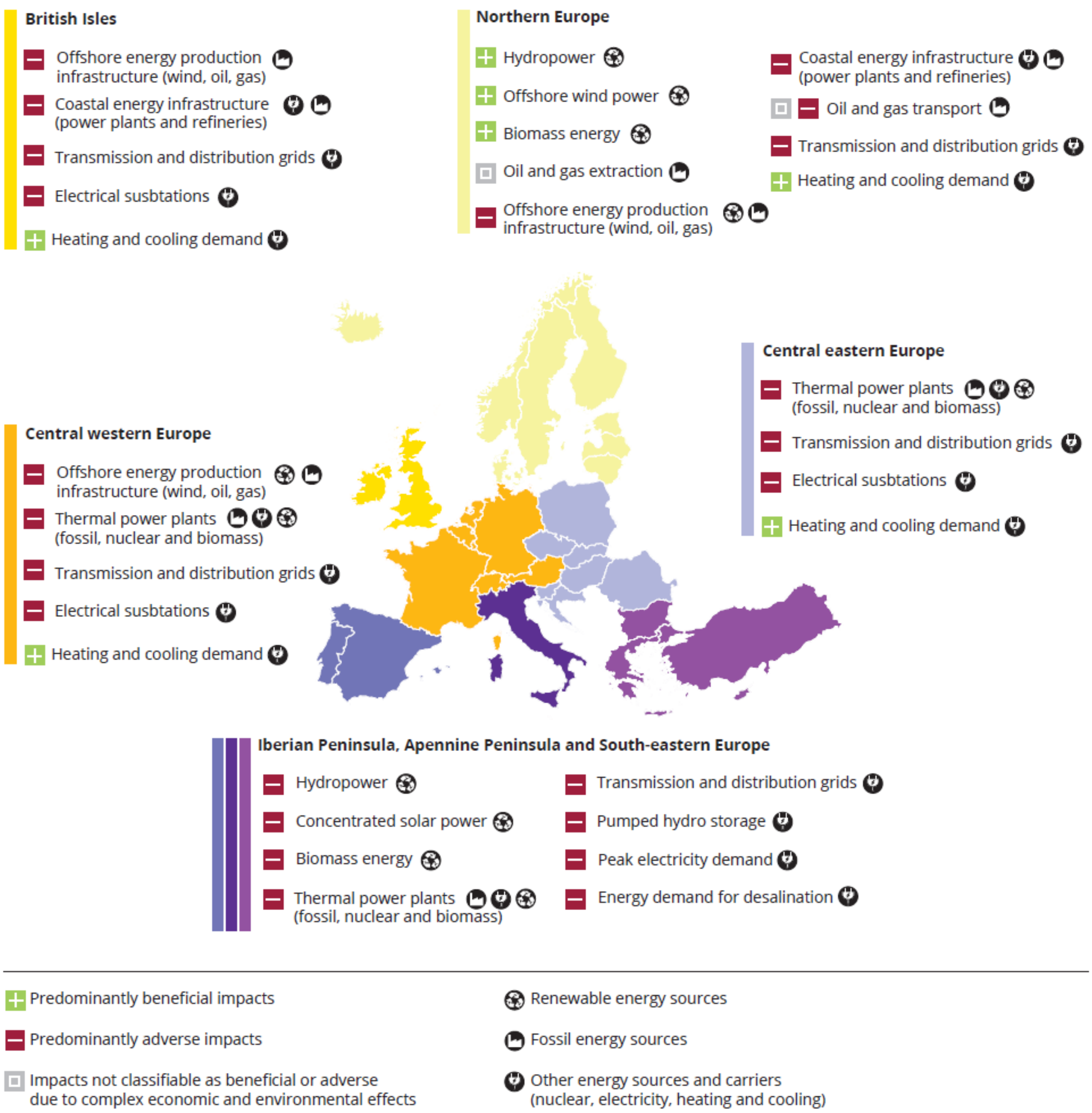
scarcity, but also on wind, solar, biomass[357]. As regards hydropower in particular, the main mechanisms through which climate change can affect hydropower production are changes in river flow, evaporation, and dam safety[358]. For Europe, most studies show a positive effect of climate change impacts on hydropower for Northern Europe and a negative effect for South and Eastern Europe[557 359 360 361 362]. The extent to which climate change affects hydropower in Europe as a whole differs among the studies from almost no effect[558] to decreases of 5-10% by the end of the century or even before[559 363]. Adaptation measures in hydropower production could offset these impacts in Europe on a yearly average (not for all months of the year): e.g. by increasing efficiency[560] or water storage[364]. As regards solar and wind energy, there are studies that indicate that production might be negatively affected on some regions in the EU[365 366 367].

Thermoelectric generation will be under more pressure in Southern European regions where their water cooling needs may no longer be met: they may generate up to 20% less under a 3ºC scenario; 15% less in a 2ºC world. [555]Thermal electricity generation may suffer most from water stress in the near term in the Mediterranean, France, Germany and Poland[368].

While the magnitude of these impacts is not expected to jeopardise Europe's long-term decarbonisation path, it may entail higher costs and different regional energy mixes, unless adaptive measures are deployed such as increased plant efficiencies, replacement of cooling systems and fuel switches[560]. Private stakeholders in the energy system and EU and national policies should reinforce the right market framework to ensure that the climate impacts do not jeopardise the EU’s stability and security of energy supply. Transitions in the electricity sector should encompass both mitigation and adaptation planning, if they are to sustain and secure a sustainable water–energy nexus in the next few decades.

[357] See COACCH 1st synthesis report.
[358] Mideksa and Kalbekken (2010), The impact of climate change on the electricity market: A review, https://doi.org/10.1016/j.enpol.2010.02.035
[359] Hamududu and Killingtveit (2012), Assessing Climate Change Impacts on Global Hydropower, doi:10.3390/en5020305
[360] Lehner et al.,(2005), The impact of global change on the hydropower potential of Europe: a model-based analysis, https://doi.org/10.1016/j.enpol.2003.10.018
[361] Van Vliet et al,(2016), Power-generation system vulnerability and adaptation to changes in climate and water resources, https://doi.org/10.1038/nclimate2903
[362] Teotónio et al.(2017), Assessing the impacts of climate change on hydropower generation and the power sector in Portugal: A partial equilibrium approach, https://doi.org/10.1016/j.rser.2017.03.002
[363] Chandramowli et Felder (2014), Impact of climate change on electricity systems and markets – A review of models and forecasts, https://doi.org/10.1016/j.seta.2013.11.003
[364] Berga (2016), The Role of Hydropower in Climate Change Mitigation and Adaptation: A Review, https://doi.org/10.1016/J.ENG.2016.03.004
[365] Karnauskaset al. (2018), Southward shift of the global wind energy resource under high carbon dioxide emissions, https://doi.org/10.1038/s41561-017-0029-9
[366] Tobin et al. (2018), Vulnerabilities and resilience of European power generation to 1.5 °C, 2 °C and 3 °C warming, https://doi.org/10.1088/1748-9326/aab211
[367] Jerez et al. (2015), The impact of climate change on photovoltaic power generation in Europe, https://doi.org/10.1038/ncomms10014
[368] Behrens et al. (2017): Climate change and the vulnerability of electricity generation to water stress in the European Union, https://doi.org/10.1038/nenergy.2017.114

The illustration[369] below indicates a range of selected climate change impacts on the energy system across Europe:



The 2019 JRC report[370] provides further reading on the water-energy nexus. Water availability is among the key constraints affecting the European energy sector, which currently requires 74 billion m3/year of freshwater, similar to the water needs of agriculture. The decarbonisation of the energy system could reduce its water needs by 38% by 2050, yet water availability will play an essential role on the way to climate neutrality by 2050. At the same time, projections indicate that water resources are expected to be under major stress, primarily due to climate change. Higher water stress is expected in Mediterranean regions and extreme weather variability is also

[369] EEA Report No 01/2019 "Adaptation challenges and opportunities for the European energy system - Building a climate- resilient low- carbon energy system", ISSN 1977- 8449, https://www.eea.europa.eu/publications/adaptation-in-energy-system
[370] https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/water-energy-nexus-europe

expected in north-west Europe. That may lead to increased strain in regions where freshwater is key for cooling thermal power plants or where hydropower capacity plays a significant role in the power system.

Cities

The need to integrate adaptation and mitigation pathways is most apparent in the transformation of European cities. They are home to 360 million people, i.e. 73% of Europe's population, and account for 80% of the continent's energy consumption and for 85% of Europe's GDP[371]. Yet, only around 40% of EU cities with more than 150.000 inhabitants have adopted adaptation plans to protect citizens from climate impacts. Globally, a 2015 OECD report recognises that, in spite of the important role local authorities have to deliver climate resilience through regulatory frameworks and incentives, "support for urban adaptation remains uneven"[527].

Trade-offs between mitigation and adaptation goals must be avoided in cities. In general, for example, densification may benefit emissions reduction (e.g. less transport needs), but can also increase vulnerability to regional climate impacts (e.g. more people and assets in less space when a flood occurs). Cities also suffer from higher temperatures than the surrounding areas, due to the concentration of built environment ("heat island effect").

There are opportunities to optimise climate action when developing joint mitigation and adaptation in urban planning. For example, urban green spaces and green infrastructure can deliver adaptation benefits and absorb emissions and pollution, and permeable surfaces to address floods in urban areas. Cities will also be major clients for climate services and emerging businesses may provide solutions to city planners that combine optimal mitigation and adaptation ideas. Cities that prioritise resilient and low-emission urban development at once will enjoy a competitive advantage and attract investments[372].

9.10.4 Progress globally on the fight against climate change

For 2030, over 180 countries have made pledges to reduce emissions under the UNFCCC Paris Agreement, called nationally determined contributions (NDCs)[373]. The EU has put in place the policies to meet its existing NDC target, which is a domestic reduction in greenhouse gas emissions of at least 40% by 2030 compared to 1990. However, few other major emitting economies are on track to meet their NDC commitments[374] and the world is not doing enough collectively to stop global warming, let alone limit it to 1.5°C or well below 2°C. Meanwhile emissions have risen up to 2019 with a temporary slowdown in the middle of the decade, which indicated that dedicated policies can slow and reverse emission growth.

In this context, it is important to recall that the fall in CO_2 emissions seen in 2020 due to the COVID-19 crisis, estimated at 4-7% in 2020[375] is the result of an extraordinary shock and not the

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[371] HELIX - https://www.helixclimate.eu/

[372] E3G (2014), "Underfunded, underprepared, underwater? Cities at risk".

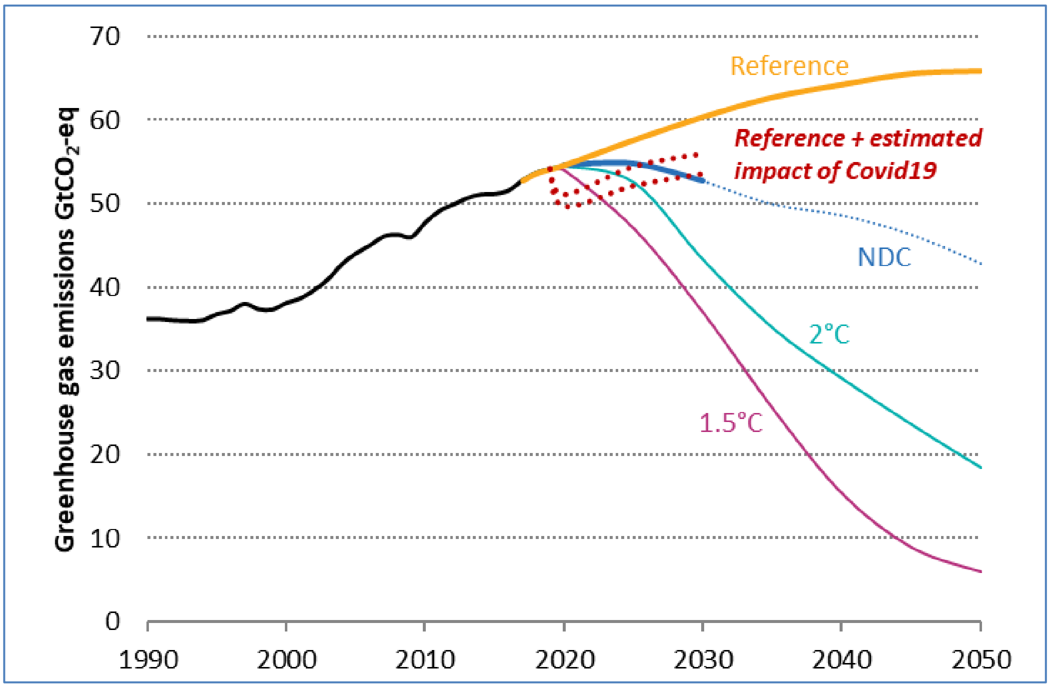
[373] While most countries' 1st NDCs have time frames up to 2030, some have time frames up to 2025.

[374] See for example the UN Environment *Emissions Gap Report 2019*, which estimates that apart from EU, five G20 countries are on track to achieve their 2030 targets. Some are on track to overachieve by more than 15%, indicating that these countries have room for raising their ambition levels.

[375] Le Quéré et al. (2020) Temporary reduction in daily global CO_2 emissions during the COVID-19 forced confinement. *Nature Climate Change*. https://doi.org/10.1038/s41558-020-0797-x . See also IEA Global Energy Review 2020. https://www.iea.org/reports/global-energy-review-2020

start of a sustainable transition towards climate neutrality, and will most likely be temporary in the absence of climate-friendly recovery options and upscaling of climate policies.

Figure 94: Global Greenhouse Gas Emissions in Reference and NDC scenarios with below 2°C and 1.5°C pathways



Note: estimated impact of COVID-19 is based on IMF short-term GDP estimates from April 2020, assuming the same annual GHG/GDP intensity as the GECO 2019 Reference scenario

Source: JRC Global Energy and Climate Outlook (GECO), 2019. https://ec.europa.eu/jrc/en/geco

9.10.5 Central role of the global energy transition

The energy use for power generation, transportation and heating, together with the emissions from industry, is responsible for 73% of the global GHG emissions[376]. Carbon dioxide produced mainly by the combustion of fossil fuels[377] and industrial processes is by far the largest cause of climate change accounting for almost 65% of total global GHG emissions[378]. For this reason, fighting climate change depends on a radical transformation of the energy system and energy use in all sectors of the economy (industry, transport, buildings and agriculture), which can also bring co-benefits for health and other environmental issues.

