EU Reference Scenario 2020

Energy, transport and GHG emissions - Trends to 2050

July – 2021

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1. Introduction

1.1. The EU Reference Scenario 2020: approach and process

The purpose of this publication is to present the "EU Reference Scenario 2020" (named thereafter "Reference Scenario"), which updates the previous version published in 2016[1].

The Reference Scenario projects the impact of macro-economic, fuel price and technology trends and policies on the evolution of the EU energy system, on transport, and on their greenhouse gas (GHG) emissions. The projections concern the 27 EU Member States individually and altogether. The Reference Scenario also includes GHG emission trends not related to energy. This publication presents and discusses the projection results and analyses various interactions among energy system sectors and impact of different policies.

In essence, the Reference Scenario is an informed, internally consistent, and policy relevant projection on the future developments of the EU energy system, transport system and greenhouse gas GHG emissions that acts as a benchmark for new policy initiatives. It reflects policies and market trends used by policymakers as baseline for the design of policies that can bridge the gap between where EU energy and climate policy stands today and where it aims to be in the medium- and long-term, notably in 2030 and 2050.

1.1.1. The Reference Scenario approach: projection, not forecast

The Reference Scenario presents a projection, not a forecast, of the evolution of the EU energy system, transport system and GHG emissions. It does not predict how these will look in the future, but provides a model-based simulation of a possible future outlook, given the current policy context, based on certain framework conditions, assumptions, and historical trends, notably in the light of the most recent statistical data on energy system (Energy Balances), transport and GHG emissions (GHG inventories)[2].

The Reference Scenario builds on EU and Member State policies. The former concerns the EU energy, transport, and climate acquis as of end of 2019[3]. Energy policies have recently been updated with the “Clean Energy for All Europeans” package (2019)[4], to facilitate the clean energy transition and to deliver on the EU’s commitments under the UNFCCC. This package consists of eight legislative acts setting the EU energy targets for 2030 and paving the way for their achievement. The recast Renewable Energy Directive (RED II)[5] and amending Directive on the Energy Efficiency[6] and the Energy Performance of Buildings Directive[7], as well as the new Electricity Regulation[8] and the amending Electricity Directive[9] are central pillars of the package. Furthermore, EU revised policies like the EU ETS[10], the CO_2 standards for vehicles[11], the Regulation on F-gas[12], the legislation on waste[13], the Directive on alternative fuels infrastructure (AFID)[14], the TEN-T

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[1] EU Reference Scenario 2016: https://ec.europa.eu/energy/data-analysis/energy-modelling/eu-reference-scenario-2016_en
[2] The Reference Scenario uses the Eurostat Energy Balances of February 2021 and the UNFCCC-CRF submissions of April 2020, as reported by the EEA.
[3] Including some EU policies considered adopted at the end of 2019 although only published in 2020.
[4] https://ec.europa.eu/energy/topics/energy-strategy/clean-energy-all-europeans_en
[5] Directive (EU) 2018/2001
[6] Directive (EU) 2018/2002
[7] Directive (EU) 2018/844
[8] Regulation (EU) 2019/943
[9] Directive (EU) 2019/944
[10] Directive (EU) 2018/410
[11] Regulation (EU) 2019/631
[12] Regulation (EU) No 517/2014
[13] Directive (EU) 2018/851
[14] Directive 2014/94/EU

Regulation[15], the Fourth Railway Package[16], the Clean Vehicles Directive[17], etc. are also considered in the Reference Scenario. Some of the transport policies considered were part of the three Mobility Packages (2017-2018)[18]. Annex I provides the detail of EU policies considered.

National policies accounted for in the Reference Scenario include the main ones laid out in the National Energy and Climate Plans (NECPs)[19] as well as in other national plans put forward as of end of 2019, i.e., the Long-Term Renovation Strategies[20], National Policy Frameworks and National Implementation Reports under the Directive of alternative fuels infrastructure. In particular, the Reference Scenario assumes achievement of the national contributions towards the current[21] EU 2030 energy targets on energy efficiency and renewables (respectively 32.5% and 32%). It thus projects slight overshooting of the current EU 2030 renewables target and an ambition gap towards the current EU 2030 energy efficiency target, which is consistent with the assessment of the NECPs[22]. The Reference Scenario is guided by principal indicators[23] of the WAM scenarios (With Additional Measures – projection) submitted by Member States, or the WEM scenarios (With Existing Measures – projection) in the cases where the WAM scenarios were not submitted. Overall, the NECPs were accommodated in terms of projections and announced polices to the extent possible, while striving to provide a consistent Reference Scenario approach based on harmonised assumptions across Member States.

Regarding GDP and demographics, the statistical data from Eurostat available at the time of the modelling (early 2020) has been used; preliminary data from May 2020 was used to establish the 2020 projections, with selected updates carried out in November 2020. The 2021 Ageing Report[24] provides the basis for this exercise, depicting long-term population[25] and GDP growth trends, while the short- and medium-term GDP growth projections are taken from the Spring 2020 DG ECFIN forecast, which includes assumptions about the impact of the COVID-19 pandemic[26]. The fuel price projections have been updated to account for recent developments. Techno-economic assumptions have been revised following updated literature research and large-scale stakeholder consultation. Assumptions are described in greater detail in Section 2 and Annex II and III. Projections are presented from 2020 onwards in 5-year-steps until 2050.

1.1.2. The Reference Scenario process

For the preparation of the Reference Scenario a dedicated experts' group was set up by the European Commission, composed of national experts from EU Member States. In addition, and specifically for the work on technology assumptions, a workshop with over 100 stakeholders from the industry and relevant non-governmental organisations was organised in November 2019 to inform the techno-economic assumptions. Technology assumptions were also consulted with national experts from the Member States.

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[15] Regulation (EU) No 1315/2013

[16] https://ec.europa.eu/transport/modes/rail/packages/2013_en

[17] Directive (EU) 2019/1161

[18] https://ec.europa.eu/transport/modes/road/news/2018-05-17-europe-on-the-move-3_en; https://ec.europa.eu/transport/modes/road/news/2017-11-08-driving-clean-mobility_en; https://ec.europa.eu/transport/modes/road/news/2017-05-31-europe-on-the-move_en

[19] https://ec.europa.eu/info/energy-climate-change-environment/implementation-eu-countries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en

[20] https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/long-term-renovation-strategies_en

[21] "current" as of the EU policy framework in place in May 2021

[22] COM/2020/564 final

[23] e.g., final energy consumption and RES shares, deployment of alternative fuel vehicles

[24] "2021 Ageing Report: Underlying Assumptions and Projection Methodologies. European Economy 11/2020", Directorate-General for Economic and Financial Affairs (DG ECFIN)

[25] Aligned on the Eurostat EUROPOP 2019 projection

[26] "European Economic Forecast. Spring 2020. European Economy 5/2020", Directorate-General for Economic and Financial Affairs (DG ECFIN)

The first plenary meeting with Member States took place in November 2019 to present the Reference Scenario process, the modelling set-up and the key demographic and GDP assumptions, as well as key elements of techno-economic assumptions. Following the dissemination of a detailed questionnaire on national policies and the collection of written replies from the majority of Member States, bilateral meetings were held in the first half of 2020 to further clarify and substantiate Member State input. As the severity of the COVID-19 pandemic became evident, an update of GDP assumptions and resulting activity levels was deemed necessary: revised assumptions were thus presented in a second plenary meeting in July 2020. The draft outcomes of the modelling and sectorial activity projections were presented in the third plenary meeting in October 2020 and consultation with Member Sates begun in order to refine the results. Member States were also consulted on the draft transport activity, energy and CO_2 emission projections, non-CO_2 emissions and LULUCF projections.

The comments received from the Member State experts have been accommodated to the extent possible, while striving to provide a consistent Reference Scenario approach based on harmonised assumptions.

1.2. The Reference Scenario modelling suite

The projections for the Reference Scenario are performed with the help of computational models for energy and GHG system analysis. The models use detailed and up-to-date databases to produce projections per sector and per country. Calibration ensures continuity between historical data and projections.

The Reference Scenario modelling suite is owned by a consortium consisting of IIASA, EuroCare GmbH and E3-Modelling S.A., who leads the consortium.

The modelling capacity consists of a series of interlinked models, combining technical and economic methodologies. Since the last Reference Scenario of 2016, it has been updated to support the preparation of the EU's 2050 long-term strategy "A Clean Planet for All"[27] (2018) and the "Clean Energy for All Europeans Package" (2019), as well as the 2030 Climate Target Plan and the Sustainable and Smart Mobility Strategy tabled in 2020. The different models have been peer-reviewed and model developments, as well as assumptions and projection results have been published in scientific journals.

The models follow an approach which is based on micro-economics, solve a price-driven market equilibrium, and integrate engineering and economic representations for all sectors.

The energy system model PRIMES, central to the modelling suite, allows for mixed-complementarity and in this way enables the handling of multiple targets via dual variables (shadow prices) associated with target constraints. This is useful for analysing emissions reduction, energy efficiency and renewables' targets all at once. This approach also assumes the incorporation of technology dynamics (vintages), which allows to represent in detail the technology progress relevant for emission formation and reduction.

A general characteristic of all models is that the mathematical design is a purposeful and simplified representation of aspects of reality. The complexity and degree of sophistication is purposeful since a model is designed to answer specific policy analysis purposes. The modelling suite used for the Reference Scenario 2020 has sufficient complexity to assess both business-as-usual and substantial transformation outlooks, such as transition to climate neutrality. It covers in detail several sectors and sub-sectors of energy demand and supply, the Europe-wide markets, and the national systems. The numerical projections are subject to uncertainties related to data and assumptions about future

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[27] COM/2018/773 final

evolution of technologies. Although relying largely on official data, as those from Eurostat, the degree of segmentation is high and requires additional detailed information with sometimes varying degrees of completeness. Despite large consultation about future evolution of technologies, the projections are conditional on technology-related development uncertainties.

1.2.1. Description and role of each model

The full projection of GHG emissions, as described in the Reference Scenario, is a complex interaction of models covering all sectors of the economy, all emission sources and abatement options. Projections are from 2020 onwards, while past years (2010 and 2015) are calibrated to relevant historical statistics.

E3-Modelling operates the PRIMES energy system model and its modules, which represent the core pillar of the modelling capacity, delivering energy, transport, and CO_2 emission projections. Years of enhancing and further expanding the modelling capacity have turned PRIMES into a modelling suite that encompasses a range of (sectoral) models, which can operate together or independently of one another.

The PRIMES modelling suite has been considerably enhanced with PRIMES- BuiMo, a new module for buildings' renovation, and PRIMES-Maritime module, which covers international maritime transportation. The GEM-E3 macroeconomic model, also operated by E3-Modelling, is an advanced general equilibrium model for the entire economy used to deliver value-added projections by branch of activity in the context of the Reference Scenario.

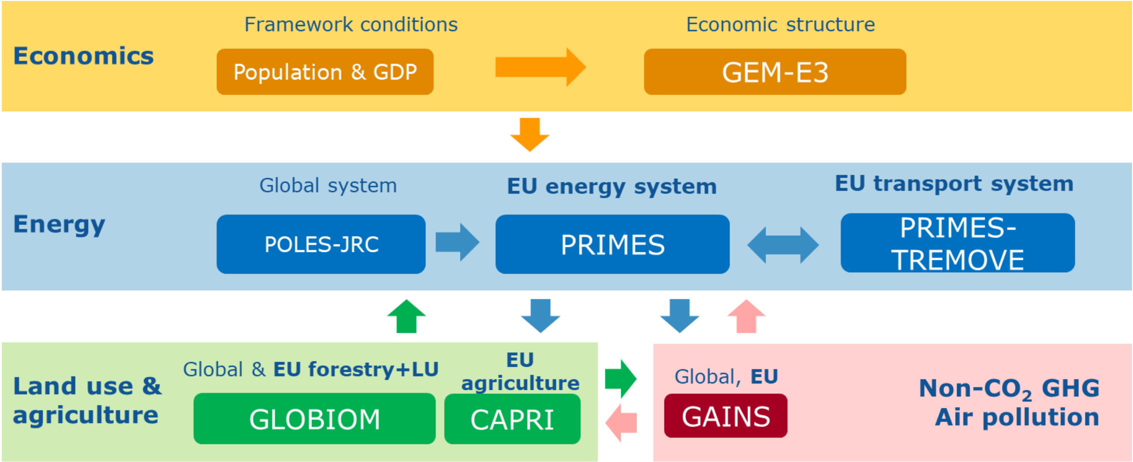
IIASA operates the GAINS and GLOBIOM/G4M models; GAINS provides non-CO_2 emission projections and air pollution impact assessments, while GLOBIOM/G4M delivers projections of LULUCF emissions and removals.

EuroCARE GmbH Bonn operates the CAPRI model, which is used for agricultural activity projections.

Finally, the Joint Research Centre (JRC) of the European Commission operates the POLES-JRC model, which is used for international fossil fuel price trajectories.

All models can be used as stand-alone sectoral models or coupled together to deliver a complete description of the GHG emissions from the EU economy and energy system. The interactions between the various models in the preparation of the Reference Scenario are summarised in Figure 1.

Figure 1: Modelling suite for the EU Reference Scenario 2020



The linking of the models started in 2007 with an FP7 project[28] and has been enhanced since, through years of collaboration between the modelling teams. The formal linking of the models was established with the creation of standardised data exchanging routines; this allows the modelling framework to use common underlying framework conditions (e.g. evolution of population, GDP, Value Added per sector, transport activity, fossil fuel prices) and exchange critical scenario-specific information, such as energy balances, power mix, investment, prices, and technology costs, in order to maximise consistency across the modelling tools and their results.

A brief description of the role and functioning of each model is provided in the following sections.

POLES-JRC

The POLES-JRC model is used to provide the global energy and climate policy context[29].

POLES-JRC 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 all GHG emissions: endogenously for the energy-industry sectors and through linkage with specialist models for GHG emissions from land-use and agriculture (global version of GLOBIOM-G4M), and air pollution (global version of GAINS).

The model includes a detailed geographical representation, with a total of 39 non-EU regions and countries covering the world; it 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-JRC 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-JRC model has participated in numerous research projects and has contributed to peer-reviewed analyses published widely[30].

For the Reference Scenario POLES-JRC provides fossil fuel price trajectories used as EU import price assumptions in PRIMES and GEM-E3.

GEM-E3

GEM-E3, operated by E3-Modelling, is a global (46 countries/regions), multi-sectorial (67 economic activities) Computable General Equilibrium (CGE) model, calibrated to a wide range of datasets (incl. GTAP, EUORSTAT, IEA). The model provides the country-level macro-economic projections to the entire suite of models used in the Reference Scenario and uses the energy system-related results from the other models (energy, transportation, agriculture, biomass, air quality, climate effects, etc.) to perform macro-economic and social impact analysis. The model closes the loop between sectorial and economy-wide analysis for emissions, emission reductions and costs, and can calculate the associated economic, employment and social implications. The model is a state-of-the-art, large-scale applied CGE model, featuring a number of innovations such as the explicit representation of the financial sector, the semi-endogenous dynamics of technical progress induced by R&D, knowledge spill-overs, the representation of multiple

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[28] http://www.ec4macs.eu/

[29] https://ec.europa.eu/jrc/en/poles

[30] https://ec.europa.eu/jrc/en/poles/publications

households, unemployment in the labour market and endogenous formation of labour skills. Details on the model can also be found in Annex II.

The purpose of the GEM-E3 within the Reference Scenario is to provide to the energy system models consistent sectorial value-added and consumption projections. The sectorial projections match the aggregate GDP and population projections by country, provided by the 2021 DG ECFIN's "2021 Ageing Report" and the Eurostat Europop demographic assumptions.

PRIMES Energy system model

PRIMES Energy system model, is a large-scale applied energy system model that provides detailed projections of energy demand, supply, prices, and investment, covering the entire energy system, including emissions from energy combustion and industrial processes. The distinctive feature of PRIMES is the combination of behavioural modelling, following a micro-economic foundation, with engineering aspects, and the coverage of all energy sectors and markets. The model represents in detail policy instruments related to energy markets and climate, including market drivers, standards, and targets by sector and for the whole energy system. PRIMES handles multiple policy objectives, such as GHG emissions reductions, energy efficiency, and renewables targets, provides pan-European simulation of internal markets for electricity and gaseous fuels (including hydrogen) and simulates fully the EU Emission Trading System (ETS) in its current form. PRIMES uses as inputs macroeconomic and multi-sectorial projections from GEM-E3, projections of world energy prices from POLES-JRC and conveys projections to GAINS, GEM-E3, CAPRI and GLOBIOM models.

Within the Reference Scenario PRIMES provides the energy system projection for demand and supply side sectors including full energy balance, investment costs, prices, and related CO_2 emissions (energy and process) per country. Moreover, it calculates total GHG emissions using inputs of other models on non-CO_2 GHG emissions (GAINS).

PRIMES-Industry

PRIMES Industry is very detailed, covering 10 industrial sectors, i.e., iron and steel (integrated steelworks, electric arc); non-ferrous metals (primary aluminium, secondary aluminium, copper, zinc, lead, other nonferrous); chemicals (fertilizers, petrochemical, inorganic chemicals, low energy chemicals); building materials (cement, ceramics, etc.); paper, pulp and publishing; food, drink and tobacco; engineering goods; textiles; other industrial sectors; and non-energy sectors. These 10 industrial sectors are further split in 31 sub-sectors and a total of 234 energy uses. 22 different fuels, including "new" fuel carriers, i.e., hydrogen, biofuels, and process emissions are modelled; hydrogen and synthetic fuels can be used directly as an energy source and as a feedstock. The model also provides extended possibilities of electrification and includes the possibility to use non-fossil hydrocarbon feedstock in all relevant sectors (e.g., iron and steel, chemicals, etc.). The penetration of new technologies, energy savings, electrification and the use of alternative fuels are endogenous and dynamic depending on technology progress, prices, standards, and policy targets. Perceived costs, uncertainty and risk factors influence costing and decisions, and can vary by scenario.

The model solves for each sector. First, it models demand for useful energy forms with a split into various industrial processes. The demand model links processes to exogenous macroeconomic activity by sector, organises the processes into flows and formulates substitutions between alternative processes (e.g., electrical vs thermal processing) where applicable. Second, it models energy production from various types of equipment and technologies in the industry, which purchase fuels from the markets in order to operate and may, in turn, sell excess fuels to the markets. The model determines the energy production system intertemporally with simultaneous consideration of heat recovery and horizontal energy efficiency investment. Substitution possibilities, perfect or imperfect, as well as complementarities play an important role in the modelling of the correspondence between technologies and processing types. A nested logit model is used for this purpose.

PRIMES Power and steam/heat

The PRIMES Electricity and heat/steam supply and market model is a fully new model version, which includes: (i) the hourly unit commitment model, with a pan-European market simulation over the grid constraints and detailed technical operation restrictions; (ii) the long-term power system expansion model; (iii) the costing and pricing electricity and grid model; (iv) the integration of heat supply and industrial steam supply with synchronised hourly operation. The PRIMES power and steam/heat supply model is based on a database of over 13,000 power plants in Europe; it simulates the simultaneous production of electricity and steam/heat production to meet the demand coming from the stationary demand and mobility sectors.

The PRIMES power and steam/heat module also calculates the flexibility needs of the power system and the storage requirements (battery or chemical, as well as hydro); it is linked to the production of hydrogen and other new fuels in order to fulfil the demand also of the emerging needs from the energy system (still limited in a Reference Scenario context).

The model also includes simulation of the steam/heat requirements from industry and from other stationary demand. The demand can be met through boilers (industrial, refinery, district heating) or through Combined Heat- and Power (CHP) plants: these are either utility or industrial plants. Industrial plants are further split into onsite plants and grid connected plants.

PRIMES BuiMo

PRIMES BuiMo model is a new module of the PRIMES model which projects energy consumption, rates and depths of buildings’ envelope renovation, choice and replacement of equipment, fuel mix and CO_2 emissions for residential and service buildings in each Member State. The model calculates costs, investment, and operating expenses, as well as implications on affordability of energy and access to efficient technologies. The key innovative aspect of PRIMES BuiMo is that it brings together engineering aspects and technical constraints with a very detailed representation of subjective and behavioural factors. In this way, the model captures the non-market barriers, which influence to a large extent the effectiveness of energy efficiency policies. Moreover, the model disaggregates the building stock in many categories (270 building classes), representing different building types, geographic locations, ages of construction, income classes, and services sub-sectors. While doing so, the model represents heterogeneous decision-makers with different characteristics regarding their preferences for each category of buildings, thus addressing the drawbacks of the representative consumer hypothesis.

PRIMES-TREMOVE

PRIMES-TREMOVE Transport model projects the evolution of demand for passengers and freight transport by transport mode, and transport vehicle/technology, following a formulation that is based on microeconomic foundation of decisions of multiple actors. Operation, investment and emission costs, various policy measures, utility factors and congestion are among the assumptions the model uses to project transport activity, fleet development, new technologies and alternative fuels, energy consumption and emissions (and other externalities). PRIMES-TREMOVE is based on and extends the features of the open source TREMOVE model, developed by the TREMOVE[31] modelling community.

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[31] http://www.tmleuven.be/methode/tremove/home.htm

PRIMES-TREMOVE depicts the links with the recharging and refuelling infrastructure and the heterogeneity of stylised trips. The model links trip distance heterogeneity with vehicle choice behaviour, which determines the choice of vehicles and fuels with range limitations and to some extent of alternative fuel vehicles such as FCEVs (hydrogen vehicles) and LNG.

PRIMES-TREMOVE also includes an econometric module for transport activity projections. It takes GEM-E3 projections (GDP, activity by sector, demographics, and bilateral trade by product and country) as drivers to produce transport activity projections, which are then fed into the model as input values for the initial activity projections in the Reference Scenario exercise. The econometric exercise also includes fuel prices coming from POLES-JRC, as well as transport network infrastructure (length of motorways and railways), as drivers.

PRIMES-Maritime

The PRIMES-Maritime module is a new development within the PRIMES modelling suite, which aims at better representing the maritime sector in the energy-economy-environment modelling nexus. The module addresses the maritime sector and can run in stand-alone and linked mode with PRIMES and PRIMES-TREMOVE.

The model covers the European intra-EU and extra-EU maritime shipping, both freight and passenger sectors. Trade activity between non-EU countries is outside the scope of the model. Instead, the model considers the transactions (bilateral trade by product type) of the EU-Member States with non-EU countries and aggregates these countries in regions. Several types and sizes of vessels are considered.

PRIMES Maritime solves a virtual market equilibrium problem, where demand and supply interact dynamically in each consecutive time period, influenced by a variety of exogenous policy variables, notably fuel standards, pricing signals (e.g., EU ETS), efficiency regulations and more. The model projects the volume of trade (in tons) and maritime transport activity (in tkm) disaggregated by Member State, by cargo type and by geographic region. Also, the model projects energy consumption by fuel type and cargo type, CO_2 and other pollutant emissions, costs, such as fuel costs, and investment expenditures in new vessels. The model covers a variety of fuels such as fossil fuels, biofuels (bioheavy[32], biodiesel, bio-LNG), synthetic fuels (synthetic diesel, fuel oil and gas, e-ammonia, and e-methanol) produced from renewable electricity, hydrogen produced from renewable electricity (for direct use and for use in fuel cell vessels) and electricity for electric vessels.

Well-To-Wake emissions are calculated thanks to the linkage with the PRIMES energy systems model, which derives ways of producing such fuels. Environmental regulation, fuel blending mandates, GHG emission reduction targets, pricing signals and policies increasing the availability of fuel supply and supporting the alternative fuel infrastructure are identified as drivers, along fuel costs, for the penetration of new fuels. As the model is dynamic and handles vessel vintages, capital turnover is explicit in the model influencing the pace of fuel and vessel substitution.

CAPRI

CAPRI is a multi-country agricultural sector model that supports decision-making regarding the Common Agricultural Policy and environmental policy. For this reason, it offers considerable technical and policy detail on all EU countries and most neighbouring countries with a more aggregate representation of other world regions and countries. The model takes inputs from GEM-E3, PRIMES and PRIMES-Biomass models, provides

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[32] Bioheavy refers to bio heavy fuel oil.

outputs to GAINS, and exchanges information with GLOBIOM on livestock, crops, and forestry as well as LULUCF effects. For the Reference Scenario CAPRI provides the agricultural outlook, in particular on livestock and fertilisers use. Further, it projects how changes in biofuel demand may affect the agricultural sector. Cross-checks are undertaken ex-ante and ex-post to ensure consistency with GLOBIOM on overlapping variables, for the crop sector in particular.