The global energy system has evolved over the past decades. CO_2 intensity of energy supply decreased relatively little over the last half century, having been reduced only by 7.3% in 2018 from its maximum in 1973. After an intermediate increase of the CO_2 intensity between 2000 and

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[376] 80% when excluding LULUCF, source: IEA (2020), "Emissions of CO_2, CH_4, N_2O, HFCs, PFCs and SF_6", IEA CO_2 Emissions from Fuel Combustion Statistics (database), https://doi.org/10.1787/data-00431-en (accessed on 26 June 2020).

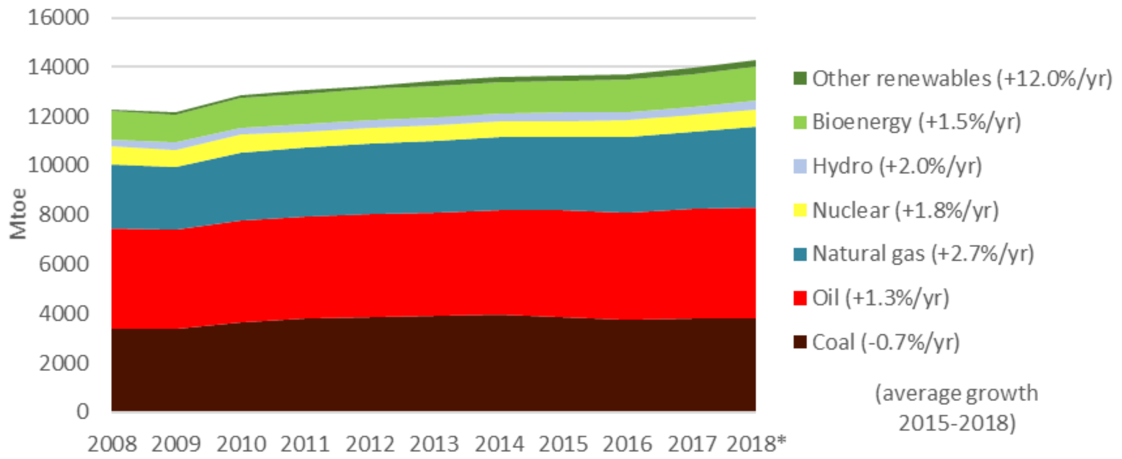
[377] In 2017, CO_2 emissions from fuel combustion alone amounted to almost 33 $GtCO_2$ – source: IEA CO_2 emissions statistics.

[378] IPCC, 2015, 5th Assessment Report, Synthesis Report, SPM.2.

2010, the trend has been changing with the rapid introduction of renewable energy reducing the CO_2 intensity by 2.1% between 2010 and 2018.

The long lasting economic recovery of the last decade was characterised by rapidly increasing primary energy demand, which grew by 11% over the 2010-2018 period, while energy intensity of GDP decreased[379]. Total energy supply (approximately 14 Gtoe in 2018) is still dominated by fossil fuels[380], which represented 81% of the total global energy in 2018 (almost the same share as in 2010[381]). This trend conceals contrasted dynamics: natural gas consumption increased 19% over the 2010-2018 period; oil increased by 9% and coal by 5%. In contrast, renewables have grown by 25% in the same period.

Figure 95: Global total primary energy supply



*Note: * IEA WEO estimations for 2018, except coal and natural gas*

Source: IEA World Energy Statistics and IEA WEO 2019

In 2018, solid fossil fuels[382] accounted for 27% of the world total energy supply. This is slightly lower than the maximum value reached in 2015. Coal still generated 36% of the world electricity in 2019 – corresponding to about 9800 TWh, 2.6% lower than the all-time-high of about 10100 TWh in 2018. At the same time, final investment decision for coal fired power plants decreased by more than 80% between 2015 and 2019[383]. Coal is also playing a smaller role in final energy demand, with a 6% decrease between 2010 and 2018. In the EU, the share of coal in electricity generation was 21% in 2018 or 45% lower than the global share in the same year.

Liquid and gaseous fossil fuels still play a major role in the energy use, notably in transportation (which is still overwhelmingly dominated by oil), heating (natural gas represent around 23% of energy consumed in industry and in buildings) and power generation (23% from natural gas). The most striking recent development is a large-scale development of shale gas and tight oil resources. Moreover, this expansion has not been without negative environmental impacts, beyond GHG emissions.

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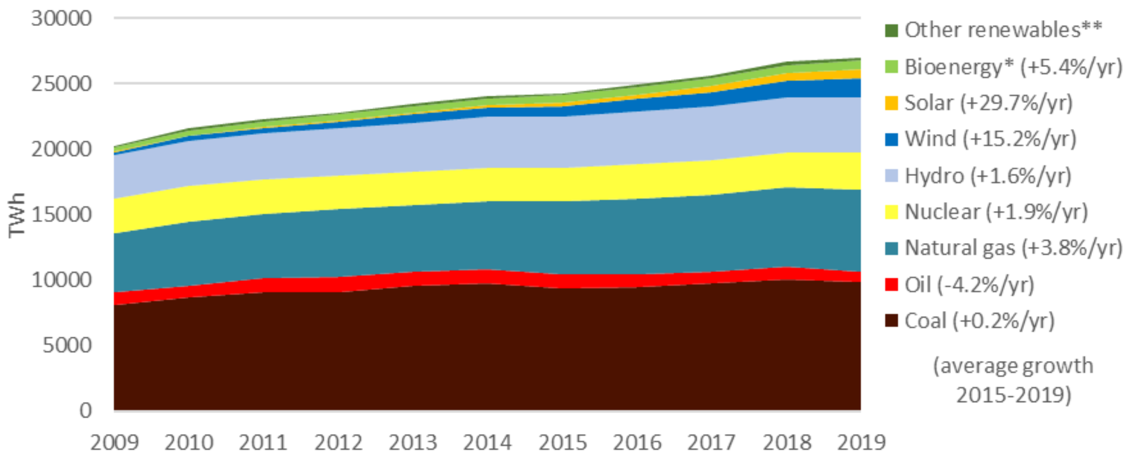
[379] Primary energy demand, source: estimate of IEA World Energy Outlook 2019
[380] Coal and lignite, oil, natural gas
[381] IEA World energy balances and statistics.
[382] Coal and lignite
[383] From 95 GW in 2015 to 17 GW in 2019; source: IEA World Energy Investment 2020

Nuclear energy is contributing to the total energy demand with 5%, a level comparable to 2010[384]. Anticipating a significant increase in electricity demand, some countries are planning to make increased use of nuclear energy[385].

Figure 96: Global gross electricity production



*Note: * including geothermal, ** no growth due to statistical differences*

Source: BP Statistical Review of World Energy June 2020

The most rapidly changing element of the global energy system is the acceleration of the electrification of energy demand. Globally, final consumption of electricity increased by almost 20% between 2010 and 2017, twice as much as the increase in final energy consumption overall[386]. Final consumption of electricity increased in all sectors. In the same period, approximately 1.2 billion people gained access to grid electricity, however around 800 million people still lack access to it[387].

Another major trend of the energy system is the rise of renewable energy. Renewables saw their share of total supply increasing to 14% (vs. 12.5% in 2010). While bioenergy is still the largest energy source (9.5% of total energy supply), the growth of renewable energy was the largest in the power generation, reaching a share of 27% of the total electricity production in 2019. Wind and solar increased by nearly a factor 6 compared to 2010 and by a factor 2 compared to 2015. The average yearly growth between 2015 and 2019 was 15% for wind and 30% for solar. The wind capacity installed worldwide in 2019 increased by 19% compared to 2018, raising the global wind capacity to 620 GW[388]. Meanwhile, solar capacity increased by 21% to reach 586 GW[587]. Globally, the increase of electricity from non-fossil origin (around +3000 TWh) did not outpace the increase of total electricity production (around +5500 TWh) between 2010 and 2019. In the EU, the increase of electricity from non-fossil origin (+200 TWh) clearly outpaced the increase of total electricity production which was practically zero in the last decade. In 2019, this

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[384] The reduction of nuclear power production in Japan following the Fukushima accident has been compensated by the commissioning of new capacities, notably in China.

[385] There are currently 55 nuclear reactors under construction worldwide (against 440 in operation), including 12 in China and 7 in India.

[386] IEA World energy balances and statistics.

[387] IEA SDG7, Data and Projections and IRENA's [Tracking SDG 7: The Energy Progress Report (2020).](#) The report also shows that affordability and utility of off-grid solutions (especially solar) has increased, allowing a growing number of people to access (off-grid) electricity services.

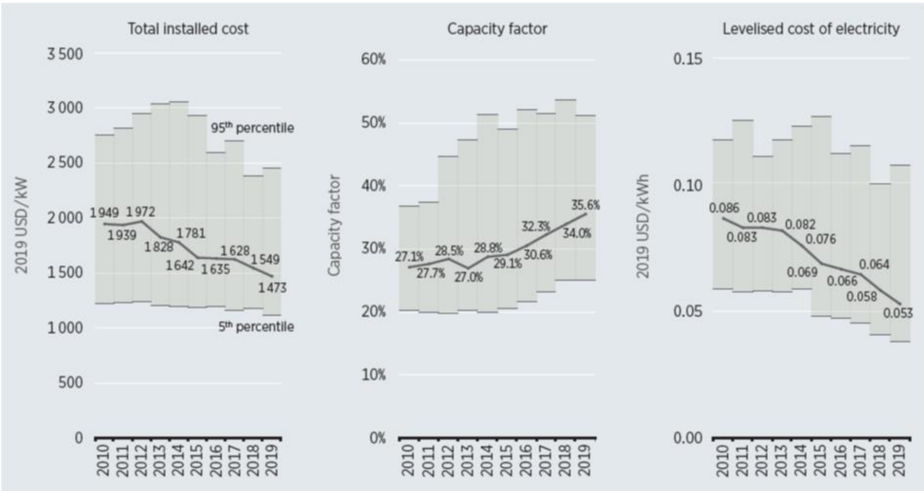
[388] IRENA, Renewable capacity statistics 2020

also happened at the global level: around 450 TWh of additional electricity from non-fossil origin versus only 350 TWh of additional total electricity production.

Increased replacement of fossil fuels by electricity from emissions-free sources like wind and solar will be an important measure to reduce emissions and to tackle air pollution. In the road transport sector, due to improvement in battery technology, the share of electric vehicles is rapidly growing. Heat pumps and other forms of electrical heating also have a large potential for reducing emissions from heating and cooling in buildings and to decarbonise low temperature processes in industry.

The growth of renewable energy was made possible by a sharp decline of the cost of electricity renewable technologies and battery storage. Since 2010, the cost of electricity from wind has fallen 49%. PV costs have dropped 85%[389] with a similar drop in battery prices[390]. These trends are expected to continue in the future.

Figure 97: Global weighted average total installed costs, capacity factors and LCOE for onshore wind power, 2010-2019



Source: IRENA, Renewable power generation costs in 2019

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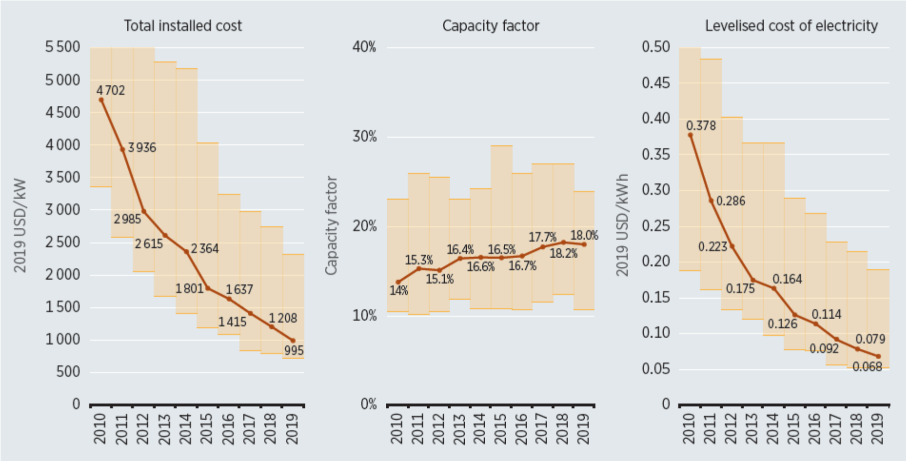
[389] BloombergNEF, New Energy Outlook 2019

[390] According to BloombergNEF, battery prices, which were above $1,100 per kilowatt-hour in 2010, have fallen 87% in real terms to $156/kWh in 2019: https://about.bnef.com/blog/battery-pack-prices-fall-as-market-ramps-up-with-market-average-at-156-kwh-in-2019/

Figure 98: Global weighted average total installed costs, capacity factors and LCOE for solar PV, 2010-2019



Source: IRENA, Renewable power generation costs in 2019

The changes had deep consequences for energy investments worldwide. Annual global investment in renewable power has increased 55% since 2010[391] and renewable sources accounted for two thirds of global investments in the power sector in 2017[392]. At the same time, investments in conventional, non-renewable, sources have diminished significantly since 2014, although upstream investments in oil and gas projects increased modestly in recent years, mostly driven by spending in the shale sector[590].

There is a consensus that the transformation of the energy system will continue. The energy and GHG intensity of the global economy should decrease further. Pressure on natural resources will promote the uptake of technologies aimed at improving energy and resource efficiency. Given that costs are expected to fall further, renewables should continue to expand at the expense of the most carbon-intensive sources of energy: coal used in power generation and oil used in transport. However, the emergence of a global consumer class[393] – and the associated increase in energy demand – slows down improvements in energy intensity.[394]

9.10.6 EU action in a global context to limit temperature increase to well below 2 ℃ and pursue efforts to limit it to 1.5 ℃

9.10.6.1 Temperature thresholds and carbon budgets

The latest IPCC Special Report on 1.5°C (SR1.5)[395] estimates that at the current rate of temperature increase, global warming (defined as in the 30-year average of global temperature) is *likely* to reach 1.5°C above pre-industrial levels at some point between 2030 & 2052[396].

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[391] IEA, World Energy Investment 2019.

[392] Adjusting for cost reductions, see IEA World Energy Investment 2018.

[393] By 2030, the consumer class is expected to reach 5 billion people. This means 2 billion more people with increased purchasing power than today (estimates from the JRC "Megatrends Hub").

[394] In 2018, energy intensity decreased by only 1.2%, the slowest rate since the start of the decade. This marked the third consecutive year of weakening energy intensity improvements.

[395] https://www.ipcc.ch/sr15/

In SR1.5, all pathways consistent with limiting warming to 1.5°C foresee the use of carbon dioxide removal (CDR) technologies and actions, and most of them require net negative emissions to return global warming to this level following a peak in temperature above 1.5°C. Chapter 2 of SR1.5 considered 54 emissions reduction pathways consistent with limiting global warming to 1.5°C by 2100, with a greater than 50% chance, and with no or limited temperature overshoot[397]. Of these, 19 were assessed as having a *likely* (>66%) chance of limiting warming to 1.5°C by 2100, and 9 were assessed as avoiding any overshoot of 1.5°C during the 21st century. However, none of the assessed pathways both limit global warming to 1.5°C by 2100 with a *likely* chance and avoid overshoot entirely. Therefore even with strong global action to limit greenhouse gas emissions, there is a strong possibility that global warming will reach and overshoot 1.5°C, at least temporarily, before temperatures can be reduced again.

Stopping global warming continuing requires net CO_2 emissions to fall to zero or below, as well as achieving a decline in the overall warming (net radiative forcing) from other greenhouse gases and forcers[596]. The term carbon budget is used to quantify the cumulative level of remaining CO_2 emissions associated with keeping global warming below a temperature threshold, such as 2°C or 1.5°C. Budgets are quantified in CO_2 since this is the most abundant *long-lived forcer* in the atmosphere. Once emitted, it accumulates in the atmosphere over decades to centuries, meaning that there is a close relationship between cumulative emissions and global temperature increase.

The level at which global temperature will peak is strongly determined by the level of cumulative CO_2 emissions[398]. In the long-term, limiting warming to below 2°C or 1.5°C requires either reducing net emissions to zero before these limits are reached, or by achieving net negative global emissions (through use of natural carbon sinks or carbon dioxide removal technologies) after the limits are exceeded.

The latest IPCC carbon budget estimates come from the Special Report on 1.5°C (SR1.5)[399]. For limiting warming to 2°C, SR1.5 gives central estimates starting in 2018 of around 1500 and 1170 $GtCO_2$ for a 50% and 66% chance respectively. For 1.5°C, the 50% and 66% chance estimates are 580 and 420 $GtCO_2$ respectively. These budgets represent the most authoritative assessment available since they are based on multiple lines of evidence following comprehensive review of the scientific literature. However, they are subject to considerable uncertainty ranges due to the inherent complexity of the interactions in the climate system. The main sources of uncertainty

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[396] See IPCC Special Report on Global Warming of 1.5°C Section 1.2. Global warming is defined in this case as the 30-year average of Global Mean Surface Temperature (GMST), which is a blend of sea surface temperature and air temperature over land. Note that the IPCC use two different measures of global temperature. For discussion of carbon budgets and emissions reduction pathways, this section follows the convention of the IPCC in using Global Surface Air Temperature (GSAT – average near-surface air temperature over both land and sea) which gives somewhat more restrictive carbon budgets than GMST. Both measures are equally valid scientifically. However, GMST is typically used in observations, while GSAT is used for models and projections. Warming since pre-industrial times, is approximately 0.2°C higher when measured by GSAT due to different warming rates of air and water, and the effect of melting sea ice.

[397] Limited overshoot is defined overshooting 1.5°C temporarily by no more than 0.1°C

[398] Maximum temperature is determined by cumulative emissions of long-lived forcers, and by the emissions from short-lived forcers around the time of CO_2 emissions reaching net zero. CO_2 is the most abundant long-lived forcer, but others such as N_2O are also significant. Some short-lived forcers such as methane are more powerful than CO_2 on per kilogramme basis and must therefore be regulated as part of climate policy. However, since short-lived forcers have a shorter lifetime in the atmosphere, they do not accumulate over time to form a cumulative 'budget' in the same way as CO_2.

[399] https://www.ipcc.ch/sr15/

around the central estimates are related to the temperature response to CO_2 and non-CO_2 emissions (+/- 400 $GtCO_2$), and the level of historic warming[400] (+/- 250 $GtCO_2$). Furthermore, Earth System feedbacks (such as release of CO_2 and methane from permafrost thawing) could reduce this budget further, out to 2100 (-100 $GtCO_2$ best estimate). Since SR1.5 gives remaining CO_2 budgets from the start of 2018, it is also important to recall that they are being depleted by around 42 $GtCO_2$ annually due to continued emissions from fossil fuels, industry and land use change. The next comprehensive assessment of carbon budgets will be included in the Sixth Assessment Report of the IPCC which is expected to be available in 2021-2022.

Taken by themselves, carbon budgets do not tell us *how* to reduce GHG emissions in a manner consistent with limiting global warming to well below 2°C or 1.5°C. For this, it is necessary to consider emissions reduction pathways that combine the atmospheric science for all greenhouse gases, not just CO_2 as summarised by the carbon budgets, as well as the technological and socioeconomic possibilities for reducing emissions of CO_2 and other greenhouse gases, including the extent to which net negative emissions will be needed.

9.10.6.2 Emissions reduction pathways and scenarios (EU and global)

The pathways and scenarios typically considered by Integrated Assessment Models look at all sources of emissions human activity and can in an integrated manner assess feasible socio economic and technology emission pathways at a global scale. The SR1.5 database[401] of such scenarios constitutes the most authoritative source on the assessment of pathways compatible with the Paris Agreement objective of keeping average global temperature rise well below 2°C and pursuing efforts to achieve 1.5°C compared to pre-industrial levels.

The more recent UNEP Emissions Gap Report (UNEP GAP 2019)[402] bases its analysis on the SR1.5 database and gives a median estimate of around 25 $GtCO_2e$ in 2030 (with a range of 22-31 $GtCO_2e$) for a least-cost pathway with a 66% of limiting warming to 1.5°C by 2100. This represents a 50% reduction compared to 2010 global GHG emissions. The 1.5°C scenarios of UNEP GAP 2019 allow maximum emissions of 600 $GtCO_2$ from 2018 up to the point of reaching net zero CO_2 emissions, and cumulative 2018-2100 emissions of at most 380 $GtCO_2$ (implying that after reaching zero, CO_2 emissions become net negative). This is consistent with the *no or limited overshoot* scenarios of SR1.5[403].

Neither report provides information on regional pathways consistent with the Paris goals. However, 1.5°C scenarios including EU28-level reductions are provided by for instance the ADVANCE[404] project (a multi-model scenario assessment project that is one of the contributors to the SR1.5 database). ADVANCE includes a set of 25 runs from 4 different scenarios and 8 different models aiming at limiting global warming to 1.5°C within a stricter budget than UNEP

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[400] SR1.5 estimates warming in the period 2006-15 to be 0.87°C above the level of 1850-1900 but with a likely range of +/- 0.12°C.

[401] Huppmann, D., Kriegler, E., Krey, V., Riahi, K., Rogelj, J., Rose, S.K. et al. (2018a). IAMC 1.5°C Scenario Explorer and Data Hosted by IIASA. https://data.ene.iiasa.ac.at/iamc-1.5c-explorer .

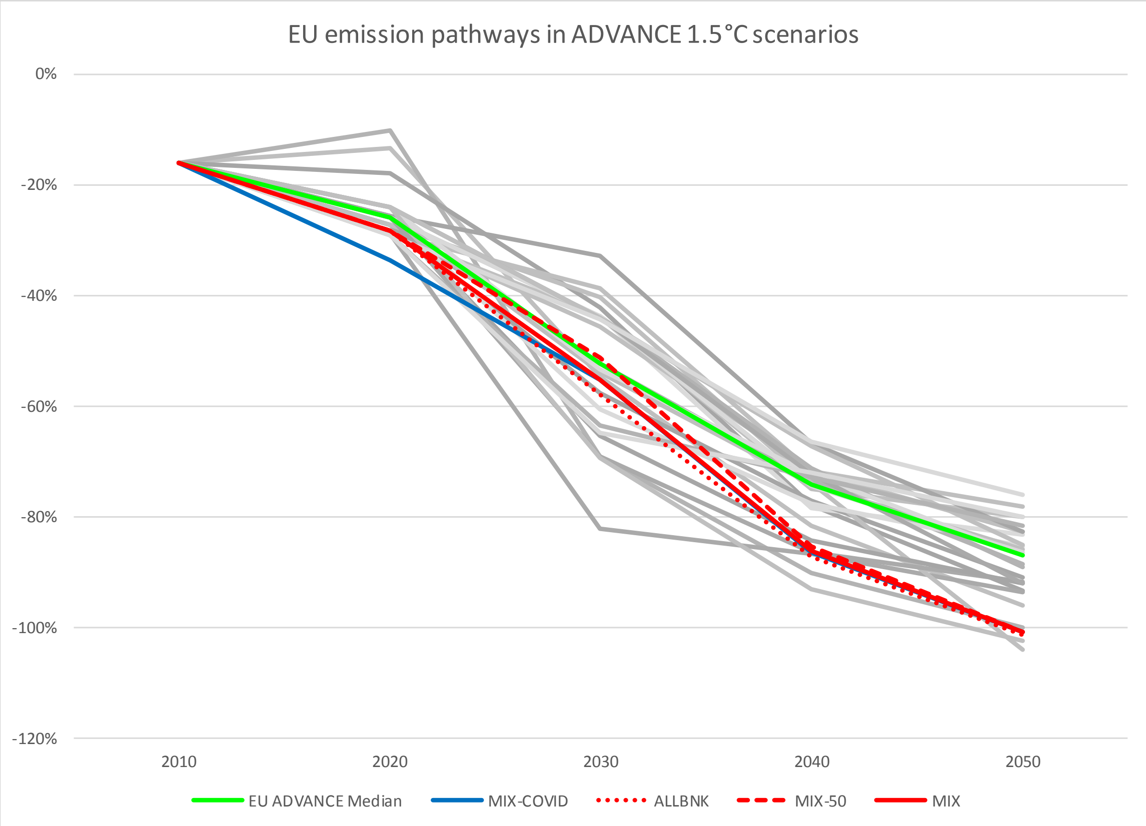
[402] United Nations Environment Programme (2019). Emissions Gap Report 2019. UNEP, Nairobi. http://www.unenvironment.org/emissionsgap

[403] Chapter 3 of UNEP GAP 2019 explains how its pathways relate to those of SR1.5.

[404] ADVANCE synthesis scenario database: https://db1.ene.iiasa.ac.at/ADVANCEDB/dsd?Action=htmlpage&page=welcome

GAP 2019[405]. When compared to the ADVANCE results, the MIX and ALLBNK scenarios (including the emissions and removals of the LULUCF sector) appears in line with EU results for global 1.5°C scenarios (Figure 99)[406].

Figure 99: 50-55% reduction pathways and ADVANCE 1.5°C scenario

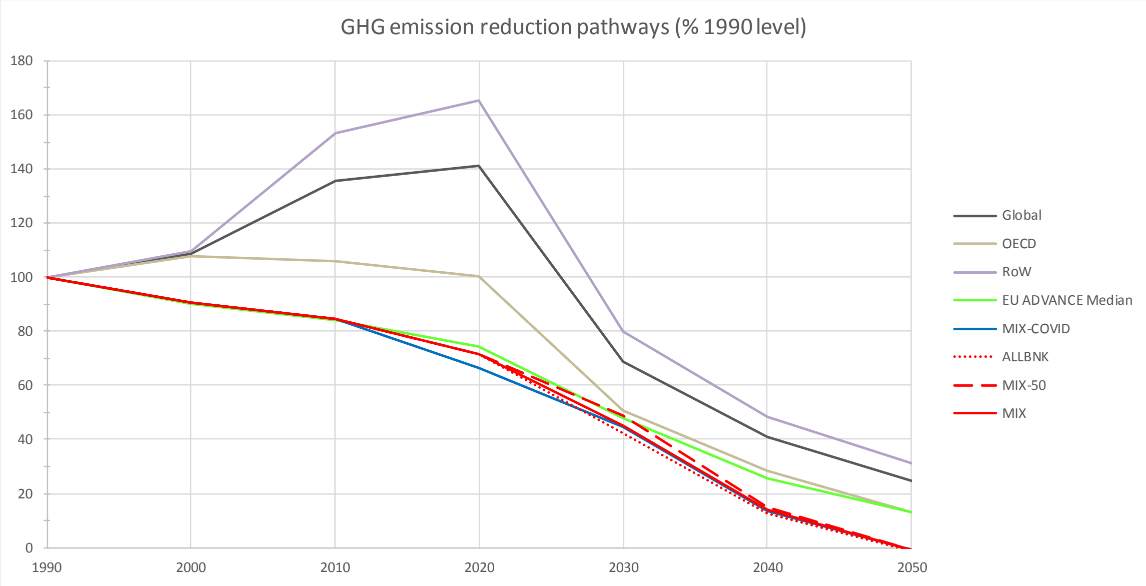


Source: IAMC 1.5°C Scenario Explorer

Figure 100 places this EU effort in historical context and compares this to 1.5°C consistent pathways for other regions taken from the SR1.5 database. Historical data show that the EU began reducing emissions earlier than the OECD as a whole. While the EU28 has reduced emissions by more than 20% below 1990 levels by 2017, emissions in the rest of the OECD *increased* by almost 20% (the 2000-2010 OECD reduction shown in Figure 100 is due to the EU emission reductions). Emissions in the rest of the world have grown by even more, especially since 2000.

[405] The ADVANCE scenarios (from 2016-16) have a 2011-2100 budget of 400 $GtCO_2$. This is stricter than the UNEP GAP 2019 and SR1.5 budgets which only begin in 2018.
[406] Note that this includes the UK, which typically reduces GHG by 2030 in such projections more compared to 1990 than the remaining EU27.