GAINS

The GAINS model delivers projections of air pollution and non-CO_2 GHG emissions abatement strategies and associated costs. GAINS explores trade-offs and synergies between GHG emission reductions and air pollution. Moreover, the model evaluates and projects atmospheric dispersion, air quality impacts, health impacts and impacts on ecosystems. The model takes energy sector activity projections as input from PRIMES, PRIMES-TREMOVE, and agricultural sector activity projections as input from CAPRI, and produces own activity projections for the waste and F-gas sectors in consistency with population and macroeconomic drivers from GEM-E3. To further ensure internal consistency among the models, GAINS exchanges data with the PRIMES model on supply limits for organic waste available to the energy sector and aligns the uptake of technology for biogas generation from manure co-digestion with PRIMES biofuel projections.

GLOBIOM / G4M

The global economic land-use simulation model GLOBIOM and the detailed forest sector model G4M are operated by IIASA and commonly applied in an iterative manner for the estimation of LULUCF emission pathways. For the EU, GLOBIOM-G4M receives input data from the GEM-E3, PRIMES-biomass and CAPRI models, while the POLES-JRC model provides bioenergy demand projections for regions outside of the EU. For the EU agricultural sector GLOBIOM is aligned with the CAPRI model to ensure consistency in Reference Scenario projections.

Within the Reference Scenario process GLOBIOM-G4M provides the outlook for the LULUCF sector which includes changes in land use, forest management and related GHG emissions. GLOBIOM mainly models CO_2 emissions or sequestrations from soil and biomass on cropland and grassland. G4M estimates the emissions from the forest (forest management, afforestation, deforestation). The model receives important inputs from GEM-E3, PRIMES and CAPRI models, as well as POLES-JRC, which provides bioenergy demand projections for the global analysis.

1.2.2. Main methodological improvements since 2016

The PRIMES model version used for the Reference Scenario 2020 builds on a number of developments to improve the representation of sectors and fuels (and their interaction), particularly in light of the transition towards carbon neutrality, as analysed in the in-depth analysis in support of the “EU Clean Planet for All” Communication[33].

PRIMES-BuiMo

As previously explained in the sections above, an entirely new buildings model has been developed and used for the first time in 2018 for the preparation of the EU’s 2050 Long-

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[33] COM (2018) 773

Term Strategy. This was a milestone in the enhancement of the PRIMES modelling capacity[34].

In order to project the energy efficiency and fuel mix in the residential and services sectors, the PRIMES BuiMo model assesses the cost-effectiveness and impacts of policy and regulatory measures. It covers market and non-market barriers, hidden costs and perceptions affecting consumer behaviour, and models a variety of policy instruments in order to influence decisions and possibly remove barriers. All this, while respecting engineering constraints and specificities, and tapping possibilities for transformation. The model calculates costs, investment, and operating expenses and reveals the implications for energy affordability and access to efficient technologies.

PRIMES BuiMo runs for residential and service buildings independently and covers every Member State individually. The model splits the stock of buildings in many categories aside from house/building types, namely: geographic locations, age of construction, income classes and service sector sub-sectors. Income classes help simulate the heterogeneity of actors and their idiosyncratic behaviour. Instead of a single actor, the model includes a variety of actors with distinct behavioural patterns. On top, distinct discount rates apply, where every income class has their specific discount rate; the highest income class has the lowest discount rate, and the lowest income class has the highest discount rate, representing the difficulty for such users to apply for financing. This allows to produce decisions that capture the heterogeneity of consumers in each class, and so to address the drawbacks of the representative consumer assumption.

The model is also based on the concept of dynamic discrete choice, where, out of a finite set of dynamic strategies, heterogeneous agents choose the most cost-efficient ones. A dynamic strategy may involve renovation of the envelope, equipment selection, premature replacement of equipment, and fuel switching.

The model uses a very large database for buildings, equipment, and electric appliances. The database is constructed by compiling information from many sources. This is necessary as it is often the case that sources do not include all data required. The data is also fully checked for their compatibility with the overall energy system data to avoid over- or under-estimations. If there is lack of data for certain elements these data have been approximated based on expert knowledge and calibration/modelling results. To fill the entire matrix in all its elements, the entropy method is used to split the data based on the available entries.

Residential sector

For the residential sector PRIMES BuiMo includes a buildings database, heating, and cooling equipment, as well as electric appliances. The buildings database includes 54 building types for each Member State, which are split into single or multi-storey buildings; by age of construction (9 age bands covering the period 1920-2015); and by spatial allocation, i.e., urban, semi-urban and rural. For the 54 building types, energy consumption is calculated based on country characteristics, which include size of dwellings, heating degree days and thermostat settings, differentiated by country and income class.

The model includes 28 different types of heating and cooling equipment for space heating, water heating and food preparation. Each of these is further split into four categories ranging from currently available technology to Best Not Available Technology (BNAT). On top, the model includes 11 categories of electric appliances: refrigeration, freezing, dishwashers, washing machines, dryers, lighting, information and communication, entertainment, vacuum cleaners, ironing, and small appliances.

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[34] Fotiou, T.; De Vita, A.; Capros, P. (2019): Economic-Engineering Modelling of the BUildings Sector to Study the Transition towards Deep Decarbonisation in the EU, Energies, Issue 12. https://doi.org/10.3390/en12142745

Each technology – heating and cooling equipment and electric appliances for each maturity category – is characterised by efficiency, technical lifetime, investment cost, operation and maintenance cost and economic lifetime, mimicking their techno-economic characteristics. Modelling a high number of technologies makes it possible to reflect in a more accurate manner the Ecodesign Directive (2009/125/EC) and its implementing regulations. The techno-economic characteristics are derived from various literature sources including the preparatory studies for the Ecodesign Directive.

Services sector

The services sector has been divided into the following sub-sectors:

- Trade
- Commercial Buildings
- Warehouses
- Cold Storages
- Market Services
- Private offices and other buildings in market services
- Hotels and Restaurants
- Non-Market Services
- Public Offices
- Hospitals and Health Institutions
- Schools an Educational Buildings

Different characteristics apply for each sub-sector with regard to the condition of the building stock (age, U-values), internal temperature set-points, ventilation demands; further the entire building stock has been divided by ventilation type into mechanically- and naturally- ventilated. For each sub-sector, the following energy uses are defined: space heating and cooling, water heating, cooking lighting, IT services, and steam uses. The different sectors are characterised by different energy usage patterns: for instance, office buildings have high cooling loads for air conditioning and electricity consumption for lighting and IT appliances; hotels have high hot water consumption while restaurants consume energy for cooking. As in the residential sector, each energy use can be satisfied by different equipment or electric appliances. The latter are split into technology categories based on the maturity of the technology ranging from current technology to BNAT. Again, the techno-economic characteristics of the technologies have been derived from the Ecodesign preparatory studies, as well as the HealthVent Project.

PRIMES-Industry

In light of projecting the functioning of a decarbonised energy system, the PRIMES Industry model has been enhanced to include a high-resolution split of industrial consumption by sector (31 subsectors) and type of industrial process (234 different energy uses). The split of the energy uses allows to estimate at a high level of detail the possible fuel and technology substitutions linked with varying mitigation potentials. Further, the split of the sectors allows to assess which processes can be electrified and which require other fuels or technological solutions. The projections for process emissions are now fully linked to the fuel consumption of the relevant sectors, which allows to assess in an accurate way the interplay between changes in fuel consumption and the evolution of emissions (e.g., switch to hydrogen in iron production).

The industrial energy demand module has been extended to include direct uses of hydrogen in high-temperature applications (e.g., iron and steel for direct reduction of iron ore), in furnaces, and in the chemical industry as a fuel and as a feedstock to synthesise petrochemicals together with captured CO_2, high temperature heat pumps, steam and vapour recompression and other advanced electrification technologies.

In addition, circular economy elements can be mimicked in the modelling through assumptions on recycling opportunities and/or reduction of primary material requirement. In that regard, the model captures waste heat that can be used for improving the efficiency of horizontal industrial processes.

PRIMES Power and Steam/Heat

An entirely new model version has been developed and used for this Reference Scenario, which extends the existing long-term power system capacity expansion model to encompass the hourly unit commitment model, with a pan-European market simulation over the grid constraints and detailed technical operation restrictions. The model solves the interconnected system of all European countries simultaneously and captures the sharing of balancing resources. The inclusion of the detailed unit commitment model, alongside the existing capacity expansion, allows to assess the flexibility and storage requirements of systems with high shares of renewable energy sources (RES) at all-time scales, while factoring in the inherent flexibility and characteristics of existing power plants and the use of interconnectors across Europe. The unit commitment model rests on PRIMES IEM module, which models the Internal Electricity Market in the EU and beyond[35,36].

Another feature of the new model version is the representation of the chemical storage of electricity as well as the synchronous operation of power generation, load, RES, and energy storage, including chemical storage inputs and the charging and discharging of the various storage systems.

Investment in storage is endogenous and depends on the costs of storage technologies, the prices of the storage inputs and the marginal costs of the power systems; the latter further depends on the RES availability and the demand by end-users for hydrogen and synthetic fuels. This way, the production of hydrogen and synthetic fuels takes place at times when renewables are abundant. In fact, the production of e-fuels offers high reliability and flexibility to the electrical system, because it allows for the indirect chemical storage of electricity. In this way, e-fuels maximise the use of RES in times of RES excess when produced, and make up for the electricity needed when RES are not available. This synergistic interaction helps reduce power and load fluctuations and improve system reliability and flexibility.

Representation of renewable energy categories and renewable energy potential

The representation of RES in the power sector has also been updated and improved in the current Reference Scenario. In order to better capture the diversity and advantages, as well as disadvantages, of some RES technologies, and improve the projection, the categorisation of solar PV, wind onshore and wind offshore has been modified.

The categorisation is used for the representation of the technologies as well as for the split of the potential; the potential is categorised by e.g., shallow or deep for offshore or placement area for solar (residential, commercial, etc.) and the technology type is categorised based on e.g., hub height. The new technological split is shown in Table 1.

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[35] Kannavou, M., Capros, P.(2019): Model-based assessment of removing distortions in the European electricity market in view of the EU 2030 targets, International Conference on the European Energy Market (EEM16), 10.1109/EEM.2019.8916518

[36] Capros, P.; Tasios, N.; Kannavou, M.; et al. (2017): Modelling study contributing to the Impact Assessment of the European Commission of the Electricity Market Design Initiative, E3Mlab

Table 1: New categorisation of RES technologies in PRIMES

Wind onshore			
Wind onshore - low resource area, high hub height	Wind onshore - medium resource area, medium height	Wind onshore - high resource area, medium height	Wind onshore - very high resource area, low hub height
Wind offshore			
Wind offshore Power, Shallow, Near-shore, Low	Wind offshore Power, Shallow, Near-shore, High	Wind offshore Power, Shallow, Far-shore, Low	Wind offshore Power, Shallow, Far-shore, High
Wind offshore Power, Deep, Near-shore, Low	Wind offshore Power, Deep, Near-shore, High	Wind offshore Power, Deep, Far-shore, Low	Wind offshore Power, Deep, Far-shore, High
Solar PV			
Solar PV Residential Low	Solar PV Residential Medium	Solar PV Residential High	Solar PV Residential Very High
Solar PV Commercial Low	Solar PV Commercial Medium	Solar PV Commercial High	Solar PV Commercial Very High
Solar PV Utility Low	Solar PV Utility Medium	Solar PV Utility High	Solar PV Utility Very High

Moreover, lifetimes of equipment have been raised to 30 years in most cases and capacity factors are fully Member-State specific, following information gathered from the ENergy Systems Potential Renewable Energy Sources (ENSPRESO) database of the JRC[37] and other databases.

The potential for RES development has been updated in the newest version of PRIMES using the information available in the ENSPRESO database. It is now adapted on a country by country level. The load and operation hours of RES power plants have been also adapted at country level based on historical data.

In the PRIMES unit commitment model, load curves are sector specific. This makes it possible to simulate the specificities of the load curves and improve the representation of the aggregate needs that the electricity and steam/heat systems have to cover. This is particularly relevant for simulating the changes in the load curves deriving from the higher penetration of heat pumps in stationary demand or battery electric vehicles in the transport sector. In essence, the model is now better equipped to simulate the transformation towards carbon-neutral energy system.[38]

PRIMES-TREMOVE

The PRIMES-TREMOVE model has undergone important enhancements since the previous Reference Scenario. The representation of CO_2 standards has been introduced also for the heavy-duty vehicles[39], while preparing the Impact Assessment[40] that accompanied the European Commission's proposal for the Regulation on CO_2 emission standards for heavy-duty vehicles[41].

Furthermore, the list of available fuels has been expanded. Gasoline and diesel are now split in fossil, biofuels, and synthetic fuels; in aviation the split includes fossil, biofuels, and synthetic fuels. Several technological pathways are represented for biofuels, in particular

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[37] https://publications.jrc.ec.europa.eu/repository/handle/JRC116900

[38] These features while moderately important in the Reference Scenario, become important in scenarios featuring deeper emission reductions and therefore greater system transformation.

[39] Siskos, P.; Moysoglou, Y. (2019): Assessing the impacts of setting CO2 emission targets on truck manufacturers: A model implementation and application for the EU, Transportation Research Part A: Policy and Practice vol. 125, pg. 123-138, https://doi.org/10.1016/j.tra.2019.05.010

[40] SWD (2018) 185 final

[41] Regulation (EU) 2019/1242

when linked with PRIMES biomass. The choice of fuels is endogenous in the model, determined by the increase in fuel costs that is derived from the PRIMES and the PRIMES Biomass model.

Moreover, the representation of policy instruments has been refined, particularly for CO_2 standards for cars, vans and trucks as well as alternative standards, namely efficiency performance standards. The model has been updated to incorporate the switch from the new European driving cycle (NEDC) to the worldwide harmonised light vehicles test procedure (WLTP) regulatory testing cycles for passenger cars and vans.

A higher resolution for new fuels (e.g., synthetic fuels in road freight, hydrogen in rail transport) has been represented in the model.

The representation of the aviation sector has been also improved significantly. The aviation sub-model has been designed to simulate changes in travel demand between an Origin and a Destination (O-D), which are induced by changes in the cost of fuels. Taxation (e.g., excise duty or ticket tax) or blending mandates for sustainable aviation fuels are factors that influence the cost of fuels. Changes in travel demand would also affect the use of the existing fleet and consequently the consumption of energy and emissions. It would also affect investment trends for purchasing new aircrafts. According to the model, a change in fuel costs would drive an adjustment of airfares. Airfares comprise of fuel costs, capital costs (related to purchasing of the aircraft), and other operation costs. Fuel costs and taxes are assumed to be passed through to the consumers. The changes in airfares induce changes in travel demand via two channels: (i) the income effect, i.e., reduced travel in case of increased airfares; and (ii) the substitution effect, i.e., the traveller opts for some other transport mode, where available. Non-air transport modes that could compete with aviation are high-speed railways and, to a lesser extent, cars (for short distances). The model captures a variety of choices of aircraft technologies through a non-linear cost-efficiency curve, denoting the frontier of technology possibilities. The fuel consumption of an aircraft depends on the length of the trip; the length determines different ratios between the landing and take-off (LTO) and cruise phases of the aircraft trip. Typically, as the length of the trip decreases, the specific fuel consumption (measured in kg/flight-km) of an aircraft increases due to the high fuel consumption associated with the LTO phase.

PRIMES-Maritime

PRIMES-Maritime features a modular approach based on the demand and the supply modules. The demand module projects maritime activity for each EU MS by type of cargo and corresponding partner. Econometric functions correlate demand for maritime transport services with economic indicators considered as demand drivers, including GDP, trade of energy commodities (oil, coal, LNG), trade of non-energy commodities, international fuel prices, etc. The supply module simulates a representative operator controlling the EU fleet, who offers the requested maritime transport services. The operator of the fleet decides the allocation of the vessels’ activity to the various markets (representing the different EU MS) where different regulatory regimes may apply (e.g., environmental zones). The fleet of vessels disaggregated into several categories is specific to cargo types. PRIMES-Maritime utilises a stock-flow relationship to simulate the evolution of the fleet of vessels throughout the projection period and the purchasing of new vessels.

PRIMES-Sectoral integration

With the need to assess carbon neutrality scenarios alongside other policy scenarios, it was necessary to extend the PRIMES model to include more storage options and new synthetic fuels such as hydrogen and its derivatives[42]. In this context, PRIMES has been expanded to model the production of synthetic fuels and storage technologies[43]. The following new or synthetic fuels are now addressed by the model:

- **Hydrogen**: whereas previously applied only in transport, the new model version considers the use of hydrogen in all supply and demand sectors and for blending in the natural gas grid. Green hydrogen is produced via electrolysis that uses renewable electricity; it can serve as *energy carrier* (either combusted or used in fuel cells in stationary or mobile applications), as *feedstock* to produce synthetic fuels and/or as *storage* to balance the generation of variable renewables. Hydrogen can be transferred via dedicated pipelines or blended in the natural gas stream up to a certain share (15%).
- **E-gas:** also referred to as synthetic methane or clean gas, is an output of methanation process, which uses hydrogen and carbon dioxide as inputs and requires significant amounts of electricity. E-gas has a lower net carbon intensity compared to natural gas or can be even considered carbon free if the carbon molecule is assumed to be sourced from biogenic sources or from Direct Air Capture.
- **E-liquids**: usually referred to as Power-2-Liquids (P2L, PtL), these are liquid fuels for use in the transport sector, mainly maritime and aviation, and less so in long-distance road freight transportation. They can fully substitute petroleum-based products in mobile applications with no radical changes in ICE powertrains. Their competition with electrification is assessed by the enhanced PRIMES modelling suite. Still, e-liquids would probably find more room for development in transport modes where decarbonisation options are limited and where they must compete only with advanced biofuels and/or technologies with low TRL (Technology Readiness Levels), i.e., electric aircrafts. In the model, e-liquids are produced via two main pathways, whose intermediate products are either syngas (blend of CO and H_2) or alcohols (methanol).

The new model version that reflects possibilities for sectoral integration therefore includes the additional interactions between the different modules of PRIMES: the enhancements imply additional fuel options in the demand side sectors and additional production capability requirements in the supply side, as well as a novel approach for trading hydrogen[44].

The module also takes care to balance the capturing of carbon dioxide in several ways, competing against each other (DAC, biomass, combustion, industrial processes). The module allocates carbon dioxide to various ways of storage, including its use as a feedstock for synthetic fuels, sequestration in materials (e.g., feedstock for chemical substances) and storage in underground caverns.

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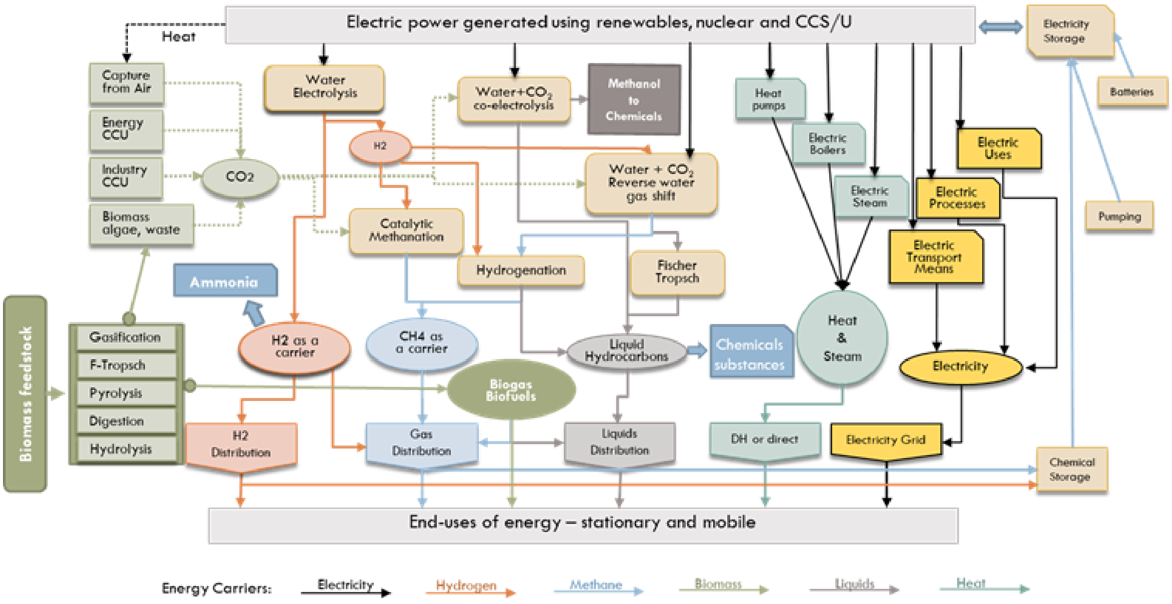
[42] Evangelopoulou, S.; De Vita, A.; Zazias, G.; Capros, P. (2019): Energy System Modelling of Carbon-Neutral Hydrogen as an Enabler of Sectoral Integration within a Decarbonization Pathway, Energies, Issue 12, https://doi.org/10.3390/en12132551

[43] Evangelopoulou, S.; Kannavou, M.; G., Zazias; P., Capros (2019): Model-Based Assessment of Electricity Storage in a European System Producing Hydrogen and Hydrocarbons from Renewable Energy, 16th International Conference on the European Energy Market (EEM16), vol. 2019, 10.1109/EEM.2019.8916518

[44] While the Reference scenario by assumption only includes limited use of hydrogen (in transport), policy scenarios which (will) use the Reference as a basis have the option of trading hydrogen between Member States.

Figure 2: Sectoral integration chains covered in the updated PRIMES model



PRIMES-Biomass

The PRIMES-Biomass supply model links the demand for bio-energy products to the supply of biomass feedstock and its conversion to bioenergy. Bio-energy/biofuel conversion technologies are evolving at different pace. The model is used to derive the availability of supply for a given demand for bioenergy and verify the compliance with the sustainability criteria of RED II. Since the Reference Scenario 2016, a number of chains have become increasingly important for the bioenergy in particular for biofuel production. Techno-economic advancements of advanced biofuel technologies have been revisited and improved over the past years including their interaction with agricultural production[45]. Compared to Reference Scenario 2016, the PRIMES-Biomass supply model, includes new chains such as the alcohol-to-jet and the Hydro processed Esters and Fatty Acids (HEFA) bio-kerosene production pathways.

GAINS non-CO_2 emissions

GAINS non-CO_2 emissions: agriculture

The GAINS model covers CH_4 and N_2O emissions from livestock systems, agricultural soils and burning of agricultural waste residuals. Historical data on livestock numbers have been updated to reflect national statistics as reported to EUROSTAT (2019). Projections of future livestock numbers and milk yield have been adapted to the trend estimated by the CAPRI model. Information on manure management structures in the EU (i.e., fractions of animals in liquid or solid systems) was updated in GAINS in 2019 as part of a review consultation process under the preparation of EU's Clean Air Outlook[46].

CH_4 livestock implied emission factors (emissions per head) were calibrated to emissions reported by countries to the UNFCCC (2019) for the year 2015. For a given technology and manure management system, the implied 2015 emission factors stay constant in future years. Hence, a decline in implied emission factors for future years can be fully

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[45] Borzęcka, Magdalena; Oberč, Barabara Pia; Haffner, Robert; Fragkiadakis, Kostas; Moiseyev, Alexander; Zazias, Georgios; Fragkos, Panagiotis; Dzene, Ilze; Verkerk, Hans; Ball, Ingo; Hussen, Karel van; Witzke, Peter; Pantelis, Capros (2018): Research and Innovation perspective of the mid-and long-term Potential for Advanced Biofuels in Europe, Report for European Commission, https://op.europa.eu/en/publication-detail/-/publication/448fdae2-00bc-11e8-b8f5-01aa75ed71a1

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referred to changes in technology, in this case installation of farm biogas plants for co-digestion of manure (farm AD). Historical uptake of this technology was adapted to information provided by EurObserv'ER (2020) with the development in future capacity following the trend in biogas production from anaerobic digestion as projected by the PRIMES model. The assumed order of the uptake of farm AD on different types of livestock farms, is based on GAINS estimates of marginal abatement costs. This results in the following order of uptake (consistent across all countries): First the potential on the largest pig farms (>500LSU) is exhausted, then on the second largest (100-500 LSU) pig farms, then on dairy and cattle farms with > 500 LSU, and finally dairy and cattle farms with 100-500 LSU. Uptake on farms with less than 100 LSU is considered economically infeasible in GAINS. There were no recent updates to the model structure or methodology for estimation of N_2O emissions from livestock.