Figure 100: Emissions reductions compared to 1990, EU, OECD and Global 1.5°C pathways and EU objective of 50-55% reduction by 2030 leading climate neutrality by 2050



Note: EU emissions (incl. LULUCF) is based on EEA for 1990-2010[407], and ADVANCE for 2020-2050 (same pathway as EU ADVANCE Median pathway Figure 99). Other regions are based on EDGAR + Global Carbon Project for 1990-2010, and IAMC 1.5°C Scenario Explorer median 1.5°C projections with no or limited overshoot for 2020-2050. Data is shown in 10-year steps with straight line in between. Series are harmonised by applying uniform scaling factor based on 2010 data.

In the projections by the ADVANCE project, with cost-efficient global scenarios, achieving climate neutrality by 2050 is not a pre-requisite for the EU, nor for OECD countries or the world in general, with projections requiring net negative emissions later in the second half of the century. Also SR1.5 concludes that global climate neutrality is achieved before around 2070 and negative emissions thereafter to achieve 1.5°C by the end of the century[408].

The EU objective of climate neutrality by 2050, defined as achieving net zero GHG emissions by 2050, combined with the 50-55% milestone in 2030, gives a strong signal that the EU is assuming its leading role on climate action in line with these scientific projections.

The EU has been reducing emissions since 40 years, with our emissions having peaked just before 1980. According to the EDGAR database, the EU share of global emissions (excluding LULUCF) has continued to fall from 15.7% in 1990 to 8% in 2015. This reduction has occurred in large part due to reductions in the energy intensity of the economy and carbon intensity of the EU energy supply, outweighing the effects of growth in GDP and population. Today the EU is one of the most efficient, if not the most efficient, major economy in term of GHG emitted by unit of production.

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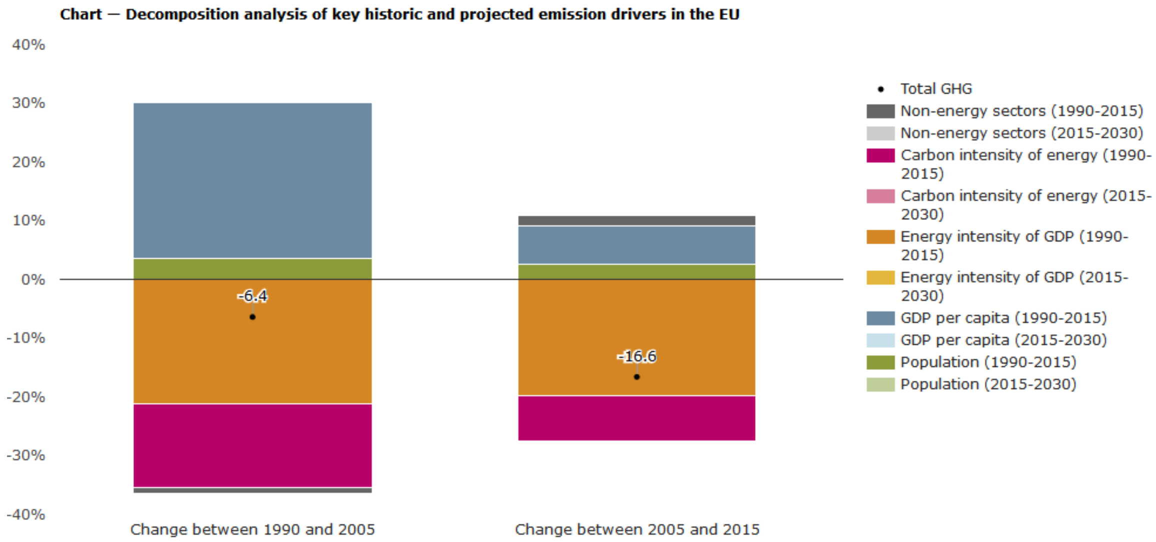
[407] https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer

[408] See Table 2.4 of the IPCC Special Report on Global Warming of 1.5°C, Chapter 2

Figure 101: Decomposition of historic and projected drivers in EU emissions (EU28)



Note: emissions refer to EU28

Source: European Environment Agency (2018)[409]

Looking beyond a least-cost approaches, SR1.5 notes that different principles and methodologies generate different calculated contributions, responsibilities and capacities[410]. Höhne et al. (2018)[411] distinguish for instance between approaches based on *technical necessity* (including cost optimisation and use of indicators such as emissions per capita, or per unit of GDP), and approaches based on *moral obligation* (such as measures that takes countries' income levels or historical emissions into account). Furthermore, questions of moral obligation related to climate change are broader than the setting of emissions reductions targets, encompassing efforts to raise ambition in other countries, as well as provision of climate finance and other assistance[412]. Estimates of EU effort for 2030 in a 1.5°C scenario included Robiou du Pont et al. (2017)[413], that look at a number of different metrics to divide efforts, give a central value of 68% below 1990 levels, with extremes of -43% to -87%, excluding LULUCF[414]. However, the study does not attempt to model EU or global transition pathways that would lead to these reductions, and clarifies that they could in principle be met by a combination of domestic mitigation, international emissions trading and support to 3rd country emissions reductions. Therefore such studies do not really look into what emission reductions the EU should and can achieve domestically but apply a set of possible equity principles without any connection to real possible emission pathways. Similarly, the website Climate Action Tracker synthesises results from a

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409 https://www.eea.europa.eu/data-and-maps/daviz/decomposition-analysis-of-key-historic

410 See Section 5.5.3.2 of IPCC Special Report on Global Warming of 1.5°C (2018)

411 Höhne et al. (2018). Assessing the ambition of post-2020 climate targets: a comprehensive framework, *Climate Policy*, 18:4, 425-441, DOI: 10.1080/14693062.2017.1294046

412 See Council Conclusions on Climate Diplomacy, 20 January 2020

413 Robiou du Pont et al. (2017). Equitable mitigation to achieve the Paris Agreement goals. *Nature Climate Change* volume 7, pages38–43. DOI: 10.1038/nclimate3186

414 From Table 2 of Robiou du Pont et al. adjusted for 1990 baseline (EU28). The land sector globally is omitted from the study's effort share calculations.

range of effort sharing studies and calculates 2030 1.5°C reductions ranging from 45% below 1990 to over 120% below 1990 levels[415].

[415] https://climateactiontracker.org/ Fair Share data download from EU page, adjusted for 1990 baseline (EU28). The land sector globally is omitted from the Climate Action Tracker calculations.

9.11 EU policies as an enabler

This section elaborates on enabling policies that would facilitate achieving higher GHG, EE and RES ambition, with a focus on policies being developed in the context of:

9.11.1 Green recovery from the COVID-19 crisis

Though the COVID-19 crisis in itself has clearly resulted in a downward pressure on GHG emissions, it does not change the fact that to achieve climate neutrality changes will be needed. The building renovation rate will need to be increase significantly, the vehicle stock will need to be replaced with low and zero emitting technologies, our energy system will need to be converted more and more to a renewables based one and our industries will need to invest in new production capacity with modern climate neutral, efficient and increasingly circular technology solutions.

The economic fallout from the COVID crisis will likely make it more challenging for private agents to mobilise the necessary levels of investment in the energy system as many agents may face weaker balance sheets and capital positions as well as higher levels of indebtedness. As assessed in section 6.4.1.3 on energy system investments, the transition to a climate neutral economy will require significant additional investments, with an estimated total investment requirement in the energy system (excluding transport) of around EUR 400 billion (2015 EUR) per annum in the next decade.

Delivering on that investment challenge, in the current economic context of increased uncertainty will thus make it all the more important that recovery plans focus have a very strong focus on green investment. This will not only deliver the much needed short term investment stimulus, it would also support long term sustainable growth (see section 6.4.2 on macro-economic impacts).

The Economic Recovery plan adopted on 27 May 2020 and adopted by the European Council in July 2020, which the Commission headlined *"Europe's moment: repair and prepare for the next generation"*, aims to stimulate economic recovery across the EU to respond to the current crisis. The Recovery plan underlines the importance of a green, digital and resilient recovery, and is based on two key elements: firstly, an emergency Next Generation EU (NGEU) instrument of EUR 750 billion[416] to temporarily boost the financial firepower of the EU budget with funds raised on the financial markets. Secondly, a reinforced multiannual financial framework (MFF) for 2021-2027 with a size of EUR 1 074.3 billion.

These two sets of stimulus mean a total of EUR 1.8 trillion of targeted and front-loaded support to Europe's recovery. In addition, there are measures worth EUR 540 billion, already endorsed by the April European Council on important safety nets for workers, businesses and sovereigns.

The plan confirms energy policy, and specifically clean green energy as a cornerstone of the recovery. While the financing instruments for the recovery are largely horizontal, energy investments within the framework of key upcoming energy initiatives can be supported by various sources. For the recovery fund, like the general budget, 30% would be earmarked for

[416] All figures of the NGEU and MFF are expressed in 2018 constant prices unless otherwise indicated.

delivering the climate goals of the Green Deal. The European Council specifically agreed that 2021-2027 MFF and NGEU instruments have to comply with the objective of EU climate neutrality by 2050 and contribute to achieving the Union's new 2030 climate targets. All EU expenditure will have to respect the green oath to ‘do no harm’. A large part of the (EUR 750bn) Next Generation EU instrument will be spent through a new Recovery and Resilience Facility (RRF) (EUR 672.5 billion) aimed at allowing Member States to support investments and reforms, including investments linked to green transition based on the Member States’ Recovery and Resilience Plans outlining their priorities. The RRF will provide grant (EUR 312.5 billion) and loan support (EUR 360 billion) for the Member States to carry out needed reforms in line with the European Semester recommendations, the National Energy and Climate Plans and the Just Transition Plans, making sure that green transition is at the heart of the reforms. In addition to the close alignment with the European Semester and the country specific recommendations, the draft Regulation on the RRF includes interactions with the National Reform Programmes, the National Energy and Climate Plans, the Just Transition Plans and the partnership agreements and operational programmes adopted under the Union funds.

The other key parts of the plan are:

- Increase the **Just Transition Fund** (the 1st pillar of **Just Transition Mechanism)** from EUR 7.5 billion to EUR17.5 billion to facilitate transition in coal and carbon-intensive regions where transition will present the biggest challenge. The revamped Just Transition Fund should support and incentivise transition choices in coal and carbon-intensive regions.

- A proposal for the 3rd pillar of **Just Transition Mechanism** - a **loan facility for public authorities** in just transition regions to help investments in areas such as clean heating, buildings renovation and clean mobility.

- The **REACT-EU** initiative includes EUR 47.5 billion of additional funds that will be made available mainly to the cohesion policy through the European Regional Development Fund (ERDF) and the European Social Fund (ESF) – until end of 2023.

- The **InvestEU** scheme (EUR 8.4 billion budget provision). It will also include a new **Strategic Investment Facility** (EUR 15 billion provision) will be the key EU instrument to crowd in private capital to support investments in policy areas essential for achieving the European Green Deal objectives: including renewable energy, energy efficiency, decarbonised energy infrastructure or research and innovation in green technologies. All projects above a certain size financed by InvestEU will be subject to **sustainability proofing**, to ensure they are in line with the Green Deal.

- A Technical Support Instrument to ensure that Member States will benefit from tailor-made expertise for developing and implementing sustainable and growth enhancing reforms. Under this instrument, Member States would be able to receive support for scaling up and improving the quality of green investments, including in the context of the National Recovery and Resilience Plans.

The EU recovery plan follows the calls from other quarters who point to the need and opportunity of implementing green recovery plans. The IEA recently released a Sustainable Recovery Plan[417] for actions that can be taken over the next three years to boosting economic growth, creating jobs and building more resilient and cleaner energy systems. The IEA plan identified six key sectors – electricity, transport, industry, buildings, fuels and emerging low carbon technologies. The analysis carried out estimates that implementing the plan would lead to a peak in global emissions, putting the world on a path towards achieving the Paris Agreement goals while leaving global GDP in 2023 3.5% higher than it would have been otherwise. Implementing the plan would require investing approximately 0.7% of global GDP.

To achieve the desired effect, recovery plans should focus on the immediate future. Funds swiftly allocated to projects would allow kick starting the energy and climate transition. For an industrialised economy such as the European Union, it will have to be assessed whether and which forms of conditionality for public support to existing businesses could contribute to the achievement of climate priorities.

The recovery packages adopted by Member States and at the EU level will determine not only the speed at which our economies will recover, but also the structure of our economies for decades to come. The European Parliament and a significant number of Member States have stressed the essential need to ensure that recovery packages are structured so as to achieve the twin objective of generating a rapid pick-up in economic activity and setting our economies firmly and definitively on an environmentally and socially sustainable path in the long term, including through the transition to a climate neutral economy by 2050. These two objectives are complementary rather than exclusive. In particular, it will be crucial to ensure that public support for investment focus on assets that promote the climate, energy and digital transition, ensure the long-term competitiveness of EU enterprises and their role in the clean technologies and products of the future, and create sustainable jobs (e.g. in buildings renovation, electric vehicles or renewables electricity equipment and infrastructure). The enabling environment will also play a critical role in facilitating and channelling private investment in the necessary areas identified above. The recently adopted Regulation 2020/852 on the establishment of a framework to facilitate sustainable investment (hereinafter, 'Taxonomy Regulation') aims to incentivise private sector investment in environmentally sustainable economic activities in general, and as such, will be crucial for guiding investments into the green recovery. The European Investment Bank is among the front runner financial institutions, which through their internal energy lending policy (revised in late 2019)[418] has set out a pathway for channelling financing to decarbonised solutions. The future revision of the Commission's guidelines on State aid for environmental protection and energy will also provide a strengthened framework to support the necessary investment in the energy system, fully aligned with the objective of climate neutrality by 2050.

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[417] Sustainable Recovery, IEA 2020, https://www.iea.org/reports/sustainable-recovery

[418] As per its new lending policy, the European Investment Bank will end financing for fossil fuel energy projects from the end of 2021; unlock EUR 1 trillion of climate action and environmental sustainable investment in the decade to 2030 (including to accelerate clean energy innovation, energy efficiency and renewables); and align all financing activities with the goals of the Paris Agreement from the end of 2020.

9.11.2 *Energy financing and climate mainstreaming of the next MFF*

The EU 2021-2027 budget was designed with a horizontal 25%[419] climate-mainstreaming target across all EU programmes. The Council's agreement on the Recovery plan increased the overall climate mainstreaming ambition up to 30%. The "global" climate mainstreaming objective is translated into programme-specific targets.[420] A large number of those programmes support energy either as an explicit objective or under broader sets of priorities:

- 60% of the Connecting Europe Facility[421] funds will contribute directly to the climate target, with EUR 5.18 billion proposed for energy infrastructure investments.
- 30% of funds under the European Regional Development Fund (EUR 196.9 billion) and 37% of the Cohesion Fund (EUR 42.5 billion)[422] support climate objectives, funding investments in for instance clean and fair energy transition (through the policy objective of a greener, low-carbon Europe), including measures to promote energy efficiency, renewable energy and the smartening of grids.
- Horizon Europe[423], the new research and innovation framework programme, with an overall proposed budget of EUR 80.9 billion and a dedicated Climate, Energy and Mobility cluster, will see 35% of its funds supporting the achievement of the climate goals.
- The LIFE Programme[424] (EUR 4.8 billion) has an ambitious 61% climate mainstreaming target: under LIFE, the Clean Energy Transition sub-programme (about EUR 1 billion) will create enabling framework for energy efficiency and renewables implementation building the capacity of private and public actors to create the right market & regulatory conditions and to mobilise investments in clean energy.
- The InvestEU Programme (with EUR 8.4 billion reserved under the EU budget for the provisioning of the budgetary guarantee is expected to contribute 30% of the overall financial envelope to climate objectives. This includes a 60% combined climate and environmental mainstreaming under the Sustainable Infrastructure Window that will support a large number of energy related investments (infrastructure, energy efficiency, including in buildings, renewable energy).
- The Just Transition Fund (EUR 17.5 billion) with a focus on the transition process towards a climate-neutral economy of the Union by 2050 is also linked to the National Energy and Climate Plans and the energy transition. The whole of the budget of the Just Transition Fund is focussed on climate action.

Outside the EU budget, albeit not explicitly included in the climate mainstreaming target, the Modernisation Fund and the Innovation Fund (c.a. EUR 14 and EUR 10 billion respectively) will help support investments in areas crucial for decarbonisation and reducing GHG emissions. Proposed areas of action include: modernisation of energy networks, renewable energy, energy storage, energy efficiency, just transition in carbon intensive regions, innovative low carbon technologies in renewable energy generation and energy intensive industries or CCUS.

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[419] Raised from 20% in the 2014-2020 MFF
[420] The mainstreaming targets as per 2018 MFF proposal. The increased climate mainstreaming target of 30% will need to be appropriately translated into relevant sectoral legislation and to be agreed upon by co-legislators.
[421] https://ec.europa.eu/inea/en/connecting-europe-facility
[422] Total values proposed for both programmes respectively as per May 2020 MFF proposal
[423] https://ec.europa.eu/info/horizon-europe-next-research-and-innovation-framework-programme_en
[424] https://ec.europa.eu/easme/en/life

9.11.3 Sustainable finance

The European Commission's sustainable finance initiative, set out in the 2018 Action Plan on Financing sustainable growth and the associated legislative and non-legislative elements brings finance closer to the needs of the real economy for the benefit of the planet and society. It puts finance at the service of decarbonisation, environmental and social objectives, therefore it is closely tied to European climate, energy and environmental policies. The initiative responds to the reality that the overwhelming proportion of capital to cover investment needs will come from private sources. Sustainable finance policy seeks to transform the financial sector by reorienting capital to sustainable investments, managing financial risks stemming from climate change and environmental degradation and fostering transparency and long-term outlook for financial and economic activity thus supporting companies in their transition towards more sustainable business models.

The sustainable finance initiatives aims at creating a clear and predictable policy framework for financial market participants and non-financial undertakings to guide their investment decisions towards more sustainable solutions. Its elements are designed with a level of flexibility that allows for re-adjustments in their features as technological development and legislative changes concerning the climate and environmental targets make it necessary. This can be observed in the main building block of sustainable finance, the EU Taxonomy. Integrating the 2030 climate and energy targets and the 2050 vision of a climate neutrality, the Taxonomy will be an important enabler to scale up sustainable investment and to implement the European Green Deal. The EU Taxonomy is a harmonised, uniform classification system of environmentally and socially sustainable economic activities. It sets a framework and principles for assessing economic activities against six environmental objectives and defines technical screening criteria that determines whether an economic activity could be considered environmentally sustainable. It is used as a reference point across a number of other elements of the 2018 Sustainable Finance Action Plan as well as in the European Green Deal Investment Plan.

9.11.4 Just transition, skills development and protecting vulnerable citizens

The analysis presented in sections 6.4 and 6.5 shows that the impact of the climate targets will be overall small but uneven. The impact on growth, for example, is estimated to be small compared to both unpredictable economic shocks (such as the COVID-19 pandemic) and long-term macroeconomic trends (such as demographic changes). However, the results presented in section 6.5 show that the costs of the transition might put an unfair share of the burden on low-income citizens. Similarly, macroeconomic analysis consistently shows that the impact of climate policies – including the targets analysed in this impact assessment – on employment is small. However, the results presented in section 6.4.2 shows that the impact on some sector (e.g., mining) will be large and disruptive.

The unwanted effects of energy and climate policies tend to be highly localised. The analysis supporting long-term decarbonisation strategy showed that only two EU regions have employment shares of more than 1% in sectors that are expected to decline. However, the closure of a coal-mine can lead to the loss of thousands of direct and indirect jobs in a mining region.

When considering the industries that will have to transform (manufacture of chemicals and chemical products, manufacture of other non-metallic mineral products, manufacture of basic metals, manufacture of motor vehicles, trailers and semi-trailers, it becomes apparent that many more regions will be affected. Out of the EU's 28 Member States[425], 24 have regions where more than 1% of the work force is employed in such a sector, with higher shares in Member States with lower GDP per capita levels. The regions with the highest exposure are Strední Cechy in the Czech Republic (10.4%), Közép-Dunántúl in Hungary (9.7%), and Vest in Romania (9.3%)[426].

To mitigate the uneven effects of the energy transition, policy intervention is necessary at all levels of governance: from the local and regional levels to the national and European levels. In this context, local and regional policies have a direct role to play in enabling the climate and energy transition.

For instance, the experience of already completed transitions away from coal in some European countries shows the importance of designing and implementing a planned process, supported by measures aimed at alleviating socioeconomic consequences while promoting the development of new, future-oriented economic activities at national, regional and local levels. This is why since 2017 the European Commission has launched the Initiative for Coal Regions in Transition,[427] with the objective of supporting EU coal regions and their local communities in their efforts to decarbonise their energy production and diversify their local economy. Specifically, it supports coal regions (including peat and oil shale) across the EU in achieving a just transition through tailored, needs-oriented assistance and capacity-building[428]. In the context of EU Green Deal the Just Transition Mechanism is most recent concrete example of how EU-level policy measure can facilitate targeted actions decided at the local level as it builds on and expands the work of the existing Initiative for Coal Regions in Transition, also including carbon- intensive regions.

The Commissions has proposed in May 2020 a revised ambitious Just Transition Mechanism resting on three pillars:

1. Upon developing a territorial just transition plan, Member States can access the Just Transition Fund to support a socio-economic transition in regions at NUTS-3 level highly dependent on extractive, carbon- and energy-intensive industries, notably coal, lignite, peat, oil shale and carbon intensive industries.

2. A dedicated InvestEU just transition scheme, implemented through InvestEU financial products, will support economically viable investments by private and public sector entities, providing complementarity and synergies with the Just Transition Fund. Being part of InvestEU, the final use of InvestEU will remain demand-driven and will depend on the project pipeline.

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[425] Before the withdrawal of the United Kingdom from the European Union.
[426] A Clean Planet for all A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy.
[427] https://ec.europa.eu/energy/topics/oil-gas-and-coal/EU-coal-regions/initiative-for-coal-regions-in-transition_en
[428] Following report is a good example of such support: Kapetaki, Z., Ruiz, P. et al., Clean energy technologies in coal regions: Opportunities for jobs and growth: Deployment potential and impacts, Kapetaki, Z. (editor), EUR 29895 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-12330-9, doi:10.2760/063496, JRC117938.

3. The public sector loan facility will encourage investments that support the transition towards a climate-neutral economy by public sector authorities to the benefit of coal- and carbon-intensive regions. The facility will be implemented with the involvement of the European Investment Bank.

It aims to mobilise up to EUR 150 billion of investments to alleviate the socio-economic impacts of the climate transition and build growth along with locally decided economic diversification strategies.

The transition to a low-carbon economy and decarbonisation will translate into new constraints on the labour market and shifts to new clean and energy-saving production processes. These will require active education and training policies and investment to meet the emerging skills needs (professional and transversal) of both emerging and existing occupations and industries[429]. The New Skills Agenda for Europe[430], adopted by the Commission on 10 June 2016, launched 10 actions to make the right training, skills and support available to people in the EU. The updated Skills Agenda for Europe, adopted by the Commission on 1 July 2020 together with a Youth Employment Support (YES) package, consists of 12 actions to boost skills for jobs, including to support strategic national upskilling action, support the green and digital transitions, and improve the enabling framework to unlock Member States' and private investments in skills.

The transition may also increase the risk of energy poverty if vulnerable households do not manage to invest in the required low carbon technologies, while being confronted with increasing prices for carbon intensive fuels for instance due to carbon pricing or revisions of energy taxation. Policies targeting energy poverty by investing in energy efficiency measures for the social vulnerable groups can alleviate the households’ energy costs while achieving important energy savings. Lump sum transfers have already been mentioned in section 6.5 as a way to mitigate the regressive impact of higher energy prices. Combinations of measures may be suited best, e.g. targeted energy efficiency measures, for example in the form of energy efficiency obligation schemes or subsidies to low-income households, job retraining programmes and funding low carbon technologies via general taxation or carbon revenues (instead than with a surcharge on electricity consumption). The upcoming Recommendation on Energy Poverty will help Member States to better identify the number of households in energy poverty and design adequate mitigating measures that support energy poor households in ways that take into consideration the building types, geographical specificities of regions and complementary financial support available to such households. The Recommendation shall underline the need to promote actions at local level (i.e. authorities and social housing associations) and to allow stakeholders to familiarise themselves with most recently identified best practices.

Other examples of EU policies with direct bearing on the just transition include the ongoing revision of the Energy Taxation Directive. Energy taxation has a direct impact on the cost of energy for European consumers. Aligning taxation of energy products with EU energy and climate policies could contribute to the climate targets, but also affect the way the burden of the

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[429] See forthcoming Employment and Social Developments in Europe 2020 report.
[430] COM(2016) 381 final, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52016DC0381&from=EN

transition is shared. The revision of the Guidelines on State aid for environmental protection and energy (foreseen for 2021) will affect how national resources are spent in the energy sector. The State aid instruments set the compatibility criteria for State aid measures for environmental protection and energy (for example for support to the production of renewable energy, to energy efficiency or to carbon capture and storage). Those rules ensure that support targets an objective of common interest in the environmental and energy field while ensuring at the same time that the support is limited to the minimum necessary to achieve the objective of common interest. A close alignment between State aid rules and the European Green Deal priorities will allow setting the right incentives for the use of national resources in a cost-effective manner.

9.11.5 Behavioural changes and their impact on energy and emission profiles

Behavioural changes may influence the future trajectory of emissions and energy use alike. A sector where this has long been recognised is transport. Recently, more walking, cycling and public transport have become more popular. Likewise, the sharing of vehicles seems to become more attractive to younger people compared to vehicle ownership, particularly in urban areas. Such trends, if they are economy-wide, increase the circularity of the transport sector and may decrease energy and material consumption and, hence, emissions. Air transport, on the other hand, has seen continuous increase in the demand for long distance air. With increasing material welfare, this trend is projected to continue, leading to increased emissions and energy consumption[431].

Transport is not the only sector in which consumption patterns influence greenhouse gas emissions. Other important behavioural changes which can have a sizeable role include:[432]

- More sustainable, low-emission dietary choices. Food products differ a lot with regards to the GHG emission and energy consumption during their production and transport. Examples for a GHG-intensive dietary choice are the consumption of red meat that is often resource and energy intensive, and contributes directly to methane emissions, but also fruits and vegetables that have to be transported over long distances, or cooled for non-seasonal consumption. The Farm to Fork Strategy will propose actions that will help consumers in following their preference for sustainably-produced food. Amongst others, the Farm to Fork strategy is to propose minimum mandatory criteria for sustainable food procurement, a proposal to empower consumers through a sustainable food labelling framework, and to further include sustainability aspects into European food promotion programs.
- House and living preferences. The size of a residence influences its energy consumption, but other elements, such as the temperature that is perceived as comfortable, also play a role. Consequently, emissions from buildings will also be influenced by the life-style choices of their inhabitants. Where one choses to live may have an impact on emissions from commuting and other trips.

[431] https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf

[432] The responses received in the public consultation displayed the following options selected the most: Travelling less by plane (18%), reduced car-use in favour of walking, cycling and the use of public transport (17%), avoiding overconsumption (16%), and changing dietary habits towards more healthy and less carbon intensive ones (16%). This is driven by the responses of individuals, professionals also see recycling and reducing of waste as a possible change.

- Uptake of new technologies, notably communication technologies. While this may increase energy consumption (e.g. higher consumption of data centres), digitalization may also deliver significant energy and emissions savings. Teleworking and better energy demand management are two examples that potentially can have such effect.[433]
- Consumer preferences need the right regulatory environment to drive the change that consumers desire. This is particularly true in the demand for energy-intensive goods – such as those made from steel or from non-ferrous metals. The Circular Economy Action Plan sets out to support consumers in making the choices they want in creating lead markets for energy-intensive products such as steel or cement. Actions announced under this plan include sustainable product policy as a key theme for, among others, legislative action on empowering consumers for active participation in the green transition[434].