The activity data for mineral fertilizer use was updated for historical years to be aligned with information reported to EUROSTAT (2019) and UNFCCC (2019), as well as checked for consistency against industry sales information from Fertilizers Europe. There were no other recent updates in GAINS for the estimation of N_2O emissions from agricultural soils.

The GAINS model accounts for CH_4 emissions from the burning of agricultural field residuals. The EU regulation (EC 1259/1999) prohibits open burning of field residuals and consequently most EU countries do not report emissions from this activity to the UNFCCC. However, remote sensing data (e.g., from MODIS) consistently shows the occurrence of hundreds of fires every year. Interpretation of remote sensing data is associated with multiple uncertainties and depending on the instrument used and models and data (e.g., land use cover) applied, the resulting estimate of mass burned vary significantly. Given these uncertainties, the GAINS model aims to reflect the multi-year trend rather than the annual variability. Using country-specific information retrieved from the MODIS instrument and further processed by the Global Fires Emissions Database (GFED) and cross-checked against other published information, GAINS reflects major trends and changes in the amount of biomass burned on fields.

GAINS non-CO_2 emissions: waste

Estimations of CH_4 from municipal solid waste (MSW) disposal and treatment in the EU were revised in GAINS to take account of updated EUROSTAT statistics on MSW generation and composition and extended information on MSW treatment streams provided in the national emission inventories submitted by countries to the UNFCCC (version 2019). Annual data on historical MSW generation and composition 1995-2017 has been taken from EUROSTAT (2019). MSW waste composition categories considered were extended to Food and garden, Paper, Textile, Wood, Plastics, Glass, Metal, and Other. Total MSW generation per capita is assumed affected by changes in economic development (average GDP per capita) and average urbanization rate. Elasticities were estimated to determine the relative impact of these two variables on the per capita MSW generation. As the average national income level is expected to affect the elasticity of MSW generation, separate income elasticity estimates were obtained for three levels of average GDP per capita; < 20,000 Euro (ε_{income}=0.21), 20,000 to 40,000 Euro (ε_{income}=0.33), and above 40,000 Euro (ε_{income}=0.67). Hence, according to these estimates, a higher per capita income tends to accentuate the generation of MSW. Projections of future generation of total MSW, as well as generation of waste in the period prior to 1995, are derived using the estimated elasticities.

Information on historical uptake of waste treatment measures was collected from the national reporting to the UNFCCC (version 2019) and EUROSTAT (2019). This includes information on overall recycling rates and specific recycling rates for paper waste, amounts of waste allocated to various types of landfills, composting and anaerobic digestion in biogas facilities, waste incineration and open burning of waste, as well as the Methane Correction Factor (MCF) for different types of landfills. In consistency with the reported treatment information and emission factors derived for each waste category and treatment stream using default IPCC (2006, 2019) methodology, the emission generation potential of waste is determined for each country in five-year steps from 1970 to 2015. Using a simplified version of the IPCC First-Order-Decay method, waste with organic content disposed off to landfills is divided into fast-decaying (food and garden waste) and medium-to-slow decaying (paper, wood, textile, other) waste, assuming on average a ten year delay between disposal and emission release for fast-decaying waste and a twenty year delay for medium-to-slow decaying waste. Composting and anaerobic digestion are assumed to give rise to limited CH_4 emissions, while no CH_4 emissions are assumed from recycling of paper, wood, or textile waste. N_2O emissions are accounted for from composting using IPCC default emission factors. To account for the impact of decay times on emissions from 1990 onwards, we must estimate the generation and treatment attribution of MSW for the entire period 1970 to 1990. This extrapolation was made assuming that in year 1970 all MSW was landfilled except a small fraction that was openly burned (same fraction as reported for 1990). Between 1970 and 1990, a linear transition to the 1990 treatment attribution was assumed. Simulations of future waste treatment pathways and associated emissions take as starting point the current treatment structure identified from national information reported to the UNFCCC for the year 2017 and assumes that countries meet the targets of the amended EU Waste Directive from 2018.

GAINS non-CO_2 emissions: HFCs in cooling, refrigeration, and other uses

The general approach in GAINS for estimation of historical HFC emissions is to combine activity data (consumption of HFC-by-HFC species) from the national reporting to the UNFCCC (Common Reporting Format tables, version 2019) with sector- and technology-specific emission factors (i.e., leakage rates) in a consistent manner across countries. The use of constant emission factors across countries means that GAINS emission estimates do not always correspond to national inventory emission levels despite using the same HFC consumption. An exception to the use of reported HFC consumption data is made for the commercial and residential air conditioning (AC), as only total use in stationary AC is reported to the UNFCCC. In GAINS, HFC consumption in these sectors is derived bottom-up from information on macroeconomic drivers, commercial floor space, number of households and average AC ownership in households.

Depending on the sector, drivers for future HFC use are e.g., growth in GDP per capita, population, expected changes in average cooling-degree days (CDDs), and uptake of alternative technologies replacing HFC use in response to measures to comply with regulations. A number of recent updates were made to the model structure to better reflect the expected implications of the EU F-gas regulation. The commercial air conditioning (AC) and refrigeration sectors were split into small and large units to reflect differences in the feasibility of available alternatives to HFC use. For commercial AC, feasible alternatives include propane and HFC-32 for small units and water chillers and HFO-1234yf for large units. For residential AC, the options considered for HFCs are propane or HFC-32. Note that HFC-32 has a GWP_{100} of 677 but is still tolerated in the F-gas regulation when it is compensated by a high energy-efficiency of the installed devices. For commercial refrigeration, feasible alternatives considered for small units are hydrocarbons (HC-600a, HC-290, HC-1270) and HFC-152a, while pressurized CO_2 and HFC-152a are considered for large units. For domestic refrigerators, all use of HFCs is assumed replaced by hydrocarbons (isobutane) by 2030. For industrial refrigeration, the model structure was split by small and large units, with feasible HFC alternatives being NH_3, pressurized CO_2, HFOs (HFO-1233ze, HFO-1233zd and HFO-1336mzz), and HFC/HFO blends (e.g., R-446A/R-447A). The modelling of the heat pump (HP) sector was updated to account for HFC use not only in ground-source HPs but in all heat pump types. Country-specific information on installed HP capacity was taken from published sources.

At the EU level, the HFC release reported for 2015 to UNFCCC attributes 34% of source sector use to Medical Dose Inhalers (MDIs). The 2015 use of HFCs in MDIs is assumed to remain into the future due to the difficulty of replacing HFCs in medical uses. No recent model revisions were made for the sectors fire extinguishers, foams, HCFC-22 production, mobile AC, solvents, and transport refrigeration, beyond updates of activity data and technology uptake to comply with the expected impacts of the F-gas regulation.

GAINS non-CO_2 emissions: industrial processes and other sources

The GAINS model structure covers N_2O emissions from production of adipic acid, nitric acid glyoxylic acid/glyoxal and caprolactam, HFC-23 emissions from HCFC-22 production, PFC emissions from primary aluminium production, PFC and NF_3 emissions from the semiconductor industry, and SF_6 emissions from magnesium production and casting. In addition, GAINS covers non-CO_2 emissions from a number of other minor sources, including direct use of N_2O in hospitals and food industry, SF_6 from high- and mid- voltage switches, and other use of F-gases to the extent that such have been reported by countries to the UNFCCC. Apart from updates of historical activity data and revisions of control strategies to comply with adopted F-gas regulations, no recent updates to the model structure were made for these emission sources.

CAPRI

The CAPRI model is used and developed for various purposes such that several improvements have been implemented since the Reference Scenario 2016, in particular:

- The initiation of a rolling process of “stable releases” with defined and tested properties’ facilitates to keep track of which innovations to incorporate in a specific application like the reference run.
- In this context a thorough revision of the feed allocation module has been undertaken to reduce the role of hard bounds as opposed to target values for the feed allocation. This improved plausibility of feed balancing in the animal sector which is directly linked to nutrient balances in the crop sector via excretions.
- The fertiliser allocation mechanism has been likewise revised both to be able to reduce arbitrariness in differences among crops and to explicitly include policy restrictions by crop where such information could be collected.
- The recently developed manure trade module has been used for the first time in the context of reference run projections.

Other innovations (for example on GHG mitigation, LULUCF representation, handling of short run projections) are useful for comparisons of scenario results within in the modelling suite but they do not directly affect the information flow which follows the established channels.

By contrast it has been crucial to update the database and some “external” modelling inputs to CAPRI, most of all the incorporation of the latest Commission Agricultural Outlook as well as recent fertiliser projections from the European Fertiliser Manufacturers’ Association.

Finally, the role of critical feedback from Member State national experts for the CAPRI projections has to be acknowledged. Early draft projections have been checked and reconsidered, leading to revisions in various areas. A common theme in the CAPRI related consultations has been a certain moderation of expectations for future increases in average milk yields and decline of dairy herds.

GLOBIOM/G4M updates

An improved version of GLOBIOM now covers the entire forest sector in much greater detail than before; from production and harvesting, including logging residues, up to the demand for final products, covering industrial processes and also accounting for industrial by-products and their demand/use in other parts of the industry or for energy production purposes. In relation to the forest sector update in GLOBIOM, the residues extraction algorithm in G4M has been updated. Furthermore, G4M parameters reflecting the intensity of forest management have been updated, using the information on forest management intensities[47]. The input data used in the GLOBIOM-G4M models were updated for the Reference Scenario. Forest harvest removals were calibrated to FAOSTAT data (downloaded in March 2020) or in exceptional cases to individual data contributions from Member States. The afforestation and deforestation rates in G4M have been calibrated to data extracted from the 2020 UNFCCC submissions. Historical harvest removals from 1960 onwards are based on FAOSTAT data and have been considered in the calculation of the harvested wood sink. Agricultural market balances, areas and prices have been calibrated to EUROSTAT statistics based on the CAPRI database and are aligned with most recent FAOSTAT data.

UNFCCC 2020 data was used for the ex-post calibration of model results to ensure consistency with UNFCCC submissions. A trend on the expansion of settlements was included in the projections based on historical UNFCCC 2020 time series (2008-2018). GLOBIOM-G4M area balances were consolidated with the reported UNFCCC 2020 data to improve consistency (i.e., natural grasslands were split out from the “other natural vegetation” aggregate and included under grassland management together with pastures). The ex-post calibration of the model has been extended to non-CO_2 emissions from LULUCF.

Changes in the energy balances

The PRIMES model has been adapted to reflect the new definitions of the EUROSTAT balances.

The new reporting of PRIMES mimics the new Eurostat energy balances. The key changes in this regard are:

- Blast furnaces are now included in the Energy Branch sector rather than in the final energy demand of the Iron and Steel sector, implying that this consumption is no longer part of final energy demand.
- Energy demand from international aviation is now treated as bunker fuel and also excluded from final energy demand.

For the energy efficiency indicators to comply with the Energy Efficiency Directive and for renewable energy shares to comply with the Renewable Energy Directive, the previous definition of final energy demand is used to allow consistency with past time series.

2. Framework conditions for the Reference Scenario

2.1. Macro-economic and demographic assumptions

The macroeconomic outlook used in the Reference Scenario provides the framework projections on how the European economy will evolve in the coming decades. The outlook is important as it offers a view of the future structure of sectors and activities of the European economy.

The macroeconomic scenario builds on recent demographic and economic projections for the EU countries provided by Eurostat and the joint work of the Economic Policy Committee and the European Commission.

The GEM-E3 model is used for simulating developments of each GDP component (investment, consumption, and trade) and of the sectorial production in each Member State. As a GCGE model, GEM-E3 ensures that the macroeconomic and sectorial

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[47] Nabuurs, GJ.; Verweij, P.; Van Eupen, M.; et al. (2018) : Next-generation information to support a sustainable course for European Forests, Nat. Sustain., vol. 2 p. 815-818, https://doi.org/10.1038/s41893-019-0374-3

projections of the EU economy are consistent with a global economy context. Details on the methodology, data and assumptions can be found in Annex II.

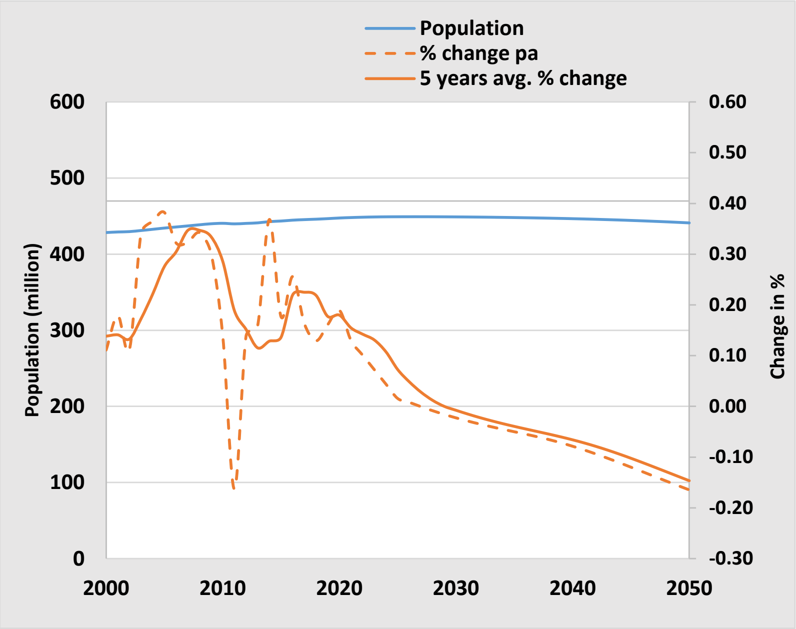
The impacts of the COVID-19 pandemic have been reflected in the macro-economic and demographic projections as well as in the sectoral composition of GDP.

2.1.1. EU population projections

According to EUROSTAT, the EU population is projected to decline over the (very) long term. However, there are wide differences in national population trends, with population growing in 11 Member States and dropping in the others. On 1 January 2020, the EU population was estimated at 447.7 million. The total EU population change was positive with 0.9 million more inhabitants during 2019 attributed to net migration.

Figure 3 shows the projection of population up to 2050 from EUROPOP 2019 as used in the Reference Scenario.

Figure 3: EU population trajectory



Source: EUROPOP 2019

Fertility, life expectancy and migration dynamics shape the EU's demographic old-age dependency ratio, i.e., the ratio between people aged 65 years and over and those aged 20-64, which is projected to continue to rise sharply over the coming decades.

Fertility rates in the EU rise from 1.52 in 2019 to 1.61 in 2050. Life expectancy also increases by 4.8 years for males and 4 years for females until 2050. Annual net migration inflows fall gradually overtime from approximately 1.3 million people in 2019 to about 1 million in 2050 (0.2% of the EU population).

From about 29% in 2010 the old-age dependency ratio rose to 34% in 2019 and is projected to rise further to almost 57% by 2050. This implies a shift from less than four working-age people for every person aged 65 years and over in 2010 to below two in 2050. Table 2 provides the population projection by Member State.

Table 2. Projected population per MS (million inhabitants)

	2020	2025	2030
EU	447.7	449.3	449.1
Austria	8.90	9.03	9.15

	2020	2025	2030
Belgium	11.51	11.66	11.76
Bulgaria	6.95	6.69	6.45
Croatia	4.06	3.94	3.83
Cyprus	0.89	0.93	0.96
Czechia	10.69	10.79	10.76
Denmark	5.81	5.88	5.96
Estonia	1.33	1.32	1.31
Finland	5.53	5.54	5.52
France	67.20	68.04	68.75
Germany	83.14	83.48	83.45
Greece	10.70	10.51	10.30
Hungary	9.77	9.70	9.62
Ireland	4.97	5.27	5.50
Italy	60.29	60.09	59.94
Latvia	1.91	1.82	1.71
Lithuania	2.79	2.71	2.58
Luxembourg	0.63	0.66	0.69
Malta	0.51	0.56	0.59
Netherlands	17.40	17.75	17.97
Poland	37.94	37.57	37.02
Portugal	10.29	10.22	10.09
Romania	19.28	18.51	17.81
Slovakia	5.46	5.47	5.44
Slovenia	2.10	2.11	2.11
Spain	47.32	48.31	48.75
Sweden	10.32	10.75	11.10

Source: EUROPOP 2019

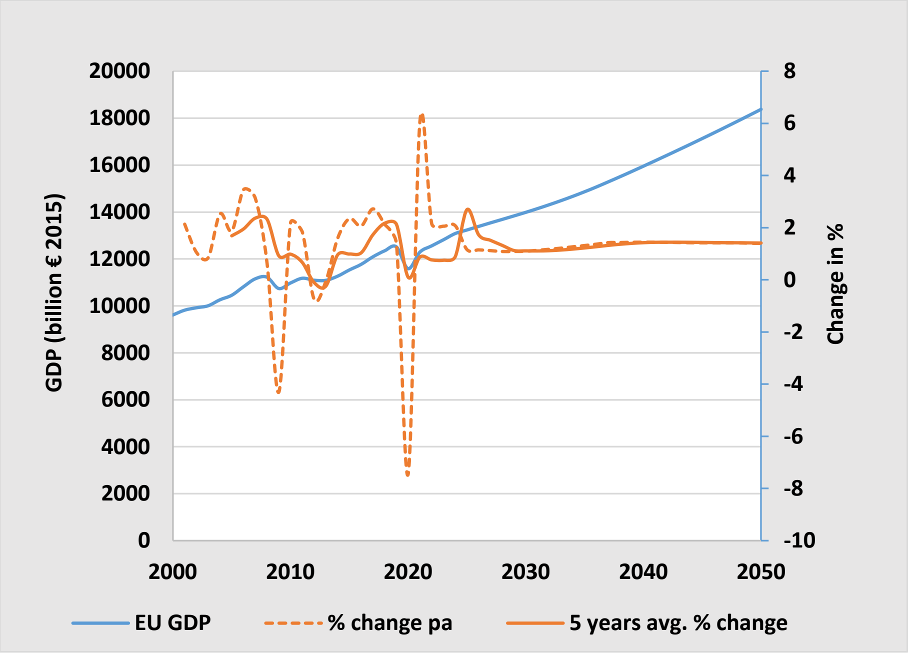
2.1.2. EU economic projections

The aggregate GDP projections used in the Reference Scenario (Figure 4) are retrieved from the European Commission's 2021 Ageing Report, itself based on the Spring 2020 Economic Forecast for short-term projections.

The 2021 Ageing Report is based on a growth accounting methodology that uses Eurostat's EUROPOP 2019 projections 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. Subsequently, projections are made regarding sectoral trends to define a macro-economic baseline down to the level of sectoral value added.

The projection for 2030 is 2.3% lower compared to pre-COVID-19 estimates of the 2018 Ageing Report.

Figure 4: EU GDP in aggregate terms

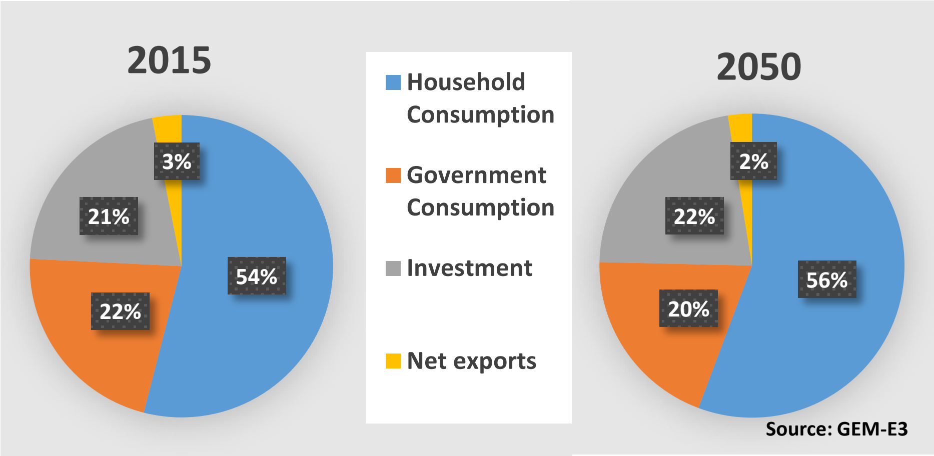


Source: DG ECFIN (Spring 2020 Economic Forecast & Ageing Report 2021)

Projections on GDP growth are characterised by very large uncertainty in the wake of the COVID-19 pandemic since the impacts are highly complex and widely varied. The pandemic struck the European economy at the moment it had started to grow at a moderate pace, recovering from the 2008 financial crisis. Now much will depend on the duration of the pandemic but also on new trends emerging in the post-COVID-19 era regarding work, global trade, production, and supply chains.

The interplay of pre-existing vulnerabilities, namely fading demographic dividends and structural bottlenecks, with the effects of the pandemic, i.e., firm bankruptcy due to debt accumulation, investor risk perception shaped by debt sustainability concerns and non-performing loans along with permanent changes regarding consumption patterns and human capital formation, can have an even larger impact on long-term growth prospects.

Figure 5: Components of GDP in the EU



Source: GEM-E3

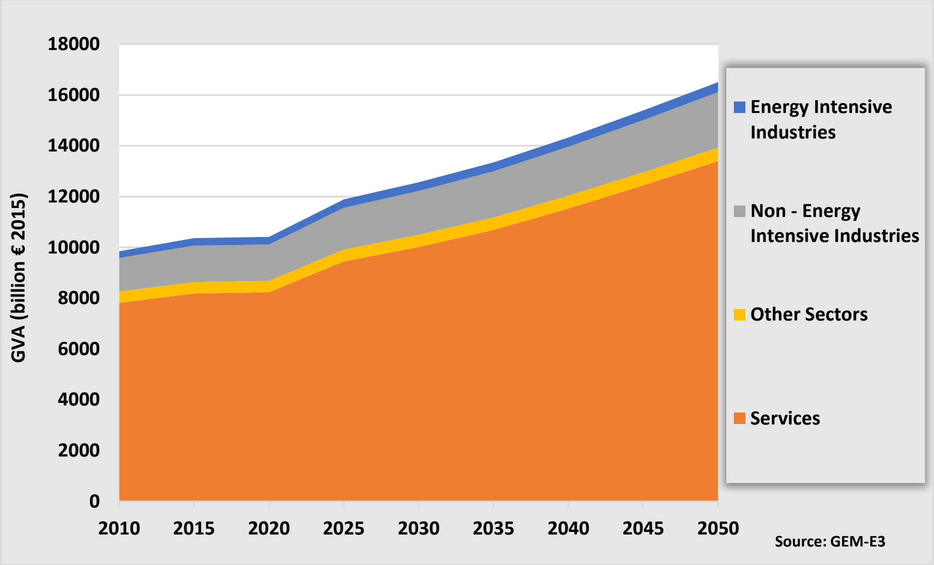
The macroeconomic components of EU GDP are projected to record only marginal changes by 2050 in their shares. The composition of the EU GDP continues current trends with high and increasing shares of private consumption followed by investments and government consumption (Figure 5). Private consumption continues to account for the largest part of GDP in the EU in 2050.

Government consumption is projected to marginally lower its share of GDP, reflecting adjustments in the aftermath of the crisis induced by the pandemic and contraction of government spending. Investments are projected to account for 22% of GDP in 2050. Trade surplus with non-EU regions continues to account for a small share of EU GDP, which remains close to present levels.

2.1.3. EU sectorial projections

Figure 6 and Figure 7 show the evolution of the sectoral gross value added over time. The services sector dominates, generating slightly over 76% of gross value added in the EU by 2050. Industry and construction are projected to decline slightly by 2030 and more so by 2050 due to structural shifts in the economy and reduced investments resulting from lower economic growth. Industries linked to construction, such as cement, also record improvements in sectorial activity to 2050. Energy-intensive industries maintain their shares in gross value added over time.