The COVID-19 crisis has displayed in dramatic fashion the short-term impact of changing consumption patterns – most notably with an impressive drop in transport activity. Transport activity is resuming as societies emerge from lockdown. However, the pandemic may impact consumers' behaviour in the long-term. The impact on energy demand and emission could be both positive (if less daily trips are made or more sustainable transport modes are chosen) or negative (e.g. more private vehicle use to avoid public transportation).

9.11.6 Circular economy and its impacts on climate change mitigation

As outlined in the Commission's Long Term Strategic Vision on GHG Emissions Reduction scenarios[435], to become climate neutral by 2050 and achieve net GHG removals thereafter, the EU will have to rely on a variety of mitigation strategies. A circular economy coupled with more climate-, environment-friendly and healthier consumer choices are a key such strategy. A reduction of materials input through prevention, re-use and recycling will improve competitiveness, create business opportunities and jobs, and require less energy, in turn reducing pollution and greenhouse gas emissions. A more circular and shared economy will also contribute positively to alleviating expected growing competition for access to strategic minerals and raw materials[436] that will be increasingly required in the ecological and digital transition.

The EU Circular Economy Action Plan will support the objective of substantial greenhouse gas emissions reductions by 2030 and climate neutrality by 2050, by addressing circularity in key economic sectors. Implementation of a highly circular economy will also benefit a green recovery, providing resilience and autonomy of key product value chains as well as job creation

[433] Studies suggest, though, that teleworking can have significant rebound effects: "A systematic review of the energy and climate impacts of teleworking" (2020, Andrew Hook et al.)"

[434] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12467-Empowering-the-consumer-for-the-green-transition

[435] The eighth scenario builds upon the previous scenario but assesses the impact of a highly circular economy and the potential beneficial role of a change in consumer choices that are less carbon intensive. It also explores how to strengthen the land use sink, to see by how much this reduces the need for negative emissions technologies.

[436] See COM(2020) 474 final on "Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability"

and increased GDP. In the context of moving towards a more resource-efficient economy, the Commission will also present an initiative on sustainable corporate governance[437]

Science and policy-makers nowadays acknowledge the relevance of resource efficiency and the circular economy for climate action. Increased circularity, in this view, can be an effective tool in the mitigation of greenhouse gas emissions. This recognition is, however, relatively new. For example, the first Circular Economy Action Plan of 2015[438] mentioned the synergies with climate policy, but without a strong emphasis or data.

A seminal report by Material Economics and Sitra, in 2018, entitled *The circular economy – A powerful force for climate mitigation*[439] was one of the first attempts to quantitatively measure the potential impacts of the circular economy for GHG emissions reductions. The study focusses on energy intensive sectors such steel, cement, plastics, aluminium, passenger cars and buildings. The study concluded that "*in an ambitious scenario, as much as 296 million tonnes* CO_2 *per year in the EU by 2050, out of 530 in total – and some 3.6 billion tonnes per year globally. Demand-side measures thus can take us more than halfway to net-zero emissions from EU industry, and hold as much promise as those on the supply side*". The analysis included circular practices like more materials circulation (i.e. reuse and recycling), product materials efficiency and more circular business models for mobility and buildings (e.g. sharing). The combined effect of such approaches would lead to 56% emissions reduction in these sectors. The report, however, recognised that there were still many methodological uncertainties and that more research was needed. Whether all of the potential GHG emissions reductions can be obtained in practice is also an open question for research.

The Commission's Long Term Strategy on GHG Emissions Reduction, Communication and in-depth analysis *A Clean Planet for All*, included circular economy actions in one of the two scenarios achieving climate neutrality by 2050[440]. It found that circular economy and lifestyle changes combined prove a cost-effective mitigation strategy which required a total level of annual investment around 5% and 8% lower, respectively, than that of the other pathways with a similar level of ambition. Even though the in-depth analysis recognised methodological limitations, the assumptions were considered very prudent and "no-regret options".

Moreover, the Commission's plastics strategy of 2018 estimated that the production and incineration of plastics produce globally every year 400 $MtCO_2$-eq emissions. If it were possible to avoid that emissions from plastics reach the atmosphere, the equivalent to 3.5 billion of oil barrels per year would be saved. Recycling a million of tonnes of plastics is equivalent to the emissions of one million cars[441].

Already in 2017, the UN's International Resources Panel (IRP) estimated that, by 2050, resource efficiency policies could reduce global extractions by 28%. Combined with an ambitious climate action, such policies can reduce greenhouse gas emissions around 63%, and increase economic

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[437] Public consultation is open until October 2020: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12548-Sustainable-corporate-governance

[438] Communication "Closing the loop - An EU action plan for the Circular Economy", COM(2015)614 final.

[439] Material Economics and SITRA (2018) *The circular economy – A powerful force for climate mitigation.* Stockholm, Material Economics Sverige AB. In: https://media.sitra.fi/2018/06/12132041/the-circular-economy-a-powerful-force-for-climate-mitigation.pdf

[440] 1.5LIFE, including a more circular economy, changing consumer preferences and a high incentive to enhance the LULUCF sink.

[441] Communication "A European Strategy for Plastics in a Circular Economy" COM(2018) 28 final.

growth by 1.5%[442]. This initial analysis was further refined, upon demand of the G7, with the report 2020 *Resource Efficiency and Climate Change: Material Efficiency Strategies for a Low-Carbon Future*[443]. The report assesses the reduction potential of GHG emissions from material efficiency strategies applied in residential buildings and light duty vehicles. Emissions from the production of materials as a share of global GHGs increased from 15% in 1995 to 23% in 2015. This corresponds to the share of GHG emissions from agriculture, forestry, and land use change combined, yet they have received much less attention than other sectors. An estimated 80% of emissions from material production were associated with material use in construction and manufactured goods. It is expected that 70% of the global population will live in cities in 2050, and 50% of this urban environment is not yet built[444]. Consequently, cement and steel production and their associated GHG emissions will have a large potential for mitigation with upgraded construction materials and techniques.

GHG emissions from the material cycle of residential buildings in the G7 and China could be reduced substantially by 2050 through: resource efficiency approaches include more intensive use of homes (up to 70% reduction in 2050 in the G7), designing buildings which use less material (8– 10% in 2050 in the G7), and sustainably harvested timber (1–8% in 2050 in the G7). However, it has to be recognised that the higher end of the plausible mitigation potential would come from substantial lifestyle changes, for instance in housing, that might be seen by some as a loss of comfort. On the other hand, consumers increasingly demand more sustainable lifestyle options but are hampered in obtaining them in practice[445]. Improved recycling of construction material could reduce GHGs by 14-18% in 2050 in the G7. Overall, using these strategies in the G7 could result in cumulative savings in the period 2016-2050 amounting to 5–7 GtCO_2-eq. Regarding transport, modelling by the International Resources Panel shows that GHG emissions from the material cycle of passenger cars in 2050, considering their production, use and disposal, could be reduced by up to 70% in G7 countries through ride-sharing, car-sharing, and a shift towards trip-appropriate smaller cars, among others.

Additional evidence comes from the European Commission’s Joint Research Centre (JRC). The JRC has quantified the climate impacts of the circular economy through the life cycle assessment-based JRC’s consumption and consumer footprints[446]. The latter has the advantage of

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[442] UNEP (2017) *Resource Efficiency: Potential and Economic Implications*. Nairobi: UN Environment. In: http://www.resourcepanel.org/reports/resource-efficiency

[443] IRP (2020) *Resource Efficiency and Climate Change: Material Efficiency Strategies for a Low-Carbon Future*. Hertwich, E., Lifset, R., Pauliuk, S., Heeren, N. A report of the International Resource Panel. Nairobi: United Nations Environment Programme.

[444] https://www.un.org/en/ecosoc/integration/pdf/fact_sheet.pdf

[445] https://www.beuc.eu/publications/most-eu-consumers-open-eat-more-sustainably-face-hurdles-new-survey-shows/html

[446] Sala S., Beylot A., Corrado S., Crenna E., Sanyé-Mengual E, Secchi M. (2019) *Indicators and Assessment of the environmental impact of EU consumption. Consumption and Consumer Footprint for assessing and monitoring EU policies with Life Cycle Assessment*. Luxembourg: Publications Office of the European Union.

The complete technical report: Sala S., Benini L., Beylot A., Castellani V., Cerutti A., Corrado S., Crenna E., Diaconu E., Sanyé-Mengual E, Secchi M., Sinkko T., Pant R. (2019) *Consumption and Consumer Footprint: methodology and results. Indicators and Assessment of the environmental impact of EU consumption.* Luxembourg: Publications Office of the European Union. For a scientific paper describing the methodology, see: Sala, S., & Castellani, V. (2019) “The consumer footprint: Monitoring sustainable development goal 12 with process-based life cycle assessment”. *Journal of Cleaner Production*, 240, 118050.

showing different environmental impacts including on climate change[447], thereby providing information on potential trade-offs to other environmental impacts. This is very relevant under the European Green Deal, which aims at tackling current environmental issues (climate change, biodiversity loss, pollution and resources depletion) in a systemic manner. Nonetheless, current models assess the benefits of specific circular economy scenarios rather than a comprehensive assessment of the full potential of circular economy-related intervention. A comprehensive scenario representing the whole circular economy quantifying the actual impact on decarbonisation is still under development.

The abundance of the different circular economy actions affecting multiple supply-chains makes it hard to grasp the cumulative effect of these actions on overall greenhouse gas mitigation. The current state of the literature does not yet allow a full quantification, though efforts are well underway[448]. A study commissioned by the EEA[449] concluded that circular actions in non-energy sectors "can make modest, yet valuable impacts on GHG abatement throughout sectors and throughout the different lifecycle stages of products in Europe". Such impacts are likely to increase overtime, from "around 80-150 $MtCO_2$-eq per year by 2030 in Europe, which equals to around 2 to 4% of the GHG baseline emissions by 2030 in the EU Reference Scenario. By 2050, the GHG abatement potential is estimated to rise to around 300-550 $MtCO_2$-eq per year in Europe, amounting to around 10-18% of the GHG baseline emissions by 2050 in the EU Reference Scenario". The study also confirms that there are not, to date, publications that give a comprehensive overview of all circular actions and points out the sectors with more potential: materials (plastics, cement, steel), food (including food waste, packaging and nutrient recycling), construction, waste management sector, and automotive (car sharing, durability, improved end of life). The study provides estimates of GHG emissions reductions for these sectors by 2050, mainly based on the Material Economics-SITRA study, as well as other sources for food waste and sustainable diets[450], the collaborative economy and waste management[451]. On the latest, the increased recycling targets that the European Parliament and Council adopted in May 2018 as a result of the Circular Economy Action Plan of 2015 are estimated to avoid 477 million tonnes of greenhouse gases emissions between 2015 and 2035[452].

At present, the different interventions therefore may imply emissions reductions as per the following examples, focused on circular economy strategies for reuse, waste prevention, use of recycled material and waste valorisation. In terms of climate impacts, the main areas of consumption are food, mobility, housing, household goods and appliances:

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[447] The 16 environmental impact categories of the Environmental Footprint method are covered: climate change, ozone depletion, human toxicity – cancer, human toxicity – non-cancer, particulate matter, ionizing radiation – human health, photochemical ozone formation – human health, acidification, eutrophication – terrestrial, eutrophication – freshwater, eutrophication – marine, ecotoxicity – freshwater, land use, water use, resource use – minerals and metals, resource use - fossil.

[448] https://de.ramboll.com/-/media/files/rm/rapporter/methodology-and-analysis-of-decarbonization-benefits-of-sectoral-circular-economy-actions-17032020-f.pdf?la=de

[449] Svatikova, K. et al. (2018) *Quantifying the benefits of circular economy actions on the decarbonisation of EU economy*. Study commissioned by the European Environment Agency, by Trinomics, Ricardo and TNO.

[450] Deloitte (2016) *Circular economy potential for climate change mitigation*; PBL (2011) *The protein puzzle: the consumption and production of meat, dairy and fish in the European Union*.

[451] CE Delft (2016) *The circular economy as a key instrument for reducing climate change*; Eunomia (2014) *impact assessment on Options Reviewing Targets in the Waste Framework Directive, Landfill Directive and Packaging and Packaging Waste Directive*; Final Report for the European Commission DG Environment.

[452] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52015SC0259

- The substitution of virgin steel produced with blast furnace by recycled steel with electric arc technology can reduce climate change impacts by almost 80% (low-alloyed steel). A steel scrap sector exists in Europe to support such change[453], though market constraints on the availability of steel scrap in a very high demand case exist. An increase in the recycled content of steel in vehicles for satisfying the mobility demand of EU citizens by 10% and avoiding the landfilling by increasing steel recycling at the end of life would have a limited effect on the climate change impact of the life cycle of vehicles (reduction of 0.3%). If current market constraints would be modified, however, and a recycled content up to 75% could be expected, climate change impacts could be reduced up to 3.5%.
- The re-use of **50%** furniture up would decrease the climate change impact of the consumption of this household product in the EU by more than **40%.** The implementation of combined food waste prevention measures could reduce up at least 10% of the climate change impact of the EU food system.
- An increased remanufacturing of household appliances enlarging their lifespan (between 10 and 20%) could decrease the climate change impacts of their life cycle between **3%** (e.g. washing machine) to **6.5%** (tumble dryer).
- The substitution of virgin PET by recycled PET in polyester textiles could reduce by at least **11%** the climate change impact of this material used in textile.
- The use of recycled PET in the packaging of bottled mineral water would reduce by **8%** the impact of this product.
- In the housing sectors, an increase by 20% of the recycled content of concrete materials and a raise in the current recycling rate from 47% to 90% would decrease by 2.2% the climate change impact of the infrastructure of buildings.
- An increased use of recycled material in concrete production between 20% and 50%, depending on national standards, can decrease climate change impacts between 1.4% and 3.5%[454].

The modelling of the climate and environmental impacts of the circular economy remains an area where more research is needed. All current methodologies and approaches have caveats and are not easily fit to integrate the traditional energy and climate models, notably the framework used by the Commission services. The numbers provided by the studies mentioned here are based on several assumptions and have to be considered as orders of magnitude. In any case, current research confirms the relevance of the circular economy to reach the EU climate ambition – together with other environmental and economic benefits.

9.11.7 R&D

Research and innovation (R&I) plays a crucial role of providing solutions in testing, demonstrating and providing solutions through individual technology development, system deployment or even social innovation. Solutions may materialise over different time horizons, ranging from the next ten years to well beyond 2050, in line with long investment cycles

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[453] BDSV (2020): "Results of the Fraunhofer Insitute's Umsicht Study on the Future of Steel Scrap. An Investigation for the BDSV", June 2020.

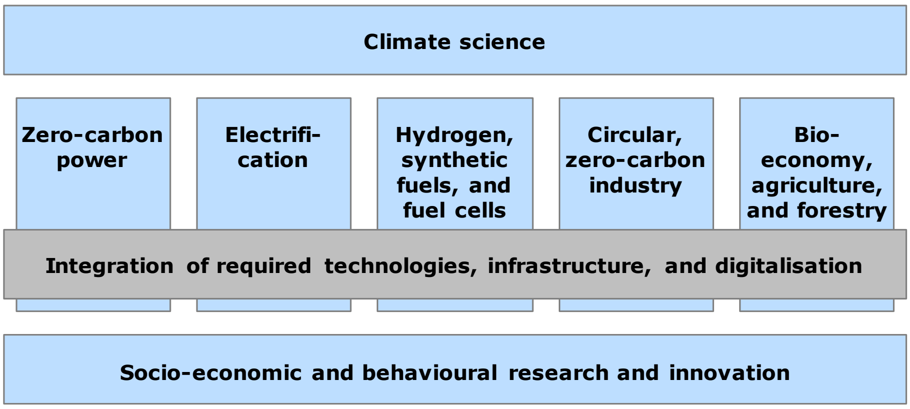
[454] Note here that the use of virgin or recycled materials for concrete production has no effect on the concrete production technology. Therefore, we are considering the difference between extracting virgin materials or using recycled ones (with the processes needed, e.g. fragmentation). In the case of steel, we observed higher climate change benefits as there was a technological change from blast furnace (virgin) to electric arc (recycled).

typically seen in capital-intensive sectors such as the energy and industry sectors. R&I can set direction and address trade-offs to ensure that long-term targets are met.

R&I will define the speed at which the decarbonisation can take place, at which costs and with which co-benefits. Reaching costs competitiveness requires a combination of deployment to scale and focussed technology improvements. Successful R&I would benefit the EU's private sector in building leadership in the upcoming global clean technologies markets and would yield the positive economic and social impacts that will underpin the necessary political support a climate transition requires[455].

The key to success in the long-term is to develop a wide portfolio of cost-effective and efficient carbon-free alternatives for each GHG-emitting activity, in combination with solutions for an integrated energy system, built on digitalisation and sector integration. In the near future, the rate at which the European R&I system succeeds in developing and commercialising such innovative solutions will steer the EU's future competitiveness of its existing and newly emerging industries. In order to secure the transition to GHG neutrality, technological development activities need to go along climate research and research on socio-economic systems.

Figure 102: Relevant research and innovation areas



As described in section 6.2.1, electrification will be key for the decarbonisation of the energy sector. Efforts are needed to further optimise mature renewable energy technologies (e.g. onshore wind, solar photovoltaics, and established bioenergy) accelerate the deployment of proved technologies (e.g. offshore wind) and to widen the portfolio of options, such as in the field of ocean energy (wave/tidal), alternative photovoltaic concepts (thin-film, concentrated PV), or concentrated solar power.

On the demand side, electrification offers great opportunities to contribute to the decarbonisation of the transport, heating and industry sectors, which largely still use fossil fuels. Bringing supply and demand side together will require enabling technologies and concepts. Batteries will become one of the key technological components of a low-carbon economy and a fast growing global value chain is emerging.

Hydrogen may provide an alternative fuel for transport, heating and industry where direct electrification might face challenges. In particular, hydrogen can help integrate renewable

[455] The High-Level Panel on Decarbonisation Pathways Initiative formulated a range of recommendations for future R&I research under Horizon Europe and other EU an Member State programmes: http://ec.europa.eu/transparency/regexpert/index.cfm?do=groupDetail.groupDetailDoc&id=36435&no=1

electricity in cases when generation by far exceeds the system load as is expected to be increasingly the case between 2030 and 2050. Innovation will be needed along the entire hydrogen supply chain to improve performance and reduce cost (e.g. for electrolysers and stationary and mobile fuel cell applications). The Commission's hydrogen strategy provides guidance to the actions needed for rolling out a European hydrogen economy. Both direct electrification as well as the production of hydrogen using electricity will increase the complexity of the energy system as supply and demand sectors will be interconnected in multiple ways. Technological innovation, taking stock of advances in digitalisation will be required for an integration of increasingly decentralised supply and demand sectors. Energy research also includes technologies, which will likely not be deployed before 2050 such as the International Thermonuclear Experimental Reactor (ITER) project, in which all major economies (EU, USA, China, Japan Russia, South Korea and India) explore the feasibility of nuclear fusion energy.

Industrial GHG related research addresses the reduction of emissions, energy needs and material fluxes, including synergies between these. Energy- and material-intensive industries can reduce their environmental footprint by converting most material fluxes into closed loops, in cases where this is decreasing the required amount of energy and raw materials. Carbon capture and storage is an option to reduce emissions of industries which have high process-related greenhouse gas emissions such as blast furnaces.

Research and innovation in the bioeconomy focusses on sustainable forestry and agricultural practices, in particular those that increase production while reducing non-CO_2 emissions and with the objective of enriching and conserving carbon in soils that can play a role as a potential source of negative emissions. Furthermore, there remains significant potential for alternatives for industrial production of fertilisers, bio-waste management, ruminant livestock management, and a reduction in burning of agricultural residues. Research addresses how to use the available land in the best way, as to increase the carbon uptake (carbon productivity), and to use the available biomass in the most resource efficient way without damaging biodiversity and environmental quality.

Socio-economic research includes the development and implementation of new business models, their financial and social attractiveness and the role of possible enablers such as trade, consumers' habits, digitalisation, big data, block-chain or artificial intelligence.

The EU shows both strengths and weaknesses in this race to new low carbon technologies markets. Europe is still a very active actor of the global research landscape, accounting for 30% of all scientific publications and one fifth of global research expenditure[456]. European enterprises are responsible for an important share of technological innovation and are responsible for almost two thirds of the EU's R&D investments[457]. However, the EU is progressively falling behind, spending comparatively less on research than other regions. The ratio of expenditures to GDP, also known as R&D intensity, remains at 2%, hence below the targeted 3% envisaged in the Europe 2020 Strategy[458] and well below levels in Japan (3.3% in 2015) and the USA (2.8% in

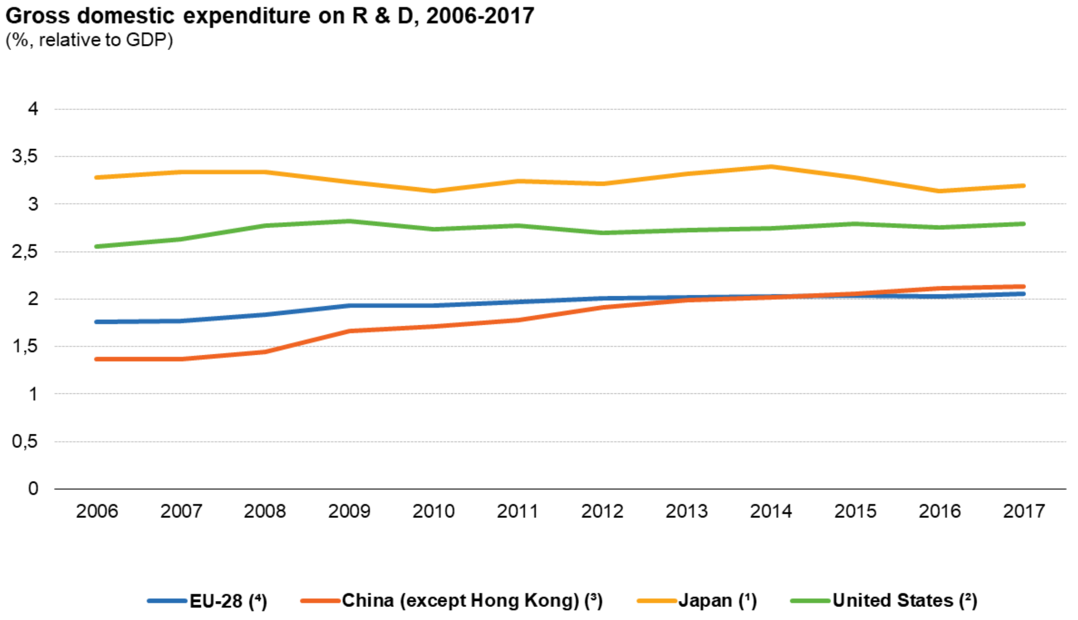
456 European Commission (2016), Open innovation, Open Science, Open to the World – a vision for Europe, https://ec.europa.eu/digital-single-market/en/news/open-innovation-open-science-open-world-vision-europe

457 European commission (2018), Smarter, greener, more inclusive? — Indicators to support the Europe 2020 strategy - 2018 edition,
http://ec.europa.eu/eurostat/web/products-statistical-books/-/KS-02-18-728

458 European Commission (2018), Europe 2020 strategy,

2017). China is also progressing and, with almost 2.1% in 2017, is now spending more on R&D per share of GDP than the EU.[459] This is due to lower private investment in research and innovation in Europe.

Figure 103: Gross domestic expenditure on R&D compared to GDP



Source: Eurostat[460]

In 2018, the EU spent 0.03% of GDP on energy-related research[461]. Patenting in clean energy technologies has been increasing over the last decade, with European companies targeting "high value" inventions with international protection, which displays a growing confidence of their competitiveness in the global energy technology market[462, 463] .

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https://ec.europa.eu/info/business-economy-euro/economic-and-fiscal-policy-coordination/eu-economic-governance-monitoring-prevention-correction/european-semester/framework/europe-2020-strategy_en

459 In the public consultation, the most selected options which areas of RI&D funding would be most important to achieve GHG emission reductions by 2030, keeping in mind 2050 targets were: Energy storage (12%), circular or zero-carbon industry (12%), and renewable energy (11%). Responses from professionals differed in this regard. While also mentioning the previous areas quite frequently, energy efficiency (10%), hydrogen and fuel cells (8%), and technology integration, infrastructure and digitalisation (7%) scored similarly for this group. Also business organisations such as the Verband der Industriellen Energie- und Kraftwirtschaft eV believe that more financial support for R&D is needed.

460 Eurostat (2018), Statistics explained, R&D expenditure, http://ec.europa.eu/eurostat/statistics-explained/index.php/R_%26_D_expenditure#Main_statistical_findings

461 European commission (2020), Indicators for monitoring progress towards Energy Union objectives, https://ec.europa.eu/energy/en/atico_countrysheets/scoreboard?dimension=Research%2C+innovation+and+competitiveness

462 JRC (2017), Monitoring R&I in Low-Carbon Energy Technologies, http://publications.jrc.ec.europa.eu/repository/handle/JRC105642

463 JRC SETIS, https://setis.ec.europa.eu/publications/setis-research-innovation-data ; JRC112127 Pasimeni, F.; Fiorini, A.; Georgakaki, A.; Marmier, A.; Jimenez Navarro, J. P.; Asensio Bermejo, J. M. (2018): SETIS Research & Innovation country dashboards. European Commission, Joint Research Centre (JRC) [Dataset] PID: http://data.europa.eu/89h/jrc-10115-10001

These general trends also reflect in the situation of EU companies, which are very active in the global clean energy market (sized at USD 1.4 trillion in 2016[464]). Indeed, in 2017 Europe was hosting 41 of the top 100 global energy companies, and the EU 6 of the 25 largest renewables companies[465]. European renewable energy businesses employed almost 1.5 million people (out of 10 million globally[466]). They are accelerating R&I investments with an increasing number of patents filed (+50% between 2010 and 2016[467]), clearly contributing to the global shift towards renewables developments (global patents in the field have doubled over 2010-2016). However, international competition is increasing, with Asian and North American companies getting an increasing weight in the market[468].

Over the years, the EU has put in place a number of instruments to deliver on research and innovation for the EU economy as a whole, and on clean energy and climate change mitigation activities in particular:

- The EU R&D programmes Horizon 2020[469] (by 2020), including the Green Deal Call which will be launched in September with a budget of EUR 1 billion to support R&I projects which address the major priorities of the European Green Deal, including: climate; clean, secure and affordable energy; clean and circular industry; energy and resource efficient buildings; sustainable and smart mobility; food systems and Farm to Fork; ecosystems and biodiversity; and zero-pollution.
- Horizon Europe[470] (2021-2027), which should benefit from a budget increase to EUR 94.4 billion, of which 35% is dedicated to climate action. Cluster 5 is on Climate, Energy and Mobility (EUR 13.706bn + 3.449bn extra proposed in the recovery plan).
- The four Green Deal Missions under Horizon Europe cover critical areas: (1). Healthy Oceans, Seas, Coastal and Inland Waters; (2). Climate-Neutral and Smart Cities; (3). Soil Health and Food; and (4). Adaptation to Climate Change, including Societal Transformation. These Missions aim to catalyse action and drive the Green Deal objectives by setting targeted, measurable and time-bound actions for systemic change.
- The Strategic Energy Technologies (SET) Plan[471] enhancing the coordination and synergies between the EU, Member State and industry has put in place 10 platforms promoting market uptake by technologies, or the European Energy Research Alliance[472] that brings together 175 research organisation across the EU.