Figure 6: Sectoral Gross Value Added in the EU



Source: GEM-E3

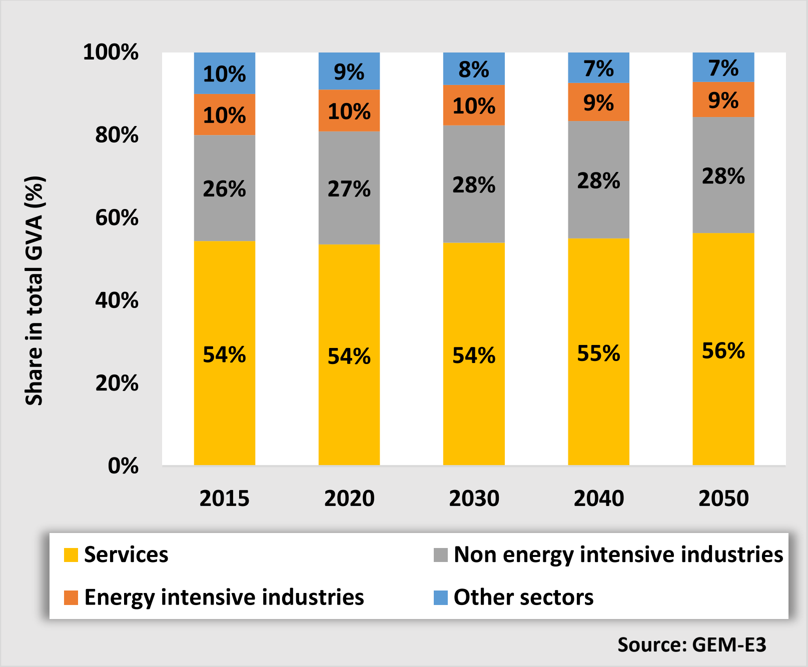
Note: "Other sectors" refers to agriculture and energy.

Iron, steel, and non-ferrous metals sectors maintain production in the EU thanks to the existence of tight links with the EU equipment goods industry. The value of the chemical sector has increased through specialisation and a focus on digitalisation even as growth in chemical production volumes has stabilised, due the strong competition from China, India, and the USA. Within the chemical sector, the EU production of fertilizers and inorganic chemicals is projected to stabilize and slightly decline in the long term as a result of increasing international competition and low EU level demand.

The equipment goods industry (engineering) is projected to remain a dynamic sector in the EU industry, growing at steady pace, but faced with higher competition from emerging markets. Affected by international competition, the textile industry is projected to decline.

Growth is projected to be slow in agriculture and the energy sector (in terms of activity volume). This would be however 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 value added domestic electricity production is expected to continue.

Figure 7: Sectoral shares in Gross Value Added in the EU



Source: GEM-E3

Note: Other sectors refer to agriculture and energy.

2.2. World fossil fuel prices

Alongside socio-economic projections, EU energy modelling requires projections of international fuel prices. The 2020 values are estimated from information available by mid-2020. The projections of the POLES-JRC model – elaborated by the JRC and derived from the Global Energy and Climate Outlook (GECO[48]) – are used to obtain long-term estimates of the international fuel prices.

The COVID-19 pandemic has had a major impact on international fuel prices[49]. The severe disruption in economic activity in 2020 created a historic shock on energy demand, in particular fossil fuels. The lost demand caused an oversupply, leading to decreasing

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[48] https://ec.europa.eu/jrc/en/geco

[49] IEA, Global Energy Review 2020, June 2020

prices. The effect on prices compared to pre-COVID-19 estimates is expected to still be felt up to 2030. Energy prices are expected to bounce back progressively with the recovery of the global economic activity. Yet, actual development of oil prices in particular will depend on the recovery of global oil demand as well as the evolution of supply side policies[50]. The table below shows the international fuel prices assumptions of the Reference Scenario.

Table 3: International fuel prices assumptions

In \$ per boe	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Oil	38.4	65.4	86.7	52.3	39.8	59.9	80.1	90.4	97.4	105.6	117.9
Gas (NCV)	26.5	35.8	45.8	43.7	20.1	30.5	40.9	44.9	52.6	57.0	57.8
Coal	11.2	16.9	23.2	13.1	9.5	13.6	17.6	19.1	20.3	21.3	22.3
In € per boe	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Oil	34.6	58.9	78.2	47.2	35.8	54.0	72.2	81.5	87.8	95.2	106.3
Gas (NCV)	23.4	31.7	40.6	38.7	17.8	27.0	36.2	39.7	46.6	50.5	51.2
Coal	9.9	15.0	20.6	11.6	8.4	12.0	15.6	16.9	18.0	18.9	19.7

Source: Estimates, derived from JRC, POLES-JRC model, Global Energy and Climate Outlook (GECO)

Details on the global energy context and the approach for the projection of the international fuel prices can be found in Annex V of this report.

2.3. The COVID-19 impact on economic activity

More than a year after the COVID-19 outbreak the pandemic continues to cast a shadow of uncertainty[51] over the pace and strength of economic recovery. The disruptions in economic value chains caused by the lockdowns have set off a sharp decline in economic activity, which affects the possible evolution of productive systems along with expectations surrounding consumption, savings, production, and investment plans in the medium- to long-term. Notably, the slump in economic activity has triggered a strong decline in sectoral activity and in energy demand. Transport has been significantly affected, especially the passengers transport segment, while freight transport activity has been affected to a lesser extent. International fuel prices have been also hit and the effect is projected to persist to some extent to 2030.

The DG ECFIN Spring 2020 short-term economic forecast used for the Reference Scenario points to a sharp drop in output in 2020 followed by fast recovery, while the projection to 2030 reveals a permanent loss of output of around 2.3% compared to the pre-COVID-19 projections. Modelling the year 2020 has proven to be particularly challenging, mainly due to the implications of the unfolding COVID-19 crisis. The modelling is based on extrapolation from historical data (until 2019) and preliminary data from 2020 (e.g., monthly statistics of electricity consumption). Moreover, the effects of COVID-19 on the different sectors, presented below, are also factored in.

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[50] IEA, Oil Market Report, June 2020 and US EIA, July 2020

[51] "Uncertainty and the pandemic shocks", November 2020, Monetary Dialogue Papers, European Parliament

2.3.1. Impact on transport

Since the COVID-19 outbreak, several governments took drastic measures to contain its spread. As a result, the activity in several economic sectors slowed down. The transport sector has been greatly affected due to international travel bans, confinement measures and stay-at-home requirements. Global trade between countries decreased to some extent due to lower economic activity and reduction in manufacturing output[52]. The impact was particularly visible in the international maritime sector and to a lesser extent to road freight transport, as far as the EU freight transport sector is concerned and consequently freight transport.

The calibration process of the model took place for the most part in 2020, when data was not yet available (also preliminary data was scarce). The projections show intra-EU passenger transport activity (expressed in pkm) to be 24% lower in 2020 compared to 2019, with public road transport, passenger cars and two-wheelers accounting for about 2/3 of the reduction. Passenger transport by rail, inland navigation and intra-EU aviation have been projected to drop by half.

Across modes, extra-EU aviation has been projected to be hit the hardest by COVID-19 pandemic, with activity (expressed in pkm) projected to drop by more than 50% in 2020. In the EU, freight transport activity (expressed in tkm) has been projected to decrease by about 7% but the reduction in international maritime freight activity has been envisaged to be significantly higher, declining by almost 30% in 2020 compared to 2019 levels.

The approach for estimating the effects of the pandemic has sought to capture possible changes in mobility trends mainly influencing aviation (e.g., reduced business travel and commuting, domestic tourism), especially until 2025. For urban mobility, the projections show a preference towards private transport modes compared to road public transport and tram and metro. Moreover, the projections do not account for significant structural changes and shifts towards other modes of transport, such as e-scooters, (e-) bicycles, or walking and other kinds of deep transformations, i.e., substantial reductions in long-distance business trips and substantial increases in remote working.

2.3.2. Impact on industry

The COVID-19 pandemic affected industrial output and led to a sharp drop in capacity utilisation, reducing the need for investment linked to capacity expansion and lowering incentives for upgrading the capital stock in 2020. After strong declines in March and April 2020 industrial growth picked up between May and July and remained rather stable afterwards. The overall growth since then has been generally sufficient to recoup the losses of the most acute phase of the pandemic. The activity projections used in PRIMES therefore have seen a slight decline in 2020 followed by almost full recovery by 2025 for almost all industrial sectors, compared to pre-COVID-19 levels.

2.3.3. Impact on services and residential

Services sectors, including retail, hospitality, tourism, and leisure have been particularly hit by the COVID-19 pandemic. The turnover of accommodation and food services (hotels and restaurants) at the end of 2020 was only about half of what it had been one year earlier. Administrative and support services (e.g., employment services, security, cleaning), usually bought by businesses, fell to a level of 78.8 % between the last quarter of 2019 and the last quarter of 2020[53]. Construction has also suffered from a double-digit fall in gross value added in 2020, negatively affecting providers of inputs to the sector,

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[52] https://unstats.un.org/unsd/ccsa/documents/covid19-report-ccsa.pdf

[53] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Impact_of_Covid-19_crisis_on_services

including cement and other non-metallic minerals[54] - the effects of the latter are included in the relevant industrial sector of PRIMES. The abrupt shift to working from home has caused energy consumption to increase slightly in the residential sector.

2.3.4. Impact on agriculture

The CAPRI projection for the Reference Scenario builds on the 2020 EU Agricultural Outlook[55], which incorporates the impact of the COVID-19.

2.4. Technological options

2.4.1. Classification of technologies

An essential input to the modelling exercise, and one which has a high influence on modelling results, relates to the assumptions about technological developments; both in terms of performance and costs. Mapping the new and emerging technologies and, more importantly, the knowledge that exists about their current and future cost and performance is crucial for envisaging the transformation of the energy system.

While one cannot have complete knowledge of all technologies that will be deployed, some indication already exists of the technologies that are being currently developed, their costs, performance, and possible evolution. Private companies and public authorities have already made investments in research and demonstration but also full-scale industrial application of these technologies. Key technological developments underpinning the Reference Scenario are outlined below.

The impressive decline in renewable energy costs that has been recorded since 2010 continue and so “renewable power generation technologies are not just competing head-to-head with fossil fuel options without financial support, but increasingly undercutting them”. Rapidly falling costs of solar PV drive a notable reduction in the cost of storage technologies, i.e., battery installations. Meanwhile, novel fuel technologies are progressively brought to the market. These include synthetic fuels/e-fuels such as e-methane and more complex hydrocarbons; hydrogen produced from increasingly carbon-free electricity; and the accompanying infrastructure, namely networks and refuelling stations for the distribution, storage, and conversion of the new fuels (e.g., CO_2 capturing, hydrogen production, methanation or production of more complex hydrocarbons for the transport sector).

The revision of the assumptions used in the Reference Scenario 2016 and of the assumptions used in the in-depth analysis underpinning the “EU Clean Planet for All”[56] rests on a rigorous literature review and an extensive consultation organised by the European Commission with the participation of industry stakeholders and Member State experts in November 2019. The stakeholder consultation addressed the PRIMES technologies, including transport, and the technologies used within the GAINS and GLOBIOM models.

The modelling of technologies in PRIMES is characterised by the following features:

- Technology vintages are tracked in the entire model.
- Cost-supply-potential curves (non-linear) for RES, power plant sites, energy savings, etc. are used in demand and supply models to mimic the increasing

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[54] SWD (2020) 176 final

[55] EC (2020), EU agricultural outlook for markets, income, and environment, 2020-2030. European Commission, DG Agriculture and Rural Development, Brussels

[56] COM (2018) 773

difficulty of exploiting a resource close to potential, the increasing marginal costs of energy efficiency, the increasing cost of RES development in remote areas, etc.

- Progress reducing the cost gap between different scales, influencing the emergence of decentralized power plants.
- Risk premium and perceived costs used to influence the uptake of not yet mature technologies obstructed by low access to financing or the reluctance of customers to buy technologies which are not yet well known and for which, for example, maintenance services are uncertain.

The technologies considered and reviewed for the purpose of the Reference Scenario are divided in the following categories:

- Power and heat
- Domestic appliances and equipment
- Renovation costs
- Industry
- Transport
- New fuels
- Non-CO_2 mitigation technologies
- LULUCF mitigation technologies

The following section presents an overview of the main assumptions about key technologies. More information on techno-economic assumptions for the technologies in the modelling is provided in Annex III.

2.4.2. Power generation technologies

In recent years, the development of RES technologies for power generation have improved significantly and at a faster pace than what was predicted only a few years ago (including in the Reference Scenario 2016). In order to better capture the diversity and advantages (as well as disadvantages) of some technologies, and so improve the projection, the categorisation of solar PV, wind onshore and wind offshore has been modified (see above and Annex C). Moreover, the lifetimes of equipment have been increased, in most cases to 30 years and capacity factors are fully Member-State specific, following information gathered from ENSPRESO and other databases.

Solar photovoltaic (PVs)

Techno-economic improvements in the solar PV industry, having surpassed previous expectations of costs, have been re-estimated using updated data. The development of PVs therefore starts from lower costs than previously expected and continues to exploit learning potential in the future. However, costs hit a floor which is justified by the incompressible costs of the modules and components such as inverters, frames, and installation costs.

Wind

Wind onshore: a steadily decreasing trend is visible. The remaining potential for learning is estimated to be small, but costs can decrease due to the size of turbines and their height.

Wind offshore: large uncertainty surrounds the costs for offshore wind. Cost increases have been recorded due to previously unforeseen challenges. Surveys have identified significant potential of cost decrease due to economies of scale and possibilities of improvement in logistics; these cost decreases are likely to occur towards 2030.

Nuclear

The Reference Scenario builds on the approach of the Reference scenario 2016, assuming high capital costs for third generation nuclear. The latest Power Purchase Agreement (PPA) contracts which have been awarded for nuclear power plants have prices in the order of 100€/MWh or higher.

CCS

The cost of CCS power plants construction has been revised upwards, as a result of lack of project developments.

2.4.3. Energy demand-side technologies

For stationary energy uses, technologies are distinguished by technology vintages (ordinary, improved, advanced and best technologies), which have increasing capital costs and efficiency. The features of the ordinary technology change over time in accordance with Ecodesign Regulations, where these are available. Perceived costs and technology-specific risk premium decrease over time for the advanced and best technologies closing the cost differences to the ordinary category.

Efficiency policies and ecodesign allow advanced and best technologies to reach maturity earlier, since barriers are removed, and manufacturers get higher market certainty.

This includes for example the most up to date studies for the preparation of the Ecodesign Regulations.

Transport

All the technologies for transport have been reviewed, consulted, and updated. They include the capital cost for the vehicles and other transport equipment but do not include any other fixed costs that may occur during the lifetime of the vehicles (e.g. replacement of battery costs).

The PRIMES-TREMOVE model includes the following modes and technology types for passenger transport:

- Private road: small, medium, large cars, powered 2-wheelers[57]; for each type of car, different power trains are available including conventional ICEs (with different fuel options) and alternative power trains (Battery Electric Vehicles and Fuel Cell Vehicles), as well as hybrid technologies, distinguished between conventional and plug-in.
- Public road: buses and inter-urban coaches; like with the private road, the public road includes ICEs as well as alternative power trains.
- Rail: conventional trains and high-speed trains, tram, and metro.
- Inland navigation (including national maritime).
- Aviation: based on aircraft size and motor type. Also, electric power trains for small aircrafts are included.

For freight transport the split of technologies includes:

- Road freight: light commercial vehicles, 3.5-7.5t, 7.5-16t, 16-32t, >32 t heavy goods vehicles; for each size different power trains are available including conventional ICEs (with different fuel options) and alternative power trains (Battery Electric Vehicles and Fuel Cell Vehicles), as well as hybrid technologies.

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[57] This includes motorcycles and mopeds. E-bikes and pedelecs are not considered.

- Rail: conventional rail.
- Inland navigation, including national maritime.
- International maritime (short-sea and deep-sea) shipping: incl. oil tankers, containers, dry bulk carriers and general cargo vessels. Different fuels are available (with different technologies): conventional liquid fuels (diesel, residual fuel oil, etc.), biofuel and synthetic counterparts, LNG, hydrogen.

In addition, the costs related to the recharging and refuelling infrastructure have been reviewed, consulted, and updated.

Industry

Substitution possibilities, perfect or imperfect, as well as complementarities, play an important role in modelling the link between technologies and processing types. The nested substitution possibilities combined with the structure of processes is a good basis to estimate the realistic possibilities of electrification and penetration of cleaner fuels, such as hydrogen, gas, and biomass in industry. Furthermore, the segmentation of processes combined with the representation of technology vintages is a basis to estimate the potential of heat recovery and energy savings.

The PRIMES Industry model represents heat and steam uses in connection to processes, and links steam supply to the model handling of industrial boilers, industrial CHP, and distributed steam endogenously. For this purpose, steam demand and supply data in the PRIMES database are estimated differently than in Eurostat, which shows only distributed steam. Also, the database includes a complete allocation of fuels to the various processes and uses, which also goes beyond Eurostat information.

The inventory of possible industrial technologies includes the classification of BAT regulation. Thus, PRIMES Industry can handle technology and emission performance standards. Primary versus secondary production (steel, aluminium, copper, glass, paper, and clinker) is handled explicitly, but depends mostly on activity-related projections, regarding recycling and circular economy. Renewables (biomass, biogas, waste, black liquor, solar and geothermal) are part of the possibilities, but cost-potential curves limit their expansion. They can be used in specific processes.

Domestic appliances and equipment

The assumptions for domestic appliances and equipment refer to purchasing costs, i.e., total acquisition costs, and efficiency by vintage for several space and water heating technologies and appliances used in the buildings sector (residential and services). The technical and economic characteristics of each technology category change over time as a result of learning-by-doing and economies of scale in industrial production.

Renovation costs

Renovation cost assumptions concern the costs reflected in the PRIMES BuiMo for renovation per climate zone and depth. Investment costs are the energy related expenditures needed to implement the indicated level of energy renovation of a building, excluding usual renovation expenditures needed for other purposes (structure, finishing materials, decoration etc.). The energy savings rate refers to a typical building as in the current stock of existing buildings, not savings in new constructions.

New fuels

Technologies for the production, transmission, and distribution of the so-called synthetic fuels (e-fuels) as well as storage technologies are presented. The following items are listed: “Investment costs”, “Fixed O&M costs”, “Heat rate” (ratio of energy input requirements over output), “Feedstock input requirements” (feedstock input required for the production of 1 unit of output from each technology).

2.4.4. Learning curves for energy technologies

The techno-economic characteristics of existing and new energy technologies used in the demand and the supply sectors of the energy system evolve over time and improve according to exogenously specified trends including learning rates. Learning curves apply for specific technologies, thus reflecting decreasing costs and increasing performances as a function of cumulative production. The steepness of the learning curve differs by technology, depending also on their current stage of maturity.

For power generation technologies the Reference Scenario takes the view that all power technologies known today are projected to improve in terms of unit cost and efficiency, without however assuming breakthroughs in technology development.

At any given time, several technologies are competing with different performance and costs. Following the logic developed in the previous Reference Scenarios, consumers and suppliers are generally hesitant to adopt new technologies before they become sufficiently mature. They behave as if they perceive a higher cost (compared to engineering cost evaluations for the operation of such equipment) when deciding upon adoption of new technologies.

Public policies at EU and national level, through information campaigns, industrial policy, R&D support, taxation, and other means, aim at pushing more rapid adoption of new technologies by removing or compensating uncertainties associated with their use. In this way, the technologies themselves reach maturity more rapidly as a result of “learning-by-doing” effects and economies of scale. Supportive policies for the adoption of new technologies thus lead to modifications of their overall perception.

Considering the technology portfolio available, energy efficiency gains in the scenarios are driven by microeconomic decisions, reflecting the market agents' aim of minimizing costs and maximizing economic benefits operating in the context of public policies that promote energy efficiency. Similarly, renewables and CHP development are driven by private economic considerations also taking into account supportive policies which are assumed to continue in the Reference Scenario and gradually decrease in the longer term (see policy assumptions).

On the macro-economic level, GDP growth is associated with continuous improvement of the technological basis leading to improved energy intensity. This is also supported by the effects from structural change in the economy.

Last but not least, the deployment of some of the new technologies depends on the development of regulations and new infrastructure, which are partly driven by policies and require investments from the relevant actors, i.e., the TSOs and DSOs. Examples are the building of interconnectors and expansion of the grid, the development of CCS to transport and store captured CO_2, the electrification of transport etc. This is also valid for the uptake of “new” fuels including hydrogen.

2.4.5. Non-CO_2 mitigation options

For non-CO_2 greenhouse gas-emitting technologies, abatement costs are differentiated per sector, technology, and pollutant to reflect the wide variety of sectors and activities covered. The following main sectors are distinguished: agriculture, waste and wastewater, energy, cooling and refrigeration, and industry. These sectors are split into sub-activities where needed (e.g., non-dairy and dairy farms). Given the uncertainty in terms of future developments, costs as well as efficiencies of options for reducing methane, nitrous oxides and F-gas emissions are assumed to remain constant over time.

2.4.6. LULUCF mitigation options

The land-use simulation model GLOBIOM and the forest sector model G4M are commonly applied in an iterative manner for the estimation of LULUCF emission pathways for each EU Member State. GLOBIOM and G4M models cover together all UNFCCC land use categories of relevance for CO_2 emissions, only wetlands and settlements are added exogenously based on the 2020 GHG inventory. Also, non-CO_2 emissions from LULUCF are added by an offset-calibration procedure.

G4M covers the forestry sector and delivers emissions from biomass, dead organic matter and soil from afforestation and deforestation activities and biomass emissions from forest management. GLOBIOM provides emissions from cropland and grassland management.

GLOBIOM[58] computes a market equilibrium for agricultural and forest products by allocating land use among production activities to maximize the sum of producer and consumer surplus, subject to resource, technological, demand and policy constraints. G4M[59] then estimates the impact of forestry activities (afforestation, deforestation, residue harvest and forest management) on biomass and other carbon pools. By comparing the net present value of managed forest (difference of wood price and harvesting costs, income from storing carbon in forests) with the potential income from alternative land use on the same place, a decision on afforestation or deforestation is made.

2.5. Key policies modelled in the Reference Scenario

The Reference Scenario builds on policies at EU and Member State level, whose implementation intensifies until 2030 and continues afterwards, assuming no additional measures apply between 2030 and 2050.

EU level policies cover those adopted in the fields of energy, transport, and climate until December 2019 (cut-off date). These include the directives and regulations included in the “Clean Energy for All Europeans” package, the revised EU ETS Directive, and key transport policies such as the CO_2 standards for vehicles, the Directive on alternative fuels infrastructure, the Clean Vehicles Directive, etc.

National policies considered in the Reference Scenario are the ones adopted as part of the NECPs and other national plans, as well as those planned to be adopted. This includes in particular coal phase-out and nuclear related policies.

Many EU countries have plans to phase-out coal-fired power generation, driven by political decisions but also by the rising carbon price following the strengthening of the Market Stability Reserve. Denmark, Finland, Greece, Hungary, Ireland, Italy, the Netherlands, Portugal, Slovakia, and Spain have committed to stop using coal until 2030. France is set to phase out coal before 2025 and keep some coal plants to meet the need for reserves, while Germany has opted for a gradual phase-out which should be completed by 2038. In Sweden coal is used only at peak times and so market forces are expected to drive coal phase-out whereas in Slovenia coal-fired generation is set to end by 2050. Bulgaria, the Czech Republic, Croatia, Poland, and Romania have not made any commitment to exit coal, while eight Member States have no operational coal power plants in place[60].

As per nuclear energy, while some Member States maintain nuclear energy as part of the mix, others including Germany and Belgium but also France have made political commitments to either ban or reduce nuclear from their power mix by 2035 at the latest. Already, the EU’s Long-Term Strategy[61] projected the share of nuclear in Europe’s power mix to drop to 15% in 2050, while according to the IEA without lifetime extension and/or

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[58] See also: https://iiasa.github.io/GLOBIOM/.

[59] See also: www.iiasa.ac.at/G4M

[60] Austria, Belgium, Cyprus, Estonia, Latvia, Lithuania, Luxembourg, and Malta

[61] See the "In-depth analysis in support of the Commission Communication COM (2018) 773”: com_2018_733_analysis_in_support_en_0.pdf (europa.eu)

long-term operation, the share of nuclear in the power mix could fall from 25% in 2017 to 5% in 2040[62].

Other important national policies considered in the Reference Scenario are policies that help Member States reach national targets, e.g., contributions to the EU energy efficiency (EE) and renewable energy (RES) targets, national transport mandates and domestic targets for ESR emission reductions. Such policies include support schemes for RES and buildings' deep renovation, programmes for the large-scale electrification of the public fleet and Public-Private Partnerships (PPPs) for the uptake of EVs and infrastructure rollout. Also, measures for fuel blending, incentives to boost demand response and self-consumption, and energy and transport taxation schemes.

2.5.1. Overview of the EU ETS and projections on carbon prices

The EU ETS is modelled following the revision of the EU ETS Directive in 2018, which paves the way for phase IV of the EU ETS (2021-2030) and allows the EU to meet the 2030 emission reduction target and deliver on its commitment to the Paris Agreement. The ETS sector includes energy related combustion, process emissions of the relevant industrial sectors and certain industrial non-CO_2 GHGs i.e., N_2O from adipic acid, nitric acid and glyoxylic acid/glyoxal production and PFC from primary aluminium production. While the former are directly part of the PRIMES model, the non-CO_2 GHGs are integrated based on results of GAINS non-CO_2 modelling (see section on non-CO_2 emission results).

In phase IV (2021-2030), the Market Stability Reserve (MSR) is reinforced. The cap on EU ETS allowances (hereinafter allowances) is subject to an annual linear reduction factor of 2.2%. The modelling accounts for the different allowance allocation rules (auctioning, free allowances based on benchmarks) foreseen in the legislation for the different sectors, including the provisions for sectors at risk of carbon leakage.

The latter are however assumed to meet the benchmarks required by legislation and to have an incentive to shift towards cleaner fuels and processes, despite being eligible for free allocation of allowances. The EU ETS legislation is assumed to continue in its current scope (phase IV) throughout the projection period to 2050; also, the rules relating to the MSR, and carbon leakage are assumed to remain unchanged in the character of "current policies" of the Reference scenario. The Reference Scenario assumes that from 2045 the ETS keeps reducing emissions, albeit at a lower rate than the current Linear Reduction Factor.

Aviation emissions are partly covered by the EU ETS, yet the geographic scope is limited to intra-EEA flights from 2017 until the end of 2023. This is in support of the resolution adopted in 2016 by the International Civil Aviation Organization (ICAO) on a global market-based measure, i.e. the 'Carbon Offsetting and Reduction Scheme for International Aviation' (CORSIA). The EU ETS for aviation is subject to a review in light of the international developments related to the operationalization of CORSIA. The review considers how to implement the global measure in Union law. In the absence of the amendment, the EU ETS would revert back to its original full scope from 2024. Aviation is modelled in the scope covered by Eurostat (and therefore PRIMES), namely it is based on fuels sold in the EU, which corresponds to domestic and outgoing international flights.

PRIMES simulates emission reductions in ETS sectors as a response to current and future ETS prices as well as other price assumptions and policy drivers, considering the risk-averse behaviour of market agents which leads to banking of allowances, perfect foresight of the carbon price progression in the period 2025-2050 and the fact that no borrowing from the future is permitted, however banking is possible. ETS prices are

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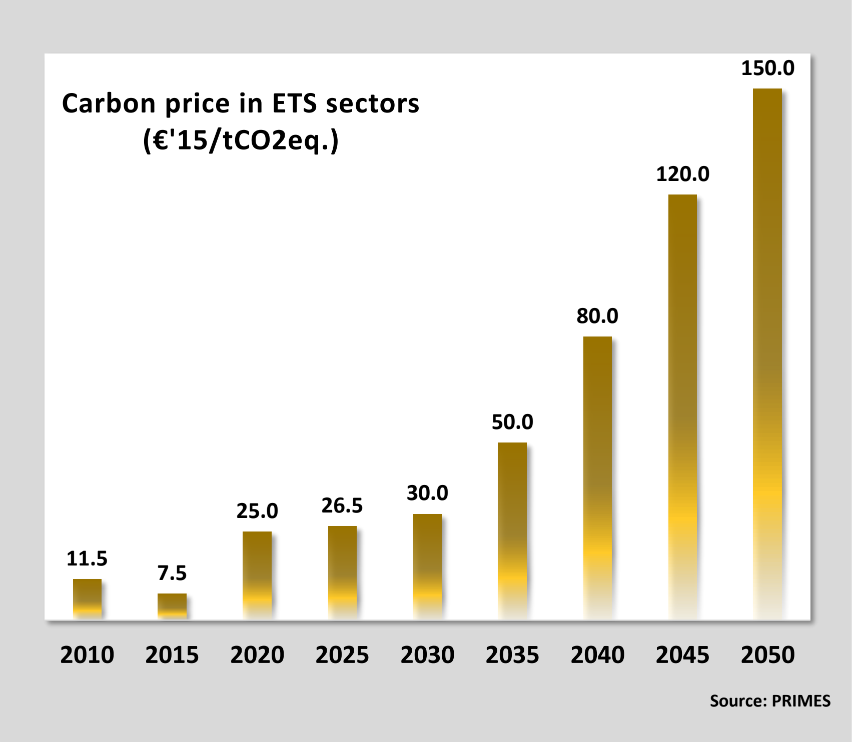
[62] "European Union 2020 – Energy Policy Review", June 2020, International Energy Agency

endogenously derived with model iterations until the cumulative ETS cap is met and the provisions of the MSR are respected.

The ETS emissions target for 2030 is overachieved. Alongside the ETS price there are also a wide variety of additional policies being implemented, particularly Member State coal phase-out policies, RES support policies but also Ecodesign and the Energy Efficiency Directive (EED), which influence the demand for ETS sector allowances.

The assumptions at the time of the modelling[63] points to EUR 30/tCO_2 in 2030 (Figure 8). From 2030 onwards, the ETS price increases to meet continued reductions in the cap, while being confronted with the reduction or phasing out of other policy drivers and a combination of energy supply factors. These include delayed technology developments of CCS, public acceptance of nuclear energy and CO_2 storage, offshore wind cost assumptions and phasing out of RES support as well as trends in world fuel prices.

Figure 8: ETS emissions and carbon prices



Source: PRIMES

2.5.2. Energy efficiency

With regards to energy efficiency, the Reference Scenario reflects policies at EU and Member State level, including the Ecodesign Directive[64] and the Energy Labelling Regulation[65] as well as the implementing measures, the revised Energy Efficiency Directive[66] (EED) and the revised Energy Performance of Buildings Directive[67] (EPBD). It also reflects the level of ambition of the national contributions set in the NECPs, meaning that the 32.5% energy efficiency target for the EU will not be met in 2030, due to the collective ambition gap and insufficient efforts proposed by Member States. The following sections briefly discuss these policies and their impact on the energy system.

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[63] The modelling applies to the ETS policy framework for 2030 as of end of 2019, and was realised before the political agreement on the new climate target of reducing EU's net GHG emissions by at least 55% in 2030, which has very likely affected the dynamics of the ETS price since the end of 2020.

[64] Directive (EU) 2009/125/EC

[65] Regulation (EU) 2017/1369

[66] Directive (EU) 2018/2002

[67] Directive (EU) 2018/844

PRIMES can simulate different energy efficiency policies with different modelling techniques. The model-specific instruments used affect the context and the conditions under which individuals, represented by stylized agents per sector, take decisions regarding energy consumption and the related equipment.

Modelling such policies and instruments can be done in different ways. One is to modify model parameters in order to mirror technology performance or the effects of building codes. These parameters are determined jointly in the process of calibrating the interdependent model output to the observations of the most recent statistical year. Another way is to assume that, within the model projection and under certain scenario conditions, improved equipment and appliances become available to consumers as future choices. Furthermore, there are specific modelling instruments for capturing the effects of efficiency performance standards ranging from ordinary technologies i.e., the currently available and common technologies, to advanced and best available technologies. Eco-design standards have been taken into account for the entire spectrum of technologies, particularly to define the standard or ordinary technologies.

Modelling instruments can be individual technologies or groups of technologies, which either modify the perception of modelled agents for associated costs or influence the portfolio of technologies that will be available for consumer choice or even eliminate equipment that will no longer be available on the market (for example due to mandatory minimum energy performance standards - MEPS).

Measures that improve consumer information through education, labelling, energy performance certificates, correct metering and billing, energy audits and technology support schemes, inciting consumers to select more efficient technologies, are either addressed by the modelling instruments discussed in this section or directly reflected in the modelling mechanisms, where economic agents are informed correctly about the prevailing and - to some extent - future prices. This depends on the sector, since final demand sectors with shorter equipment lifetimes offer limited foresight compared to e.g., power generation or certain industrial sectors.

The penetration of ESCOs as explicitly incited by the EED creates a low-risk environment for consumers to engage in energy efficiency investments in the building structure and energy equipment. As is the case with labelling policies, the potential benefits of the penetration of ESCOs are modelled through reduced discount rates for certain sectors, mirroring the changes in the decision-making conditions and constraints of e.g., households and services. In addition, these measures induce lower technical and financial risk, reducing the perceived costs of new technologies and saving investments (see also point above on perception of costs).

Another key modelling tool relates to energy savings or efficiency value, acting as a virtual subsidy (or penalty) that makes energy saving investment more profitable for decision-makers. The energy efficiency value may represent the market clearing price of white certificates, namely the marginal cost of policies that oblige utilities to perform energy savings at their customer’s premises - otherwise they are subject to a penalty.

In the Reference Scenario these values represent the implementation of the EED energy savings obligations in domestic and service sectors, specific building renovation policy efforts or a large range of other pertinent measures, such as energy audits, energy management systems, good energy advice to consumers on the various benefits of energy efficiency investment and better practices, targeted energy efficiency education, significant voluntary agreements, etc.

In the new PRIMES BuiMo model building codes are explicitly introduced. The country relevant regulations for new buildings as well as for major renovation of existing buildings are directly included in the modelling. The Reference Scenario does not assume full compliance with the minimum performance requirements; compliance rates concern only the building codes of new buildings. For the years until 2015 the model makes use of the compliance rates recorded in the relevant study led by ICF International[68] and from that year onwards it assumes a steady increase of compliance rates with the EPBD. Moreover, the provisions of the EPBD for new buildings are considered, as well as country-specific regulations laid down in the NECPs, such as the Long-Term Renovation Strategies (where available).

The EED includes specific public procurement provisions and induces multiplier effects, as the public sector assumes an exemplary role, i.e., private consumers are imitating the public sector energy efficiency actions. Energy efficiency improvements also occur on the energy supply side, through the promotion of investments in CHP and in distributed steam and heat networks. These investments are combined with incentives on the consumer side to shift towards heating through district heating, both in the residential and the tertiary sectors, where applicable based on country plans and regulations.

Improvements in the network tariff system and the regulations regarding the design and operation of gas and electricity infrastructure are also required in the context of the EED; moreover, the EED requires Member States and regulators to encourage and promote participation of demand side response in wholesale and retail markets. In this context, the Reference Scenario assumes that intelligent metering is gradually introduced in the electricity system. This enables consumers to manage their energy use more actively. It allows for demand response so as to decrease peak and over-charging situations, which generally imply higher losses in the power grids. Thus, efficiency is also improved as a result of the intelligent operation of systems.

Finally, some policies and measures that do not target energy efficiency per se lead to significant additional energy efficiency benefits. Among these policies are the ETS Directive, the Effort Sharing Decision (ESR), and the CO_2 standards for light duty and heavy-duty vehicles.

Policies on promoting RES also indirectly lead to energy efficiency gains; in statistical terms many RES, such as hydro, wind and solar PV, have an efficiency factor of 1; thus, the penetration of RES in all sectors, in particular in power generation, induces energy savings in primary energy terms.

Other measures that foster energy efficiency relate to taxation, in particular excise duties and national carbon taxes. Excise duties are directly modelled in PRIMES by Member State and type of fuel, allowing for the full reflection of the effects of energy taxation and other financial instruments on end user prices and energy consumption. By assumption, current tax rates per Member State are kept constant in real terms throughout the projection period.

2.5.3. Renewable energy policies

The Reference Scenario starts from the assumption that the EU energy system would need to evolve based on the EU legally binding target for RES in the revised RES Directive (at least 32% share of gross final energy consumption from RES by 2030), which is slightly overachieved (33.1%) based on the aggregation of national contributions laid down in the NECPs.

The Reference Scenario considers the most recent available data on RES potentials by Member State and the projections on RES share trajectories by sector (overall, RES-H&C for heating and cooling, RES-T for transport and RES-E for electricity) as expressed in the

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[68] https://ec.europa.eu/energy/sites/ener/files/documents/MJ-04-15-968-EN-N.pdf

NECPs. Furthermore, RES potentials, which previously relied on different sources, have been updated and refined on the basis of the ENSPRESO database of JRC.

According to the projection, the enabling conditions for the penetration of RES improve significantly, since the Reference Scenario incorporates known direct RES aids (e.g., feed-in tariffs, feed in premium schemes) and other RES supporting policies, such as priority access, grid development and streamlining of authorisation procedures.

PRIMES provides a detailed modelling of Member State policies representing a variety of economic support schemes. RES investments and incentives resulting from the overall policy and economic context have been projected, assuming that investors evaluate project-specific Internal Rates of Return including the financial incentives and decide upon investing accordingly. The projected RES investments implied directly for the financial incentives are considered as given by the market model, which decides upon the remaining potentially necessary investments (among all power generation technologies) based on pure economic considerations with a view to meeting the RES obligations.

Moreover, special fuel and electricity price elements (fees) are accounted for in the model to recover fully all the costs associated with RES deployment, which are calculated through the incentives and the contracting obligations over time. The model keeps track of the RES technology vintages as projected too.

The RED II requires fuel suppliers to supply a minimum of 14% of the energy consumed in road and rail transport by 2030 as renewable energy. Renewable energy used in aviation and maritime transport sectors can also contribute towards this target. For this target to be met, RED II defines a series of sustainability and GHG emission criteria that bioliquids used in transport must comply with. Some of these criteria are the same as in the original RED, while others are new or reformulated and are thus captured in the modelling. In particular, the RED II introduces sustainability for forestry feedstocks as well as GHG criteria for solid and gaseous biomass fuels.

To address the issue of Indirect Land Use Change (ILUC) RED II sets limits on high ILUC-risk biofuels, bioliquids and biomass fuels with a significant expansion in land with high carbon stock. Member States will still be able to use (and import) fuels covered by these limits, but not include these volumes when calculating the extent to which they have fulfilled their RES targets (overall and in transport). These limits freeze at 2019 levels for the period 2021-2023 and start to decrease gradually from the end of 2023 reaching zero in 2030. The Directive also introduces an exemption from these limits for biofuels, bioliquids and biomass fuels certified as low ILUC-risk.

Within the 14% transport sub-target, there is a dedicated target for advanced biofuels produced from feedstocks[69]. Their contribution as a share of final consumption of energy in the transport sector shall be at least 0.2 % in 2022, at least 1 % in 2025 and at least 3.5 % in 2030. Multipliers as foreseen in the RES-T calculation of the RED II are fully accounted for in the modelling for advanced biofuels as well as for electricity consumption in transport. The multipliers foreseen for aviation and maritime are also accounted in the modelling.

For Member States which are not projected to achieve their RES target through direct incentive policies in the first place, an additional instrument is included in the modelling, the so-called RES-value. In modelling terms, the RES-value is the shadow value of the RES target: it can be applied to all types of RES individually e.g., to RES-E, RES H&C and RES-T. It represents yet unknown policies, which would be implemented by 2030 to provide the necessary incentives to reach the national RES shares. These could include further legislative facilitations, easier site availability or grid access, or even direct financial incentives. The costs related to investments induced through the RES-value are fully

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[69] Part A, Annex IX, Directive (EU) 2018/2001

reflected in the model and recovered through electricity prices, the steam/heat prices and are accounted for in the investment costs of buildings for direct RES use. A separate RES-value for transport is also applied, where necessary, to achieve the 14% obligation for RES-T in 2030.

Beyond 2030, no additional RES targets are set and therefore no additional specific RES policy support is modelled, as a general rule.

Although direct incentives are phased out in power generation, investments in RES continue beyond 2030 due to three main factors: (i) the learning-by-doing assumed in the techno-economic assumptions (see Annex III), which makes several RES technologies economically competitive; (ii) the increasing ETS carbon price; and (iii) extensions in the grid and improvement in market-based balancing of RES as well as maintaining priority dispatch, although the possibility for RES curtailment is also modelled. The latter implies that RES curtailment is possible if the system requires it, however the continuation of RES priority dispatch in the Reference Scenario implies that this option is barely used under such conditions. In addition, some incentives for innovative technologies such as tidal, geothermal, solar thermal, and remote off-shore wind are phased out more gradually than for mature technologies.

In transport, national blending obligations are assumed to be maintained post-2030, where these exist.

2.5.4. Transport policies

For the transport sector, the Reference Scenario reflects a wealth of policy measures at EU level, which drives: (i) the uptake of zero- and low-emission vehicles and the roll-out of the associated recharging/refuelling infrastructure[70]; (ii) the uptake of renewable and low carbon fuels[71]; (iii) improvements in transport system efficiency, by making the most of digital technologies and smart pricing and further encouraging multi-modal integration and higher use of sustainable transport modes[72]. The Reference Scenario also includes initiatives addressing road safety[73], contributing in this way to the reduction of external costs on transport.

For the CO_2 standards for light duty vehicles (LDVs), the Reference Scenario considers the Regulation that sets CO_2 emission performance standards for new passenger cars and for new light commercial vehicles, adopted in 2019. The modelling assumes that average CO_2 emissions of new cars registered in the EU will have to be 15% lower in 2025 and 37.5% lower in 2030, compared to 2021. The CO_2 emissions of new light commercial vehicles will need to be 15% lower in 2025 and 31% lower in 2030. These are represented as EU-wide fleet targets in the model, in line with the Regulation. The CO_2 reduction effort will be distributed among manufacturers on the basis of the average mass of their vehicle fleet. Incentives provided for in the regulation are included in the modelling.

For heavy duty vehicles (HDVs), the Reference Scenario takes into consideration the 2019 Regulation[74] that sets first-ever EU-wide CO_2 emission performance standards to achieve a 15% average emissions reduction from new lorries from 2025 onwards, and a 30% reduction from 2030. The targets are expressed as a percentage reduction of

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[70] It includes the post-2020 CO2 standards for new light duty and heavy-duty vehicles, the Clean Vehicles Directive, and the Directive on the deployment of alternative fuels infrastructure.

[71] It covers the Renewables Energy Directive, the Fuel Quality Directive, and the Directive on the deployment of alternative fuels infrastructure.

[72] It includes the TEN-T Regulation supported by CEF funding, the fourth Railway Package, the Rail Freight Corridors Regulation, 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, the EU urban mobility package, etc.

[73] Based on the fatality and serious injury savings projected by the changes to the General Safety Regulation (Regulation (EU) 2019/2144) and the Road Infrastructure Safety Management Directive (Directive (EU) 2019/1936).

[74] Regulation (EU) 2019/1242

emissions compared to EU average in the reference period (1 July 2019 - 30 June 2020). Incentives provided for in the Regulation are included in the modelling.

The PRIMES-TREMOVE model has been shifted entirely to WLTP test cycles for the achievement of the regulations and the true energy consumption and emissions are based on the real-world performance of cars.

The energy consumption calculated in the model accounts for the gap between the laboratory tests and the real-world performance of cars. The model uses the COPERT methodology to calculate energy consumption by vehicle type, type of trip and time, as a function of the average speed. The model does not assume one single value for specific fuel consumption of vehicles. The model considers discrete specific fuel consumption formulas for all trip types (i.e., more than 30) and for all vehicle technologies. The congestion effect, which is partly responsible for the discrepancy, is also captured through changes in the average speed of vehicles. Assuming, for example, that a vehicle is mostly used in urban areas, this results in lower average speed, which increases its specific fuel consumption. Furthermore, different types of technologies (battery electric, internal combustion, plug-in hybrid) have different characteristics which can influence their performance depending on the trip type. This implies that the model calculates different divergence factors taking into consideration vehicle type and trip type. The market uptake of new vehicles complying with these standards continues to drive emissions down post-2030.

Moreover, the Reference Scenario considers the AFID Directive[75], which promotes electro-mobility and the use of alternative fuels (e.g., liquefied natural gas in road freight and shipping), accounting for incentives for the uptake of alternative fuels infrastructure in place at Member State level.

Improvements in transport system efficiency, by tapping into digital technologies and smart pricing and further encouraging multi-modal integration and shifts towards more sustainable transport modes, are facilitated by the TEN-T Regulation, the Fourth Railway Package, 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, the Reference Scenario considers the implementation of the EU ETS (section 2.5.1), the Single European Sky, the deployment of SESAR solutions, the research and development of cleaner aircraft technologies lead by the Clean Sky public-private partnership and aircraft CO_2 emissions standards, as part of the so-called “basket of measures” that aims to reduce emissions from the sector.

For maritime, the Reference Scenario reflects the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP) adopted by the International Maritime Organisation (IMO), as well as IMO MARPOL Annex VI rules as regards the reduction of nitrogen and sulphur oxides emissions, the latter being transposed into EU legislation by the Sulphur Directive[76]. It also accounts for other initiatives addressing air pollution from inland waterways vessels[77].

2.5.5. Other policies impacting sectors covered by the ESR

For sectors not covered by the EU ETS, excluding LULUCF, the Effort Sharing Regulation (ESR) sets binding annual reduction targets for Member States aiming at an EU-wide

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[75] Directive 2014/94/EU

[76] Directive (EU) 2016/802 of the European Parliament and of the Council of 11 May 2016 relating to a reduction in the sulphur content of certain liquid fuels, OJ L 132, 21.5.2016, p. 58–78.

[77] Regulation (EU) 2016/1628 of the European Parliament and of the Council of 14 September 2016 on requirements relating to gaseous and particulate pollutant emission limits and type-approval for internal combustion engines for non-road mobile machinery.

emission reduction of 30% by 2030 compared to 2005. The ESR targets are set according to national wealth and cost-effectiveness and flexibilities such as transfers between Member States are foreseen. The national ESR 2030 targets range from 0% to -40%. To achieve the targets, the ESR also defines for each country a linear reduction trajectory defining annual emission allocations between 2021 and 2030.

The ESR maintains flexibilities of the Effort Sharing Decision (e.g., banking, borrowing, and buying and selling between Member States) and provides two additional flexibilities to allow for a fair and cost-efficient achievement of the targets: access to allowances from the EU ETS and access to credits from the land use sector.

Overall existing policies as reflected in the Reference Scenario result in an emission reduction in the ESR by 2030 that is more ambitious than the set target.

Accessing allowances from the EU ETS

The ESR allows certain Member States that have national reduction targets significantly above the Union average and their own cost-effective reduction potential, or that did not allocate any EU ETS allowances for free to industrial installations back in 2013, to use a limited amount of ETS allowances in the period 2021-2030 in order to offset emissions in the effort sharing sectors. Member States may as well request downward revisions of their percentages for later years in the compliance period in 2024 and 2027, respectively. Some Member States intend to use their full amount of flexibility, others have decided not to. The allowances used under the ESR are deducted as of 2021 from the amounts that would normally be auctioned under the EU ETS and thus reduce the overall ETS cap.