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[464] Advanced Energy Economy (2017), 2017 Market Report, https://info.aee.net/aen-2017-market-report

[465] Thomson Reuters (2017), Top 100 Global Energy Leaders. https://www.thomsonreuters.com/en/products-services/energy/top-100.html

[466] IRENA (2018). Renewables and Jobs – Annual Review 2018, https://irena.org/-/media/Files/IRENA/Agency/Publication/2018/May/IRENA_RE_Jobs_Annual_Review_2018.pdf

[467] IRENA (2018), Database on patents evolution, http://resourceirena.irena.org/gateway/dashboard/

[468] Stash Investments, Top 10 Largest Clean Energy Companies by Revenue, https://learn.stashinvest.com/largest-clean-energy-companies-revenue

[469] https://ec.europa.eu/programmes/horizon2020/en/

[470] European commission (2018), Horizon Europe - the next research and innovation framework programme, https://ec.europa.eu/info/designing-next-research-and-innovation-framework-programme/what-shapes-next-framework-programme_en

[471] COM (2015) 6317 https://ec.europa.eu/energy/en/topics/technology-and-innovation/strategic-energy-technology-plan

[472] https://www.eera-set.eu/

- The SET Plan is complemented by the Knowledge Innovation Community scheme (KIC), which aims at spurring public-private partnerships on different societal challenges, including on energy[473].
- The Innovation Fund under the Emissions Trading System is an instrument to support the development of innovative low carbon technologies. It aims to create financial incentives to invest in the next generation of clean technologies that can enable the climate transition. The Innovation Fund also helps to boost the competitiveness of EU companies in this growing sector.
- R&I is a key dimension of the National Energy and Climate Plans (NECPs[474] [475]). The inclusion of specific and measurable R&I objectives in the NECPs will help integrating national strategies and priorities at EU level in a 2030-2050 perspective.
- Publication in Autumn of the first Progress Report on Competitiveness with the State of the Energy Union, underpinned by the ”Clean energy transition technologies and innovations report”, an evidence-based assessment of the technology status, gaps and competitiveness of the EU clean technologies.
- InvestEU (EUR 31.6 billion of provisioning for a EUR 75 billion budget guarantee) with a sustainable Infrastructure Window (doubling of guarantee) and a strategic Investment Facility (EUR 15 billion provisioning for a EUR 31 billion budget guarantee), which includes an R&I window.
- Energy related innovation is among the most frequently identified priorities in the current 120 Smart Specialisation Strategies that chart out the investment of over EUR 41 billion from European Regional Development Fund (ERDF) programmes. The current Smart Specialisation Platforms [476] (on agriculture, energy, industrial modernisation, all relevant topics for the decarbonisation) help coordinating the efforts and use of regional funds to strengthen the regional innovation capacities. As of 2021, a new interregional innovation investment scheme under the Interreg part of the ERDF will further strengthen the cooperation of regions around shared smart specialisation priorities.
- The EU is participating in international fora on innovation related to decarbonisation, in particular as a member of the Clean Energy Ministerial[477] and of the Mission Innovation[478], the global initiatives launched in the context of COP15 and COP21, to accelerate clean energy innovation. Members of the Mission Innovation[479] have committed to double governments' clean energy research and development investments, and to cooperate on different Innovation Challenges[480]. Furthermore, the EU supports the IPCC which makes a major contribution to the advancement, assessment and dissemination of climate science.

[473] http://www.innoenergy.com
[474] COM(2016) 759 final/2
[475] https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/governance-energy-union
[476] http://s3platform.jrc.ec.europa.eu
[477] http://www.cleanenergyministerial.org/about-clean-energy-ministerial
[478] http://mission-innovation.net/
[479] As of September 2018: the EU, 9 EU Member States and 14 non-EU large countries
[480] The European Commission is co-leading on 3 of them: "Affordable heating and cooling of buildings", "Converting Sunlight" and "Hydrogen"

9.11.8 Maritime Policy

Member States' National Energy and Climate Plans already envisage at least four fold increase of offshore wind deployment by 2030 and this will also be reflected in the maritime spatial plans that they will submit to the Commission by March 2021. Furthermore, the policy scenarios and the zero carbon scenarios of the "Clean Planet for all" Communication foresees a further threefold increase by 2050. This implies allocating more than a quarter of some Member States waters[481]. Site selection takes 2 years, consenting another 4, financial closure 2 more and installation a further 3 years thus planning for this expansion cannot wait. Even if the process can be speeded up, space will need to be found for these installations in the next year or so. At the same time, plans will need to take into account the potential of these locations to host the low-trophic aquaculture for food and feed that can compensate for land lost for biomass production.

These plans will necessarily need to apply the ecosystem-based approach and take into account the need to protect or reinforce biodiversity. This requires surveying potential sites beforehand and monitoring them during construction and operation. Industry has reported that the different requirements of Member States increase their costs. Scientists and environmental groups insist that a more common approach in each sea basin, taking into account ongoing monitoring for other purposes, would give more confidence that biodiversity targets would be met.[482]

In the light of this, the Commission will undertake an evaluation of the Maritime Spatial Planning legislation to determine how to incorporate a more long-term approach and take into account plans of neighbours. This could build on existing mechanisms such as the North Sea Energy Cooperation. At the same time an impact assessment will examine options for a more joined-up approach to ocean observation.

[481] WindEurope, Our energy, our future How offshore wind will help Europe go carbon-neutral, November 2019

[482] European Sustainable Energy Week - Green Deal and Ocean Observation, June 2019 https://webgate.ec.europa.eu/maritimeforum/en/node/4705

GLOSSARY

Term or acronym	Meaning or definition
AFOLU	EU Agriculture, Forestry and Land Use
BACS	Building Automation and Control Systems
Biofuels	Biofuels are liquid or gaseous transport fuels such as biodiesel and bioethanol which are made from biomass.
Biofuels (conventional)	Biofuels are produced from food and feed crops.
Biofuels (advanced)	Biofuels produced from a positive list of feedstock (mostly wastes and residues) set out in Part A of Annex IX of Directive (EU) 2018/2001.
BOE	Barrels of oil equivalent
CAP	Common Agricultural Policy
CAPRI (model)	Common Agricultural Policy Regionalised Impact model: a global multi-country agricultural sector model, supporting decision making related to the Common Agricultural Policy and environmental policy.
CCS	Carbon Capture and Storage: a set of technologies aimed at capturing, transporting, and storing CO2 emitted from power plants and industrial facilities. The goal of CCS is to prevent CO2 from reaching the atmosphere, by storing it in suitable underground geological formations.
CCU	Carbon Capture and Utilisation: the process of capturing carbon dioxide (CO2) to be recycled for further usage.
CEDEFOP	European Centre for the Development of Vocational Training
CEF	Connecting Europe Facility: an EU funding instrument to promote growth, jobs and competitiveness through targeted infrastructure investment at European level.
CGE	Computable General Equilibrium: a family of economic models.
CHP	Combined Heat and Power: a combined heat and power unit is an installation in which energy released from fuel combustion is partly used for generating electrical energy and partly for supplying heat for various purposes.

CH_4	CH_4 is the chemical formula for methane, a greenhouse gas. CH_4 is used as shorthand to refer to methane.
CO_2-eq	CO_2-eq stands for carbon dioxide-equivalent. This is a measure used to compare quantities of different greenhouse gases in a common unit on the basis of their global warming potential over a given time period.
COP	Conference of the Parties: decision-making body of the United Nations Framework Convention on Climate Change (see UNFCCC)
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
COVID-19	Global pandemic caused by a coronavirus unknown before the outbreak began in Wuhan, China, in December 2019.
DG ECFIN	Directorate General Economic and Financial Affairs
E3ME	Energy-Environment-Economy Macro-Econometric Model: a model for macroeconomic analysis.
ECB	European Central Bank
EE	Energy Efficiency
EEA	European Environment Agency
EED	Energy Efficiency Directive: Directive 2012/27/EU and amending Directive 2018/2002/EU
E-fuels	Liquid fuels produced on the basis of hydrogen obtained from electricity via electrolysis
E-gas	Gaseous fuels produced on the basis of hydrogen obtained from electricity via electrolysis
EIB	European Investment Bank
EII	Energy intensive industries
Energy system costs	Sum of fixed and variable costs for the energy system, including investments, operations and maintenance, as well as fuels.
EPBD	Energy performance of buildings directive: Directive 2010/31/EU and amending Directive 2018/844/EU
EPC	Energy Performance Certificates (see also EPBD)

ERDF	European Regional Development Fund
ESOS	Energy savings obligation scheme
ESR	Effort Sharing Regulation: Regulation 2018/842/EU
ETD	Energy Taxation Directive: Directive 2003/96/EC
EU ETS	European Union Emissions Trading System as established under Directive 2003/87/EC
EU, EU27	European Union with 27 Member States since 1 February 2020
EU28	European Union with 28 Member States from 1 July 2013 to 31 January 2020
EUTL	European Union Transaction Log: central transaction log, run by the European Commission, which checks, records and authorises all transactions between accounts in the Union Registry (see also EU ETS, NIMs)
FAO	Food and Agriculture Organization
FEC	Final Energy Consumption: all energy supplied to industry, transport, households, services and agriculture, excluding deliveries to the energy transformation sector and the energy industries themselves (see also GIC, PEC)
F-GASES	Fluorinated greenhouse gases, including hydrofluorocarbons (HFCs) perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6).
FRL	Forest Reference Level (see also LULUCF)
G20	Group of 20: international forum for the governments and central bank governors from 19 countries and the European Union (EU)[483].
GAINS (model)	Greenhouse gas and Air Pollution Information and Simulation
GDP	Gross Domestic Product
GEM-E3-FIT (model)	General Equilibrium Model for Energy Economy Environment interactions: a computable general equilibrium model, version operated by E3Modelling, a company (see also JRC-GEM-E3).

[483] The Group of Twenty (G20) is a forum made up of the European Union and 19 countries: Argentina, Australia, Brazil, Canada, China, Germany, France, India, Indonesia, Italy, Japan, Mexico, Russia, Saudi Arabia, South Africa, South Korea, Turkey, the United Kingdom and the United States.

GHG	Greenhouse Gas
GIC	Gross Inland Consumption: the quantity of energy necessary to satisfy inland consumption of the geographical entity under consideration, i.e. the Total Energy Supply, plus the international aviation (see also FEC, PEC).
GLOBIOM (model)	Global Biosphere Management Model: a model for land use of agriculture, bioenergy, and forestry.
$GtCO_2$	Giga tonnes of CO_2
GW	Gigawatt
HBS	Household Budget Surveys: national surveys of households focusing mainly on consumption expenditure.
Hydrogen	A feedstock for industrial processes and energy carrier that can be produced through a variety of processes from fossil fuels or electricity via electrolysis.
Hydrogen (GHG neutral)	Hydrogen from GHG neutral sources, mainly through electrolysis using GHG neutral electricity. This includes renewable hydrogen, which is from renewable electricity via electrolysis.
Hydrogen (Clean, Renewable)	Hydrogen, which is from renewable electricity via electrolysis.
IA	Impact assessment
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
ICT	Information and Communication Technology
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
JRC	Joint Research Centre of the European Commission
JRC-GEM-E3	General Equilibrium Model for Energy Economy Environment interactions: a computable general equilibrium model, version

	operated by the JRC (see also GEM-E3-FIT)
LRF	Linear Reduction Factor (see also ETS)
LTS	COM(2018) 773: A Clean Planet for all - A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy
LULUCF	Land Use, Land-Use Change, and Forestry
LULUCF regulation	Regulation on emissions and absorptions of the LULUCF sector: Regulation (EU) 2018/841
MFF	Multiannual Financial Framework
MRV	Monitoring, Reporting and Verification scheme implemented in Regulation (EU) 2015/757 on the monitoring, reporting and verification of CO_2 emissions from maritime transport
MSR	Market Stability Reserve (see also EU ETS)
$MtCO_2$	Million tonnes of CO_2
Mtoe	Million tonnes of oil equivalent
MWh	Megawatt hour
N_2O	N_2O is the chemical formula for nitrous oxide, a greenhouse gas. N_2O is used as shorthand to refer to nitrous oxide.
NDC	Nationally Determined Contributions (as required by the Paris Agreement)
NECP	National Energy And Climate Plan
NGEU	Next Generation EU
NIMs	National Implementation Measures, submitted under Article 11 of the ETS Directive (see also ETS)
NOX	Nitrogen Oxide(s)
‘No Debit rule’	Under EU legislation adopted in May 2018, EU Member States have to ensure that greenhouse gas emissions from land use, land use change or forestry are offset by at least an equivalent removal of CO_2 from the atmosphere in the period 2021 to 2030.
NZEB	Near Zero Energy Building

OECD	Organisation for Economic Co-operation and Development
PDF (indicator)	Potentially Disappeared Fraction of global species
PEC	Primary Energy Consumption: Gross Inland Consumption (GIC) minus the energy included in the final non-energy consumption (see also, FEC, GIC)
PHS	Pumped Hydropower Storage
PM 2.5	Particulate Matter with a diameter of 2.5 micrometre or less
POLES-JRC (model)	Prospective Outlook on Long-term Energy Systems: a global long-term energy system model operated by the JRC
PRIMES (model)	Price-Induced Market Equilibrium System: an energy system model for the European Union.
PRIMES-TREMOVE (model)	Model for the transport sector, integrated in the PRIMES model.
PtG	Power to gas: technologies for the production of E-gases (see also E-gases)
PtL	Power to liquids: technologies for the production of E-fuels (see also E-fuels)
QUEST / E-QUEST (model)	Quarterly Economic Simulation Tool: a global macroeconomic model used by the Directorate General for Economic and Financial Affairs (DG ECFIN)
RED / RED II	Renewable Energy Directives 2009/28/EC and 2018/2001/EU
RES	Renewable Energy Sources
RES-E	Renewable Energy Sources in the generation of Electricity
RES-H&C	Renewable Energy Sources in Heating and Cooling
RES-T	Renewable Energy Sources in Transport
RFNBO	Renewable Fuels of Non-Biological Origin: liquid or gaseous fuels which are used in the transport sector other than biofuels or biogas, the energy content of which is derived from renewable sources other than biomass
SET-Plan	EU Strategic Energy Technology Plan
Sink	Any process, activity or mechanism that removes a greenhouse gas, an aerosol, or a precursor to a greenhouse gas from the atmosphere

SME	Small and Medium-sized Enterprise
Synthetic fuels and gases	See E-fuels, E-gases
TEN-E	Trans-European Networks for Energy
TEN-T	Trans-European Networks for Transport
TFEU	Treaty on the Functioning of the European Union
TWh	Terawatt-hour
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
VAT	Value Added Tax
ZELV	Zero and low emissions vehicles
ZEV	Zero emissions vehicles

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