Accessing credits from the land-use sector

Member States can use up to 262 million credits from the land-use sector over the entire period 2021-2030 to comply with their national targets deriving from the ESR. All Member States are eligible to make use of this flexibility if needed, while access is higher for Member States with a larger share of emissions from agriculture, which acknowledges the lower mitigation potential for emissions from the agriculture sector. The use of such credits is not explicitly modelled, given that the ESR as a whole is projected to be in compliance

Agriculture

Much of the legislation affecting agriculture has impacts on projected activity. The new Common Agricultural Policy (CAP) reform[78] for the period 2021-2027 was agreed on 29 June 2021 between the European Parliament and Council of the EU, and so the provisional start date has been pushed to 2023. The new CAP includes various changes to the system of direct payments which are included in CAPRI. Agricultural policies that aim at improved use of fertilizers or that have impacts on livestock productivity and stock numbers are reflected in the CAPRI parameters reflecting nitrogen use efficiency. However, while a general improvement in nitrogen use efficiency is included, the CAPRI projections do not include the specific targets set out in the Farm to Fork Communication[79], for example a 25% share for organic agriculture, a 20% reduction in fertiliser use and a 50% reduction in nutrient losses. It neither includes the impact of CAP strategic plans under development. Requirements to avoid further conversion of permanent grassland into other uses were directly implemented. The resulting changes in projected activity levels (herds and mineral fertiliser consumption) had direct impact on non-CO_2 greenhouse gas emission estimates in GAINS via the use of CAPRI activity data as drivers.

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[78] https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/future-cap_en

[79] COM/2020/381 final

F-gases

The Reference Scenario considers the EU F-gas Regulation, in force since 2015, which aims to phase out the amount of hydrofluorocarbons (HFCs) that can be sold in the EU to 1/5 of today's sales. In the Reference Scenario this is expected to cut EU F-gas emissions by 65% between 2015 and 2030, and by around 81% until 2050. The corresponding cuts in expected HFC emissions are 70% by 2030 and 88% by 2050. To assess the impact of the new Regulation, the modelling work has accounted for the useful lifetime of the refrigeration and air-conditioning units, market penetration of low-GWP HFC alternatives, etc. In GAINS, a number of low GWP alternatives to HFCs are considered (with varying applicability to different sectors), i.e., hydrocarbons (i.e., HC-600a, HC-290, HC-1270), ammonia (NH3), pressurized carbon dioxide (CO_2), hydrofluoroolefins (i.e., HFO-1234yf, HFO-1234ze, HFO-1233zd, HFO-1336mzz), low-GWP HFCs and blends (HFC-32, HFC-152a, HFC-446A, HFC-447A), water chillers and fluorinated ketone (FK). Though a range of hydrocarbons have refrigerant applications, iso-butane (HC-600a) is the most frequently used in domestic fridges and freezers, while for commercial fridges and freezers propane (HC-290) is substituting HFCs in smaller units and pressurized CO_2 in larger units. Propane (HC-290) and HFC-32 are common substitutes for HFCs in stationary air-conditioning. Due to its relatively high GWP100 of 677, the use of HFC-32 in residential ACs makes up most of the remaining warming potential from HFCs in 2050. Furthermore, impacts on PFC emissions from a voluntary agreement in the semiconductor industry have been considered in the GAINS Reference Scenario.

Waste

The Circular Economy Package was adopted in 2015 with the aim to stimulate Europe's transition towards a circular economy that boosts competitiveness, fosters sustainable economic growth, and generates new jobs. The Package includes revised legislative proposals on waste, which have been adopted and included in the Reference Scenario. These are: Directive on Waste[80] and Packaging Waste[81], Landfill[82] and Electrical and Electronic Waste, End-of-life Vehicles, Batteries and Accumulators and Waste Batteries and Accumulators[83].

By 2030 a number of targets have been set: a common EU target for recycling 65% of municipal waste and a common EU target for recycling 75% of packaging waste; a binding landfill target to reduce landfill to maximum of 10% of municipal solid waste (MSW) by 2035 and a ban on landfilling of separately collected waste. The Reference Scenario also includes a number of national waste policies that may go beyond the Directives. In GAINS, the respective future treatment paths are simulated, and associated emissions estimated by taking the current treatment structures as starting points and assuming that countries meet the targets of the amended EU Waste Directive from 2018. A linear phase-in of the future targets is assumed for the period 2020 to 2035. The targets are met by moving increasing amounts of MSW away from landfill disposal and towards other treatment options (recycling, anaerobic digestion, incineration with energy recovery), considering the specific options available for different types of waste and following the treatment priority order of the EU waste hierarchy.

2.5.6. LULUCF Regulation

The Land Use, Land Use Change and Forestry (LULUCF) Regulation[84] adopted in 2018 enshrines for the first time in EU law the requirement accounted GHG emissions from land

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[80] Directive (EU) 2018/851
[81] Directive (EU) 2018/852
[82] Directive (EU) 2018/850
[83] Directive (EU) 2018/849
[84] Regulation (EU) 2018/841

use, land use change or forestry are balanced by at least an equivalent accounted removal of CO_2 from the atmosphere in the period 2021 to 2030. In practice, the LULUCF Regulation sets a binding commitment for each Member State to ensure that accounted emissions from land use are entirely compensated by an equivalent accounted removal of CO_2 from the atmosphere through action in the sector (“no debit” rule). Moreover, the scope is extended to all land uses.

The Regulation points to the critical role of the land use sector in reaching long-term climate mitigation objectives and includes incentives to improve land use practices. It also foresees flexibility and trading clauses, and flexibility towards the ESR; namely if a Member State has net accounted emissions from land use and forestry, they can use allocations from the ESR to satisfy the "no debit" rule. Moreover, Member States can buy and sell net accounted removals from and to other Member States or choose to enhance removals or reduce emissions in the LULUCF sector, thereby helping compliance of the agriculture sector in the ESR where emissions from fertilizer and livestock are accounted.

Regarding emissions from biomass used in energy, these are recorded and accounted towards each Member State's 2030 climate commitments for the first time, through a novel accounting application introduced by the LULUCF Regulation.

In October 2020, the Commission amended Annex IV of the Regulation with a delegated act that lays down forest reference levels (FRLs) which each country must apply between 2021 and 2025. Forest reference levels are forward-looking benchmarks for accounting net emissions from the existing forests in each EU country. They are based on a continuation of sustainable forest management practices from the period 2000-2009. They draw on the best available data and dynamic age-related forest characteristics.

2.5.7. Assumptions on implementation of internal energy market policies

The Reference Scenario modelling includes a shift towards flow-based allocation of interconnection capacities, assuming a market model purely relating trade to market forces throughout the EU internal energy market with perfectly operating market coupling across all participating countries. The EU target model is assumed to be successfully implemented from 2025. This implies that the Net Transport Capacity (NTC) levels will be higher than currently (closer to their physical capabilities) and that there is higher coordination between TSOs reducing the balancing costs.

Consequently, the balancing of RES is assumed to occur in a very cooperative and cost-efficient manner, allowing to avoid excessive investments in peak devices. Assuming that improvements in grid infrastructure take place and that the Ten Years Network Development Plan (TYNDP) of ENTSO-E (see next section) is completed, the integration of RES is significantly enhanced. Moreover, market improvements and market coupling across the EU keep balancing costs for RES low, which further eases their market penetration.

2.5.8. Updates in infrastructure developments

The PRIMES model and its sub-models consider the official infrastructure development plans from ENTSOE, ENTSOG and the TEN-T networks for transport.

Electric grid

All interconnectors between Member States with their technical characteristics and capacities are represented in PRIMES; the import-export module further includes also non-EU countries such as Switzerland and Norway, as well as the Southeast European area, due to their strong connection with the EU electricity market. Interconnections to and from these countries are fully included.

Regarding grid development and the interconnectors between countries the developments of the ENTSOE Ten Year Development Plan (TYNDP) are accounted for in the import-export module of PRIMES. The timeline of the TYNDP is also followed. After the end of the TYNDP, expansions are based on the known capacity expansion developments and the developments of RES. Within countries the grid expansions are assumed to be a function of capacity expansion particularly for RES.

The ENTSOE development plan regarding grid reinforcements within each country is also being considered. Such reinforcements aim at relaxing some of the tight Net Transfer Capacity constraints prevailing today and causing congestions, and so help maximise the integration of RES into the grid. The combination of these elements implies that the ENTSOE development plan not only reinforces interconnection of countries, but also allows for wide market coupling in parallel with inter-TSO coordinated dispatching. This interconnector list is largely based on the ENTSOE Ten-Year Network Development Plan, answers to questionnaires distributed during the consultation procedure, other studies and further review undertaken by E3-Modelling.

Gas networks

The PRIMES-Gas module represents in detail the present and future gas infrastructure of each Member State and of gas producing and consuming countries of the Eurasian area, including Russia, Ukraine, Belarus, the Caspian countries, Middle East (including Israel), Persian Gulf (including Qatar which is the largest LNG supplier worldwide) and North African countries (Algeria, Libya and Egypt). The model also represents the supply possibilities of LNG worldwide and the demand for LNG. The infrastructure types include gas production, pipelines (represented as a network), gas storage facilities, LNG regasification terminals and gas liquefaction. Operation of infrastructure and related gas flows are constrained by a physical system involving pipelines, LNG terminals, gas storage facilities, liquefaction plants and gas producing wells.

The PRIMES-Gas module considers a comprehensive list of PCI gas infrastructure projects, including major gas infrastructure projects with neighbourhood countries, interconnections between EU Member States, expansion of existing pipeline capacities, new bidirectional pipelines, LNG import terminals and storage facilities in each of the EU 27 Member States. This list is largely based on the ENTSOG Ten-Year Network Development Plan, answers to questionnaires distributed during the consultation procedure, other studies and further review undertaken by E3-Modelling.

Transport infrastructure

The developments in transport infrastructure mainly affect transport activity projections. In the EU Reference Scenario, the core TEN-T network is assumed to be completed by 2030 and the comprehensive TEN-T network by 2050. Foreseen developments for rail and motorways are included, also reflecting information received through the replies to the MS policy questionnaires.

Regarding high-speed rail, the plans foreseen in the TEN-T guidelines have been included, complemented by information received through the replies to the MS policy questionnaires. In addition, the replies to the MS policy questionnaires (including existing plans) have also been used for assumptions on rail electrification.

2.6. Other important assumptions

2.6.1. Discount rates

The PRIMES model is based on individual decision making of agents demanding or supplying energy and on price-driven interactions in markets. The modelling approach is not taking the perspective of a social planner and does not follow an overall least cost optimization of the entire energy system in the long-term. Therefore, social discount rates play no role in determining model solutions.

On the other hand, private discount rates pertaining to individual agents play an important role in their decision-making. Agents' economic decisions are usually based on the concept of cost of capital, which is, depending on the sector, either the weighted average cost of capital (for larger firms) or a subjective discount rate (for individuals or smaller firms). In both cases, the rate used to discount future costs and revenues involves a risk premium which reflects business practices, various risk factors or even the perceived cost of lending. The discount rate for individuals also reflects an element of risk averseness.

The discount rates vary across sectors. In the Reference Scenario modelling, the discount rates range from 7.5% (in real terms) applicable to public transport companies or regulated investments as for example grid development investments (in the form of weighted average cost of capital) up to 12% applicable to individuals (households). Additional risk premium rates are applied for some new technologies at their early stages of development impacting on perceived costs of technologies.

The decision-making discount rates used by sectors are summarised in the following tables.

Table 4: Discount rates in energy supply sectors

Assumptions for EU Reference Scenario 2020	Discount rates
Regulated monopolies and grids	7.5%
Companies in competitive energy supply markets	8.5%
RES investment under feed-in-tariff	7.5%
Investment under contract for differences	7.5%
RES investment under feed-in premium, RES obligation, quota systems with certificates	8.5%
RES investment in competitive markets	8.5%
Risk premium specific to immature or less accepted technologies	1%-3%
Risk premium specific to investment surrounded by high regulatory or political uncertainty	None
Country-specific risk premiums	None

Table 5: Discount rates of firms in energy demand sectors

Assumptions for EU Reference Scenario 2020	Discount rates
Energy intensive industries	7.5%
Non energy intensive industries	9%
Services sectors	11%
Public transport (conventional rail, public road)	7.5%
Public transport (advanced technologies, e.g., high speed rail)	8.5%
Business transport sectors (aviation, heavy goods vehicles, LCVs, maritime)	9.5%
Country risks	None

Table 6: Discount rates of individuals in energy demand sectors

Assumptions for EU Reference Scenario 2020	Discount rates	Modified discount rates due to EE policies[85]
Passenger cars and powered two wheelers	11%	
Households for renovation of houses and for heating equipment	14.75%	12%
Households for choice of appliances	13.5%	9.5%
By income class (for the decision on renovation and the choice of equipment)		
Low	14.1%	
Low-Mid	13.6%	
Mid	13.2%	
Mid-High	12.8%	

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[85] It is assumed that standard discount rate values are pushed downwards by policies addressing the barriers which caused the high discount rate values in the first place.

Table 7: Discount rates of refuelling/recharging infrastructure

Assumptions for EU Reference Scenario 2020	Discount rates
Refuelling/recharging infrastructure	8.5%

The use of discount rates is also necessary for annualising capital or investment expenditures (CAPEX) for cost reporting. The yearly energy system cost in the Reference Scenario modelling is calculated using, over the entire period of the projection, a flat discount rate of 10% for annualising CAPEX of end-consumers.

Details on the methodology related to the discount rates can be found in Annex V of this report.

The GAINS Reference Scenario modelling also uses private discount rates, using a flat discount rate of 10% for decision-making and cost reporting.

3. Results of the Reference Scenario

The Reference Scenario reflects the outcomes of adopted EU level policies by the end of 2019 and takes into account national contributions and planned policies as well as Member State projections as provided in the respective NECPs in relation to transport activity, energy demand, power generation and GHG emissions in the EU until 2050. Projections are available on a five-year basis for each Member State and for the EU as a whole[86].

Considering the timeline of the policies included in the Reference Scenario, the modelling results are presented for two periods: 2015-2030 and 2030-2050. For the decade 2021-2030 the Reference Scenario captures the impacts of policies adopted at EU level by the end of 2019 and mirrors the targets from the NECP With Additional Measures (WAM) scenarios where available, while maintaining a homogenous and consistent set of assumptions across all EU Member States.

National policies and measures may be accompanied by voluntary initiatives at sectoral and/or regional level, provided these include monitoring and some form of enforcement and sanctioning mechanisms. The aforementioned policies, measures and initiatives form part of the NECPs.

The aim of the Reference Scenario is not to reach climate neutrality but to reveal the distance to be covered to that end, having the current policy framework as starting point. For this reason, as described in section 2.5, the level of intensity of policies does not increase beyond 2030, but technology and market dynamics along with the EU ETS are those factors shaping the projections in the period 2030-2050.

3.1. Energy consumption

After peaking in 2006, energy consumption had started to decline already before the global financial crisis of 2007-2009 hit. The decoupling of energy demand from economic growth has been the trend since then. The fall in consumption is projected to be halted only between 2020 and 2025, due to the rebound of energy demand in the aftermath of the COVID-19 pandemic. Energy efficiency and RES policies accelerate the decoupling in the decade 2021-2030. Long-lasting effects of these policies and technology trends sustain the decoupling also after 2030.

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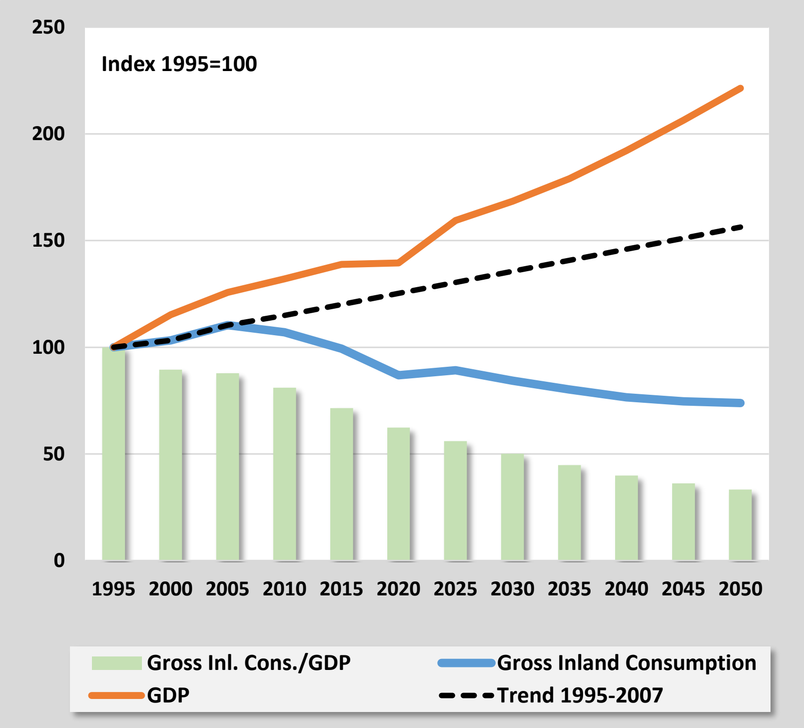
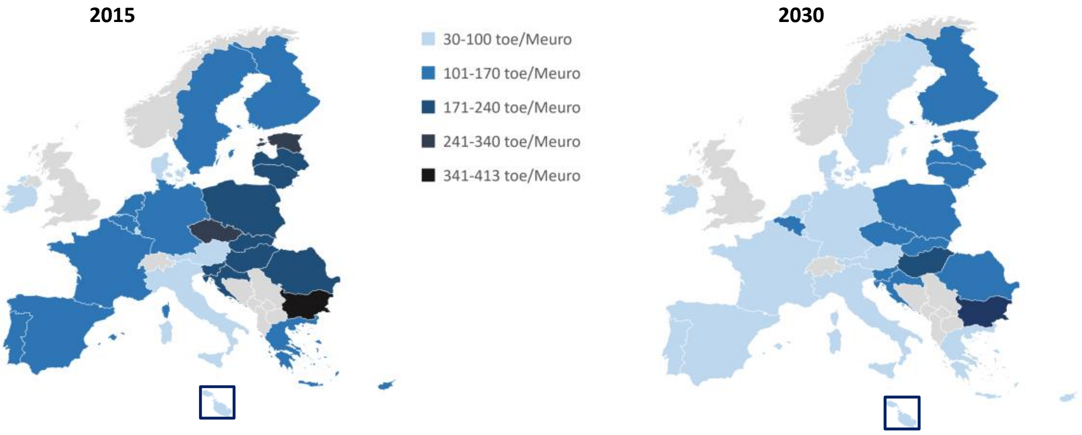
[86] Summary results for EU27 and for each country are presented in the Annex.

Figure 9: GIC in relation to GDP



Energy intensity of GDP varies by country (see Figure 10), depending on the structure of primary energy production, industrial structure and renovation and the fuel mix used for electricity generation. Overall, the energy intensity of the economy is improving throughout the projection period and over time in all countries and a slow convergence can be observed as energy intensity declines and GDP increases faster in countries with initially high energy intensity.

Figure 10: Gross Inland Consumption over GDP (toe/m euro'2015) by Member State in 2015 and 2030



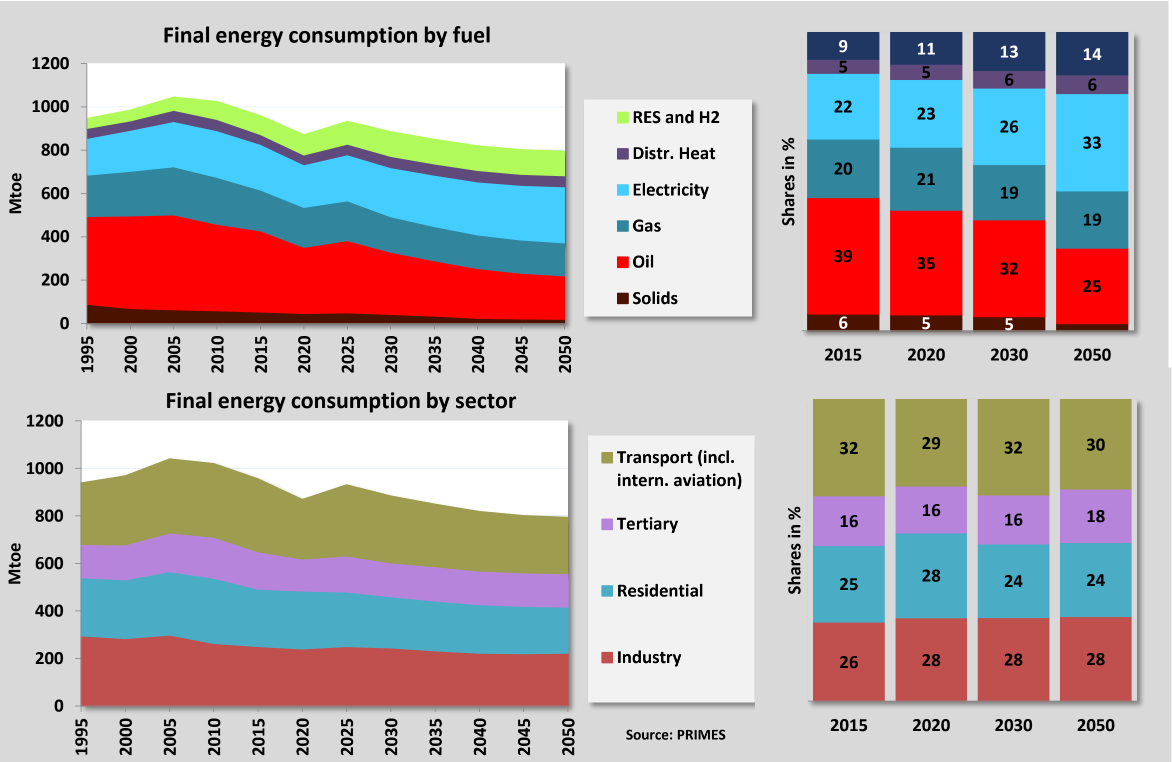
The decreasing trend of total primary energy requirements is associated with the developments in final energy demand, as well as a shift towards renewable energy sources in power generation. Energy efficiency promoted through the EED, EPBD and the Ecodesign Directives and a host of regulations for specific products, CO_2 emissions standards for vehicles, etc. is a key driver of the drop in energy demand. It is clear that the period 2021-2030 will set the ground for an economy with lower energy intensity, while the assumed continuation of these policies is expected to deliver energy efficiency improvements after 2030 too.

Figure 11 shows the projection of final energy consumption (including international aviation) by fuel and by sector. The effects of COVID-19 pandemic in 2020 can be observed in all sectors, and especially in transport. After a short-term rebound following the exceptional decline recorded in 2020, final energy demand of transport is projected to decline gradually from 2025 onwards driven by energy efficiency improvements. The structure of final energy demand by sector remains rather stable over time, with transport occupying the largest share until the end of the projection period, followed by industry and residential.

In industry, the uptake of energy efficiency measures and the shift towards higher value added and less energy intensive products causes energy demand to drop. The share of energy consumption in houses and buildings decreases in 2030 thanks to the energy efficiency policies. In the meantime, the EU ETS continues to indirectly support energy efficiency and higher RES penetration in the ETS sectors.

Final consumption of oil decreases over time. However, oil retains a significant share of total demand, due to its persistence in transport and the limited uptake of alternative fuels under Reference Scenario assumptions. Meanwhile, natural gas is projected to remain relatively stable over time, slightly declining both in share and absolute terms. The impressive decline in solid fuels is the result of fuel switching in industry triggered by the EU ETS and the phase-out of coal boilers, linked with market trends and domestic policies. The share of direct RES use in final energy increases steadily over time but direct use of RES remains small in volume. District heating remains almost stable until 2050 with a tendency to increase slightly.

Figure 11: Final energy consumption by fuel and by sector


Final energy consumption by fuel

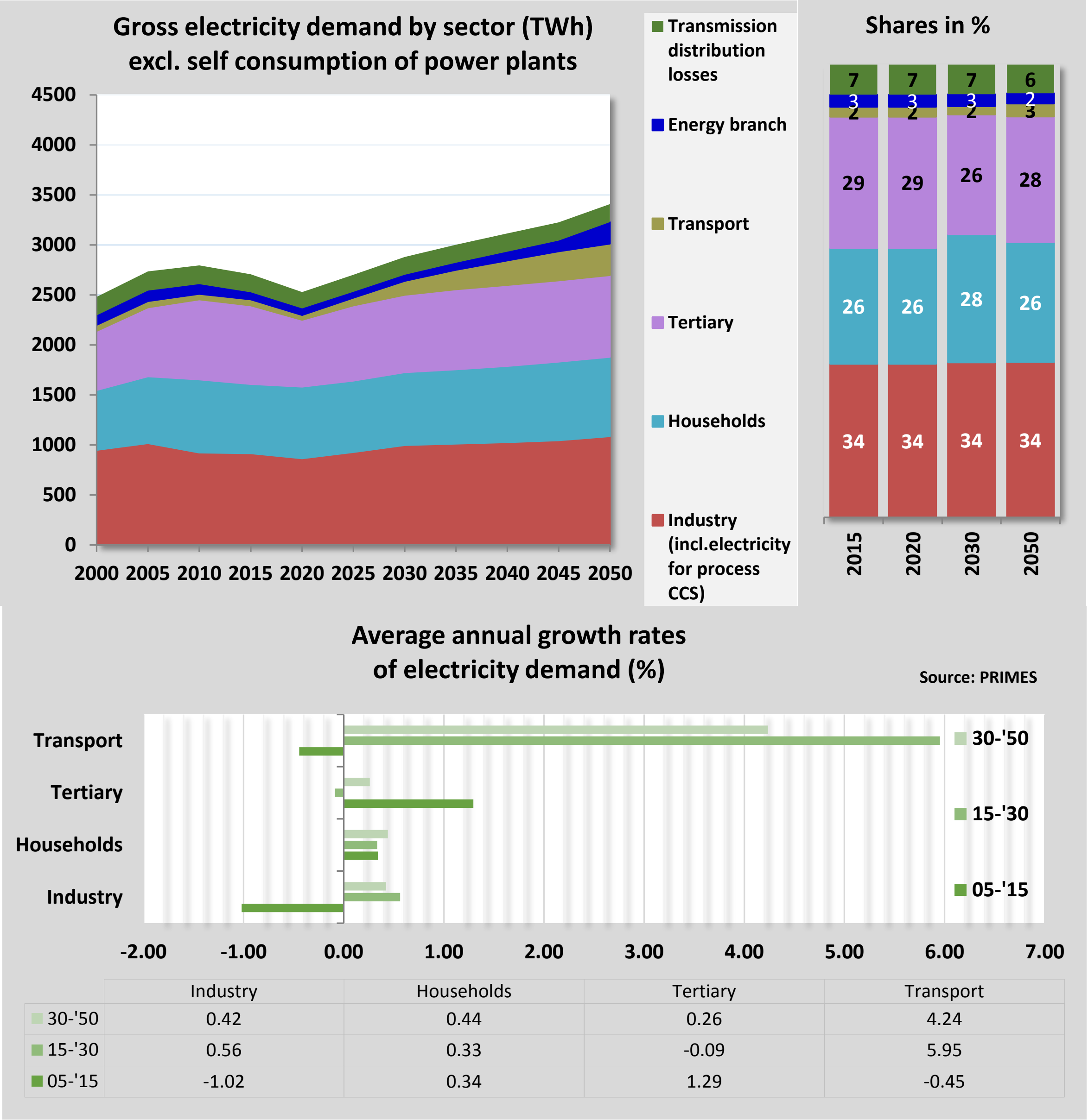
Final energy consumption by sector

Source: PRIMES

Electrification of final energy demand is a persisting trend. The share of electricity in total final demand reaches 26% and 33% in 2030 and 2050, respectively (compared to only 22% in 2015, see Figure 11). This is attributed to two main trends: **(i)** the electrification of heating in buildings, with the uptake of heat pumps and the continuous increase in the use of electric appliances in the residential and the tertiary sectors (mainly IT, leisure, and communication appliances); **(ii)** the electrification of transport, due to the penetration of electric vehicles. Electricity shares increase in industrial processing also, yet at a slow pace, in accordance with the Reference Scenario context.

At the end of the projection period, electricity consumption increases in the energy branch too, driven by hydrogen production that is used in road transport. Overall, the absolute growth in gross electricity demand by 2050 is driven mainly by transport and to a lesser extent by the energy branch sector at the end of the projection period.

Figure 12: Trends in electricity demand by sector



	Industry	Households	Tertiary	Transport
30-'50	0.42	0.44	0.26	4.24
15-'30	0.56	0.33	-0.09	5.95
05-'15	-1.02	0.34	1.29	-0.45

3.1.1. Industrial sector

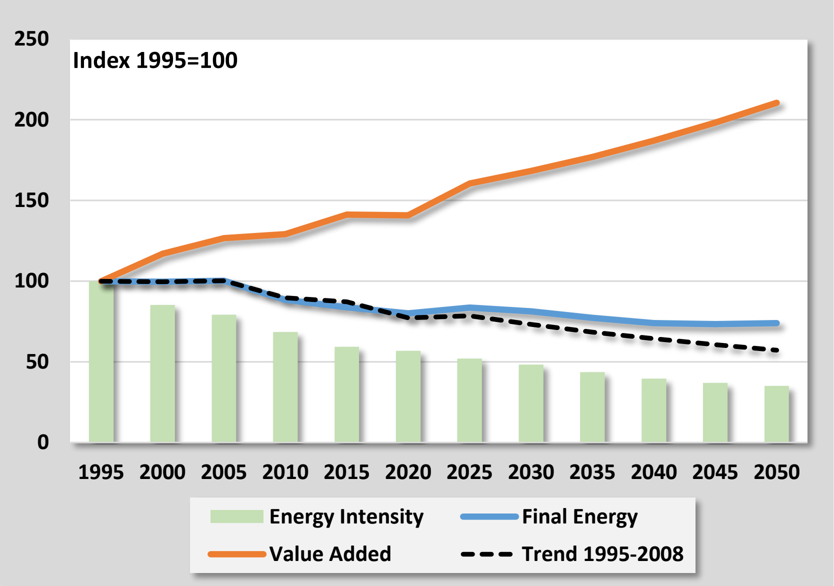
The macro-economic projection underlying the Reference Scenario implies that significant part of the energy-intensive industrial productions will remain in the EU territory. Still, it assumes a gradual shift towards high value-added industrial products over time in an international competition context. This implies that production volume increases in the future at a pace slightly slower than the economic value added of the sectors and their contribution to GDP growth.

Moreover, the Reference Scenario takes into consideration strategies, initiatives and measures aimed at closing the loop in industry in the context of the Circular Economy Action Plan (2015). While the analysis does not consider the new Circular Economy

Action Plan[87] and the dedicated New Industrial Strategy for Europe[88], introduced in 2020, which put circular economy at the heart of industrial processes and so help deliver the European Green Deal, recycling of materials is assumed to progress over time, which implies a further improvement in the overall energy intensity of the sector, since recycled products are less-energy intensive than non-recycled ones. Finally, improvement of energy efficiency supports the overall improvement of energy productivity of the sector. These trends are even more pronounced in non-energy intensive sectors.

These structural shifts explain the growing gap between value-added and final energy in industry. The pace of energy intensity improvement is similar in all sectors. In 2020, industry felt the effects of the COVID-19 crisis but is assumed to be back to almost pre-COVID-19 levels by 2025. In the medium and long-term, energy intensity drops along the cycle of capital turnover (and investments in more efficient technologies and processes), driven also by carbon pricing.

Figure 13: Industrial energy demand vs. activity



The projection keeps track of vintages of productive equipment in industry. The recovery of activity growth in the short term implies that industries use mainly existing equipment, including the less efficient ones, as low activity growth in recent years has discouraged investment and has left part of capacities unused. The post-pandemic economic rebound is expected to lead to investment in new productive equipment. Energy efficiency technologies and practices are projected to be embedded in new industrial capital vintages in the period 2021-30, allowing to mitigate costs and thus support industrial competitiveness.

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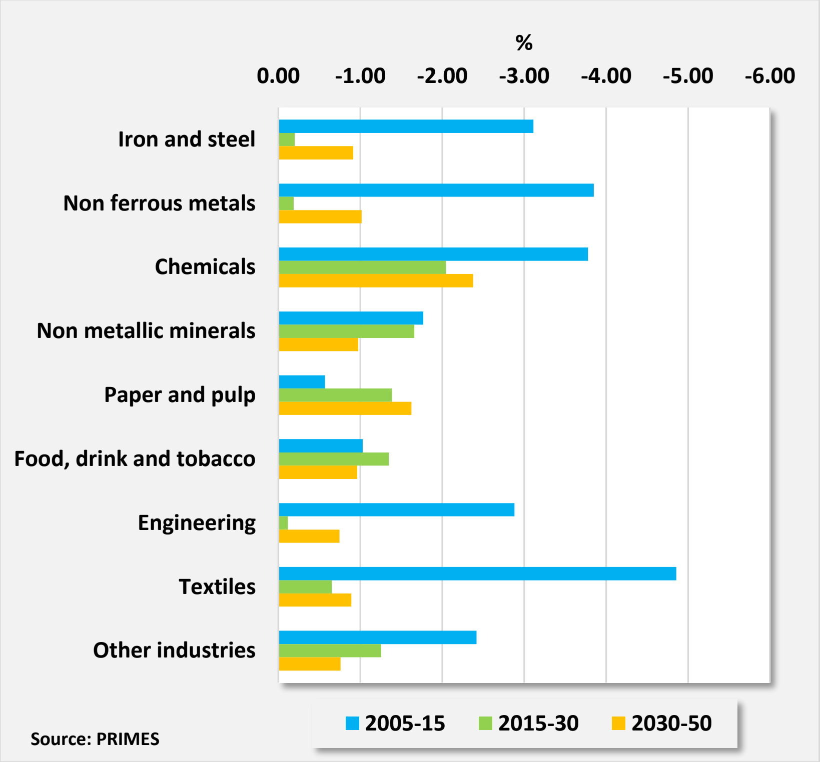
[87] COM/2020/98 final

[88] COM/2020/102 final

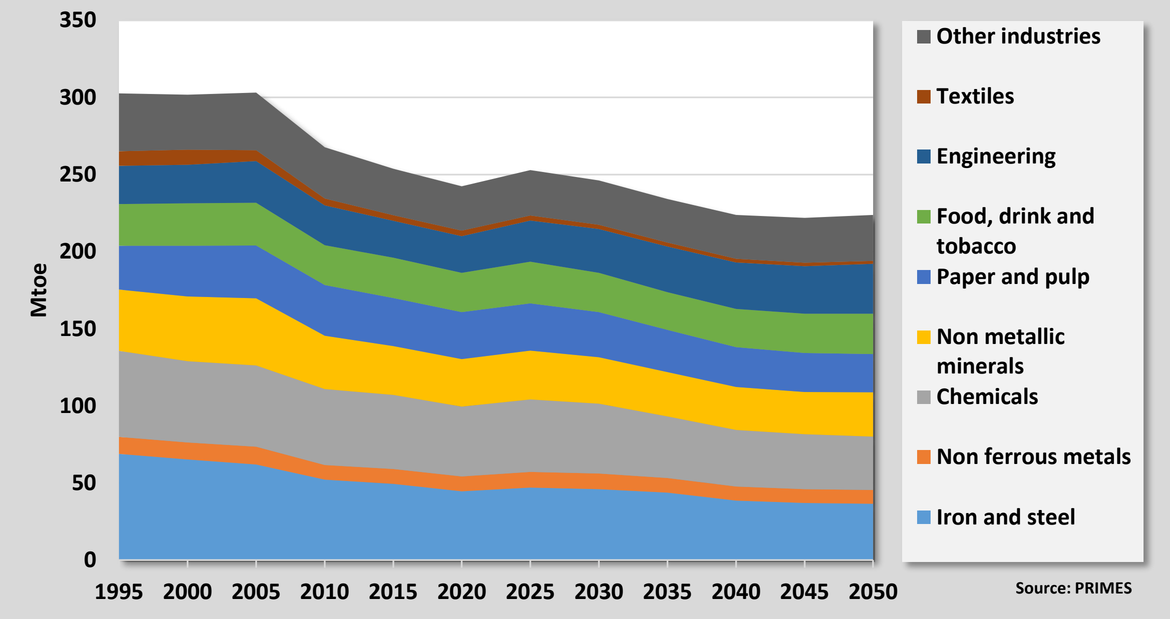
Figure 14: Average annual change of energy consumption in the industry sector



Source: PRIMES

Overall, the structure of final energy consumption in industry remains rather stable over time. The variations are explained by the capital turnover, business cycles and the impact of policy divers such as the EU ETS (Figure 15).

Figure 15: Final energy consumption in industry



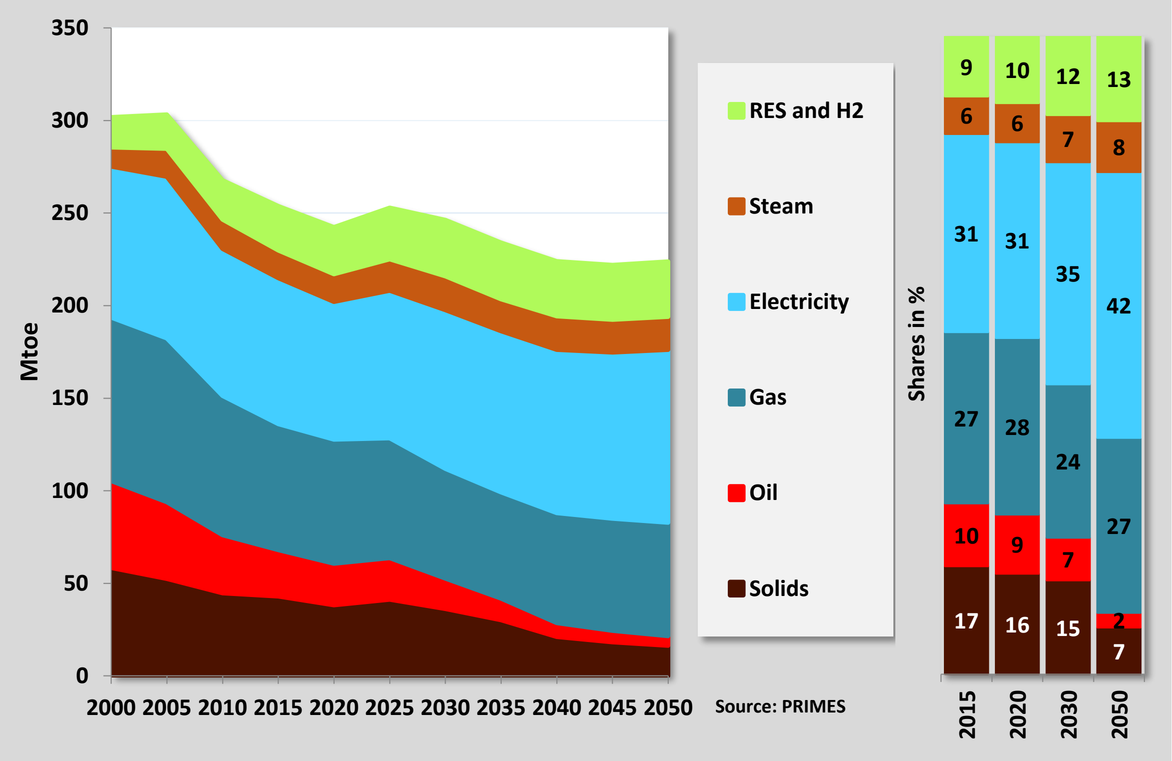
Source: PRIMES

To reflect the fuel mix in industry, PRIMES fully captures how industries produce steam, the role of co-generation and the evolution of the use of industrial boilers. The model covers 10 industrial sectors, on top of non-energy sectors, further split into 31 subsectors. Each subsector has its own processes, fuels, and equipment, as well as boilers and CHP units, where applicable. The fuel switching possibilities are specific to each subsector, which allows capturing the options available at great detail.

The projections point to a lengthy change in the fuel mix under Reference Scenario conditions. The phase-out of high CO_2 emitting fuels cannot certainly happen overnight and thus a structural shift away from oil and coal is not imminent. Still, restructuring is envisaged to take place in the long run, as a result of market forces. In the short- and medium-term, obligations arising from the Industrial Emissions Directive[89] (IED), along with national coal phase-out, RES support policies and the EU ETS are gradually affecting the fuel mix.

Electrification is manifested in the projection to 2030 and in the longer-term, with electricity shares rising by 3% every 10 years, on average. This is an important increase, considering the Reference Scenario context. Meanwhile, RES remain small in magnitude. The share of gas remains relatively constant over time.

Figure 16: Final energy consumption in industry by energy form



The upward trajectory of fossil fuel prices and EU ETS carbon prices prompt the switch to biomass, mainly biomass solids, in line with the quest for resource-efficiency. The use of waste, both industrial and waste gas for some industries such as chemicals is limited, since the carbon price that applies on emissions makes it less attractive.

Finally, the provisions on cogeneration in the EED promote the penetration of highly efficient cogeneration and the use of waste heat for steam generation in industrial sites. Also, industrial boilers and CHP follow similar trends regarding fuel split.

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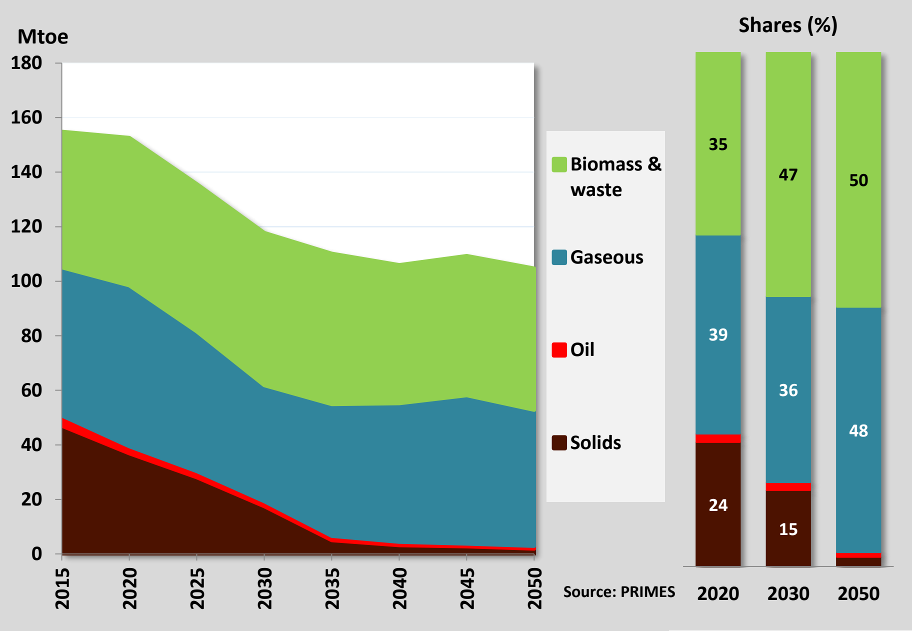
[89] Directive 2010/75/EU

Figure 17: Fuels for industrial CHP and boilers

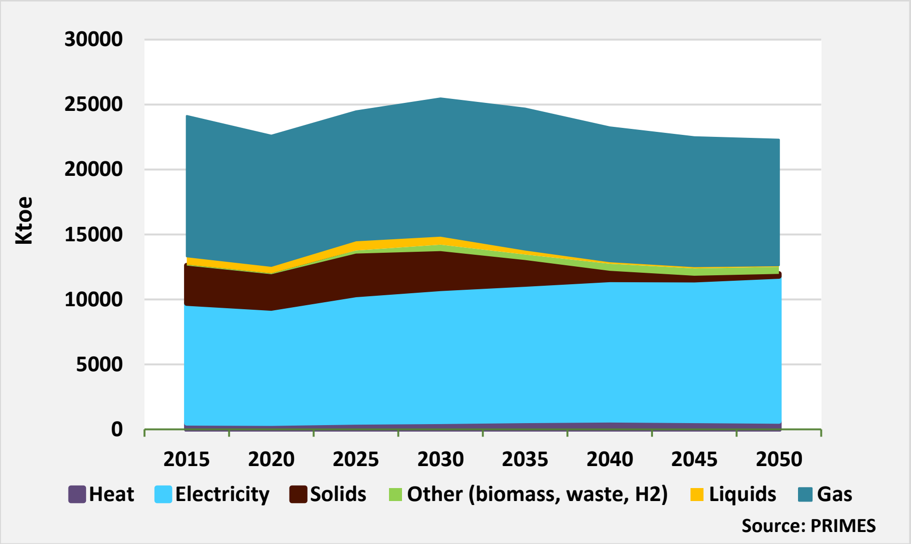


Source: PRIMES

Developments in Iron and Steel

Production from integrated steelworks is projected to be almost stationary until 2050, whereas steel production from electric arc increases: overall value added increases. The use of solids drops, switching to natural gas takes place and biomass use increases. Overall process efficiency improves, however blast furnaces continue to use solid fuels, since the EU ETS prices assumed in the Reference Scenario are not high enough to force the switch to alternative processes such as direct reduction and hydrogen use.

Figure 18: Fuel mix in iron and steel

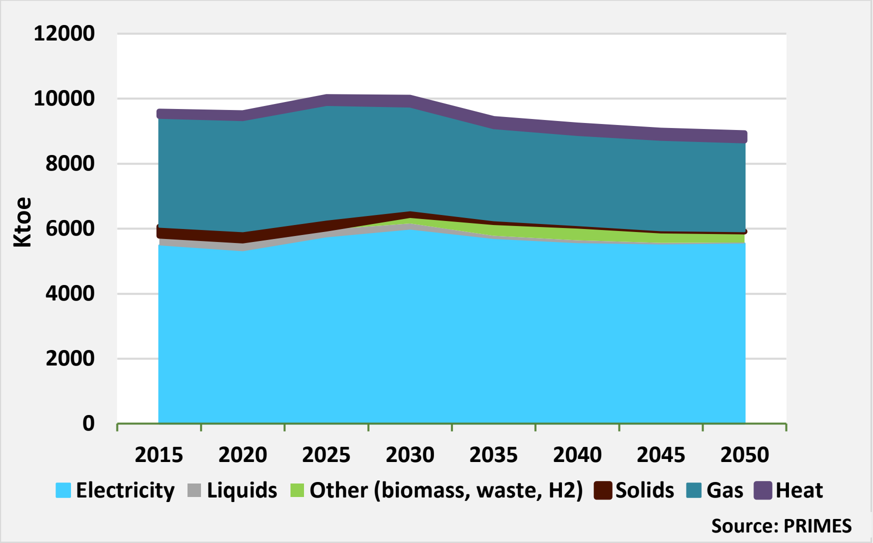


Source: PRIMES

Developments in Non-Ferrous

For non-ferrous metals, physical production and value added follow a similar trajectory. However, as energy consumption decreases, a moderate decoupling from GDP growth is projected in the long run. The trends in energy consumption are characterised by increasing electrification and incremental improvement of process efficiency including heat recovery. Biomass consumption increases slowly in the long term.

Figure 19: Fuel mix in non-ferrous metals

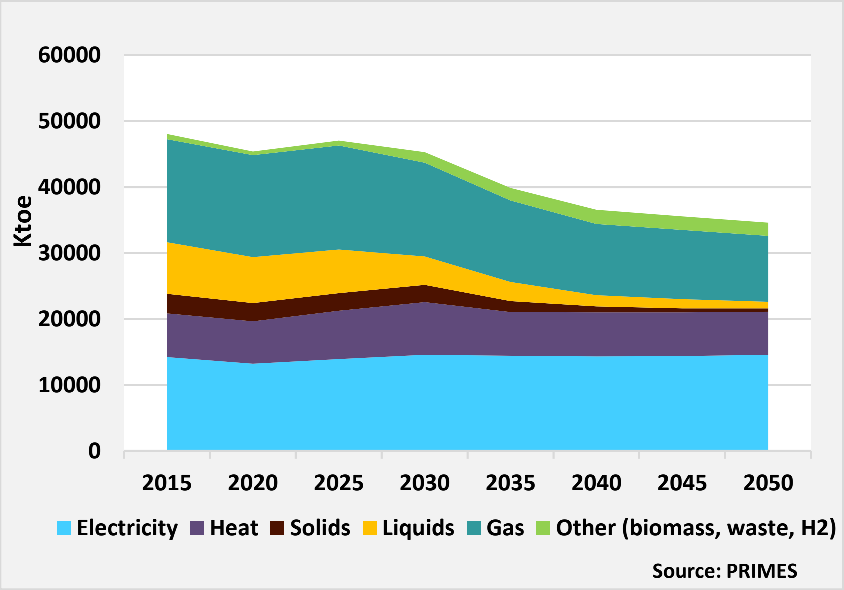


Source: PRIMES

Developments in Chemicals

Chemicals include both energy intensive chemicals (such as fertilisers and petrochemical) as well as low enthalpy chemicals – mainly pharmaceuticals and cosmetics. Energy intensity improvements occur in both categories. The overall savings in terms of emissions are clearly driven by the big improvements in energy intensive chemicals, where – like in all sectors – a shift away from oil and solids can be observed in the Reference Scenario context.

Figure 20: Fuel mix in chemicals

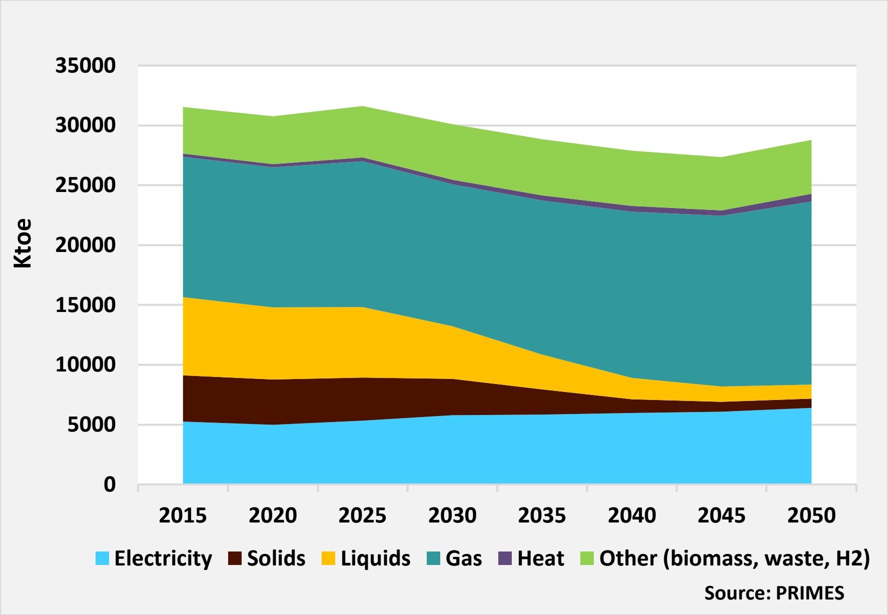


Source: PRIMES

Developments in Non-Metallic Minerals

The value added of non-metallic minerals increases throughout the projection period, however energy consumption decreases, which reveals significant progress in terms of curbing energy intensity in all subsectors. Fuel switching is the key driver: liquids and solids reduce significantly and are replaced by gas and electricity. Biomass also increases its share.

Figure 21: Fuel mix in non-metallic minerals

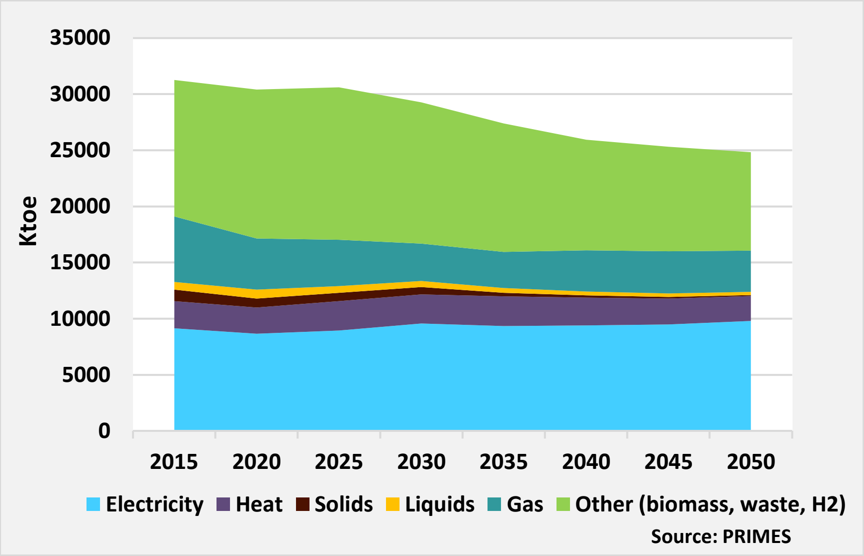


Source: PRIMES

Developments in paper and pulp

Output and value added are both projected to grow while energy intensity is on a downward path. The use of solids and liquids, being already very low, almost disappears. Likewise, gas reduces almost by half while biomass maintains its share while decreasing in absolute terms thanks to energy efficiency improvements. The use of electricity is on a rise.

Figure 22: Fuel mix in paper and pulp

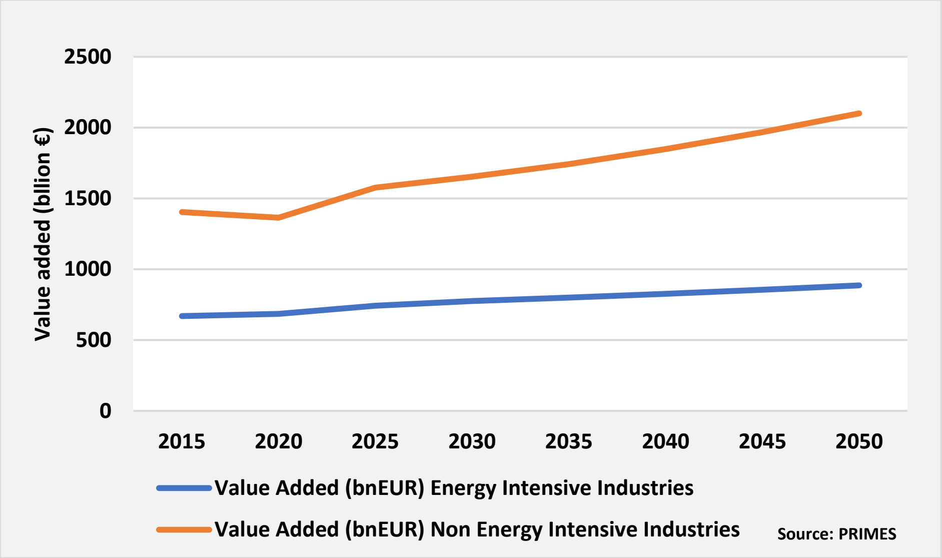


Source: PRIMES

Developments in non-energy intensive industries

As shown in Figure 23, non-energy intensive sectors, namely Food, Drinks and Tobacco (FDT), Engineering (ENG), Textiles (TEXT) and Other Industries (OI) produce more value added than energy intensive industries.

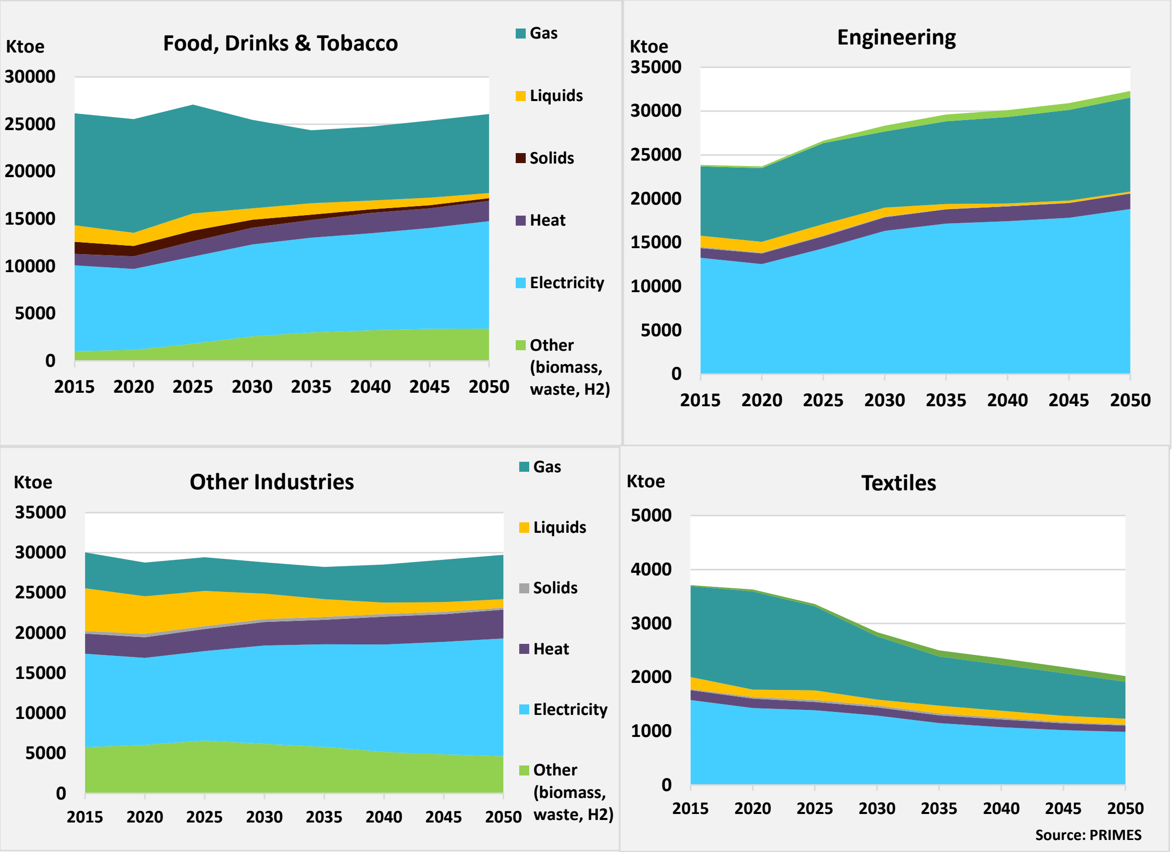
Figure 23: Value added in energy-intensive vs. non-energy-intensive sectors



Source: PRIMES

The main trend across sectors is the decrease in the use of fossil fuels (solids and liquids). A switch to gas is projected for FDT, ENG and TEXT while electrification and steam use increase in FDT, ENG and OI.

Figure 24: Fuel mix trends in non-energy-intensive industries



Source: PRIMES

3.1.2. Residential sector

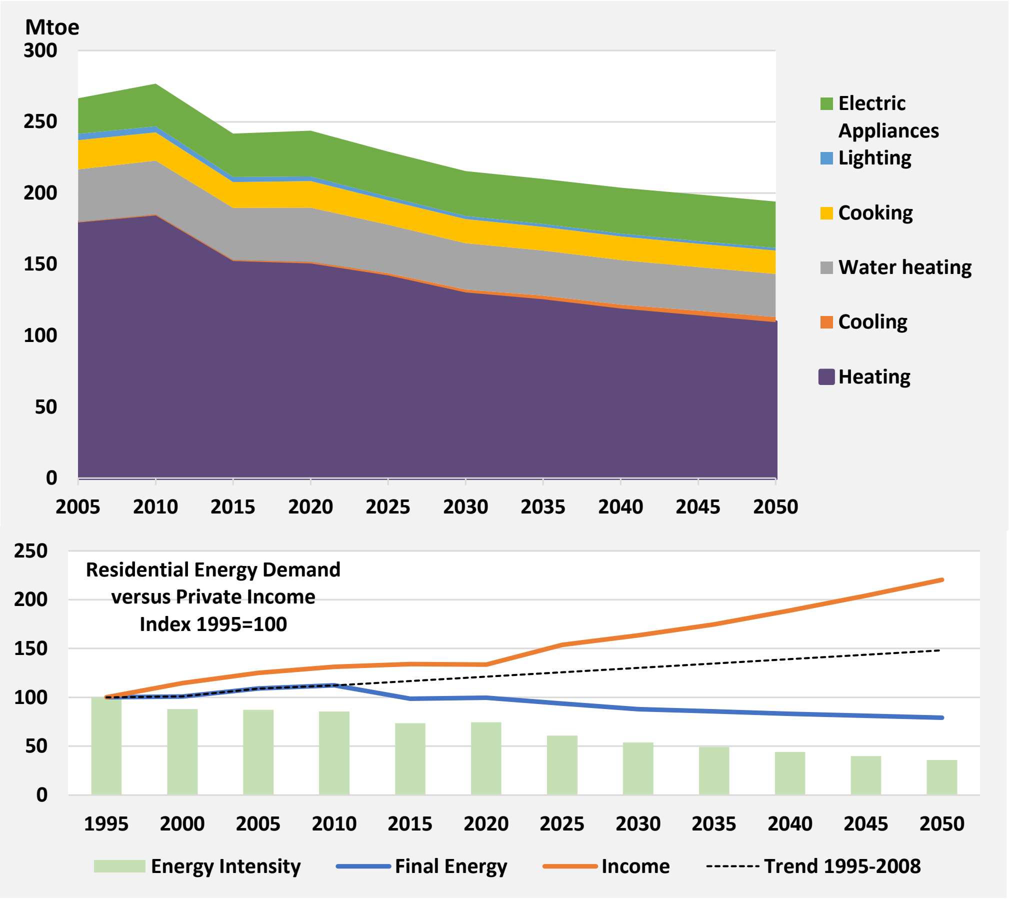
A model that combines economics and engineering, PRIMES BuiMo disaggregates the building stock in 270 building categories, representing different building types, geographic locations, ages of construction, income classes, and service sub-sectors. This is critical for capturing the different challenges facing the building sector in the transition to decarbonisation.

Projections show a remarkable decoupling of energy demand from income growth, much above historical trends, which intensifies in the period 2021-2030 as a result of national renovation strategies and the policies included in the NECPs. These policies have an impact also after 2030, causing demand for energy to decline. However, the decline is not as substantial in the absence of additional policies.

Space heating continues to represent the largest share of residential energy demand, which decreases nonetheless due to efficiency improvements (Figure 25). Economic growth drives an increase in the stock of appliances (black and white). Between 2015 and 2030 the stock of white appliances increases on average by 2% per annum. For black appliances the growth is also of around 2% per annum with information and communication technologies increasing by approximately 4.5% per annum in that time period. Advancements in lighting technologies are projected to continue at a moderate pace.

Cooking shares remain rather stable and so does demand for water heating. The increase in useful energy for cooling is associated with the increasing cooling degree days (CDD) and the increase in household income, which together lead to higher penetration of cooling equipment. The drop in the shares of heating comes as a result of renovation and more efficient space heating equipment becoming available. Again, these developments are significant until 2030 and continue at a slower pace afterwards.

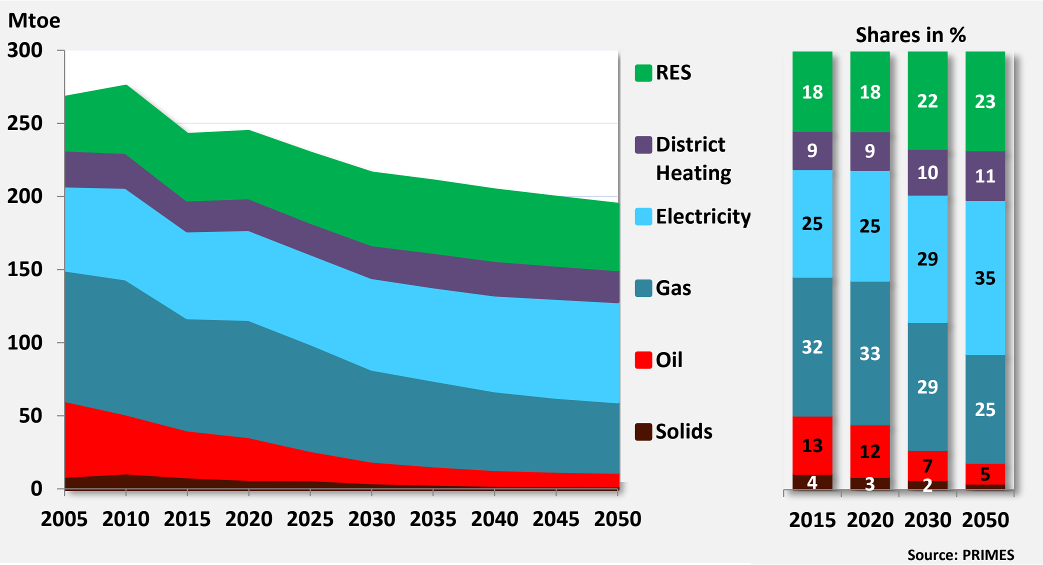
Figure 25: Residential energy demand by use



The fuel mix in the residential building stock is characterised by lower use of solids, due to policies for air quality, and lower use of oil due to the growing electrification, connection to gas networks and some extension of district heating infrastructure. Gas roughly maintains its market shares, which decline slightly in the long run.

Electricity shares are on the rise, driven by the increased use of appliances and the penetration of heat pumps, albeit at a slow pace under Reference Scenario assumptions. The choice of heat pumps is facilitated by technological progress and measures taken by few Member States. The model also prioritises heat pumps in cases where deep renovation is pursued, or the building is highly insulated. Renewables shares are projected to increase until 2030, mainly thanks to support measures for solar thermal and biomass pellets, a trend that continues after 2030 also, yet at a slower pace.

Figure 26 : Residential energy demand by fuel

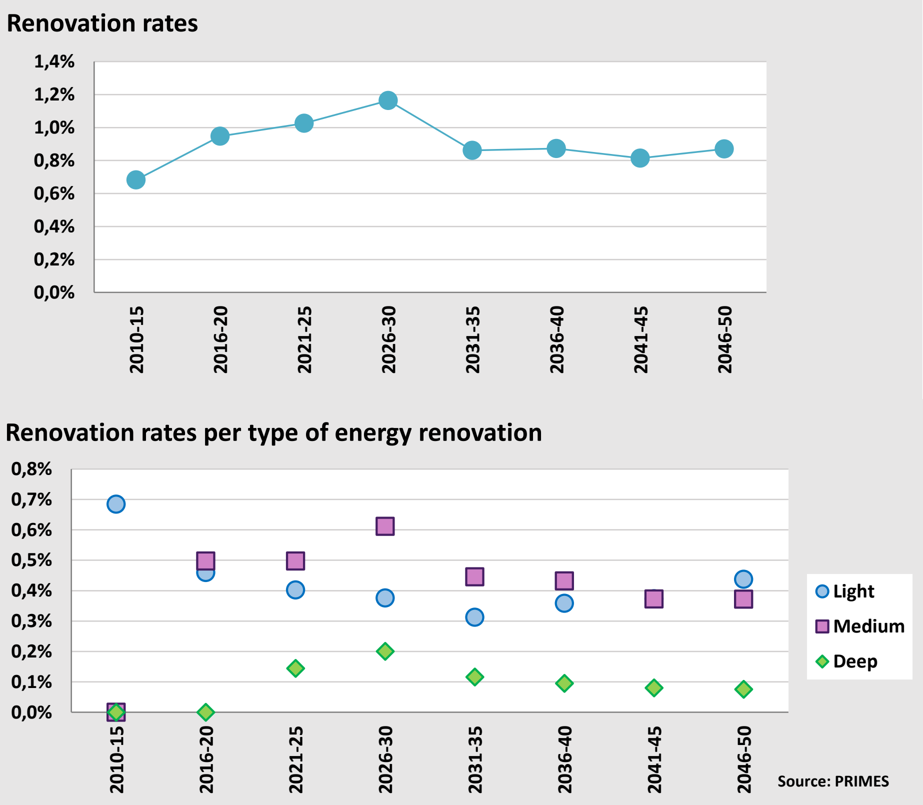


Source: PRIMES

Historically, demolitions and new constructions have been limited in the EU. Thus, renovation has come under the spotlight for achieving energy savings. While today the majority of renovations are described as “light” offering limited energy savings, the implementation of the EED and EPBD at national level is expected to increase the depth and rate of renovation. The lack of additional policies after 2030, implies a slowdown of the trend.

For the most part, Europe’s renovation rates, i.e., the number of houses undergoing renovation over the total stock of houses, have been on average below 0.8% per annum. The first stream of energy efficiency policies pushed that rate upwards, and current policies are expected to boost it further towards 2030. Despite the slowdown, renovation rates are projected to remain above 0.8% per year also after 2030, which is attributed to the inertia of the currently implemented policies.

Figure 27: Renovation rates of residential buildings



Renovation rates

Renovation rates per type of energy renovation

Source: PRIMES

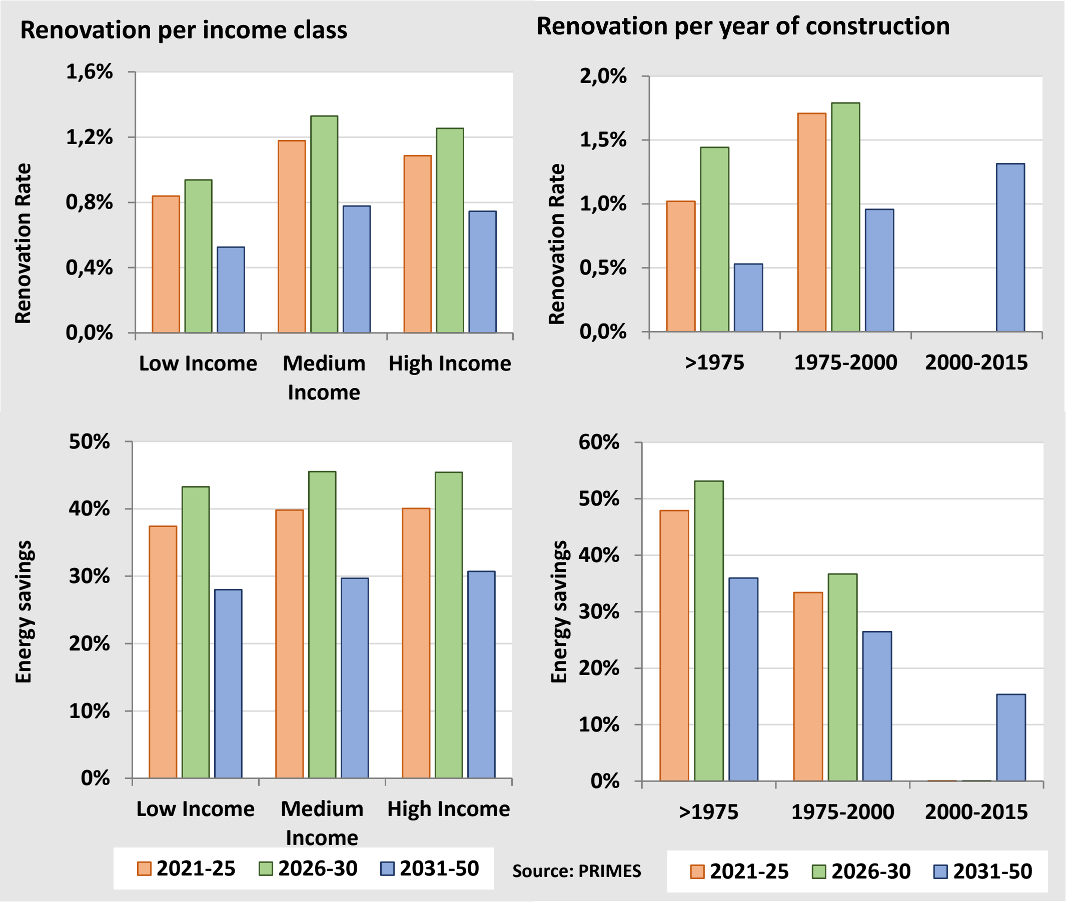
Analysing renovation rates from the perspective of income class and age, the projection reveals that the majority of renovations is carried out by medium and high-income classes (Figure 28). Limited access to capital forces lower income classes to undertake only lighter renovations, which are less capital intensive. In the absence of additional policies after 2030, the depth of renovations decreases for all income classes.

Furthermore, according to the simulation, mid-aged buildings have higher average renovation rates compared to older buildings. Old and very old houses are more difficult to renovate for reasons related to unknown structures that may require additional works and owners belonging to low- and medium-income classes.

At the same time however, the energy savings achieved in mid-aged buildings are lower than what would be the case in older houses, since mid-aged buildings already have some insulation; still, it is more cost-efficient to perform medium depth renovations in buildings of over 20 years.

Member States have already put in place and are projected to implement policies for overcoming market and non-market barriers to the renovation of buildings. While these policies and measures are expected to lead to substantial fuel switching and energy savings in the residential sector, still the projected savings are found not to be in line with the EED target. The model results project that low-income classes in particular face significant economic obstacles, which cannot be overcome in most Member States with the policies assumed in the Reference Scenario.

Figure 28: Renovation rates by age/income class of residential buildings



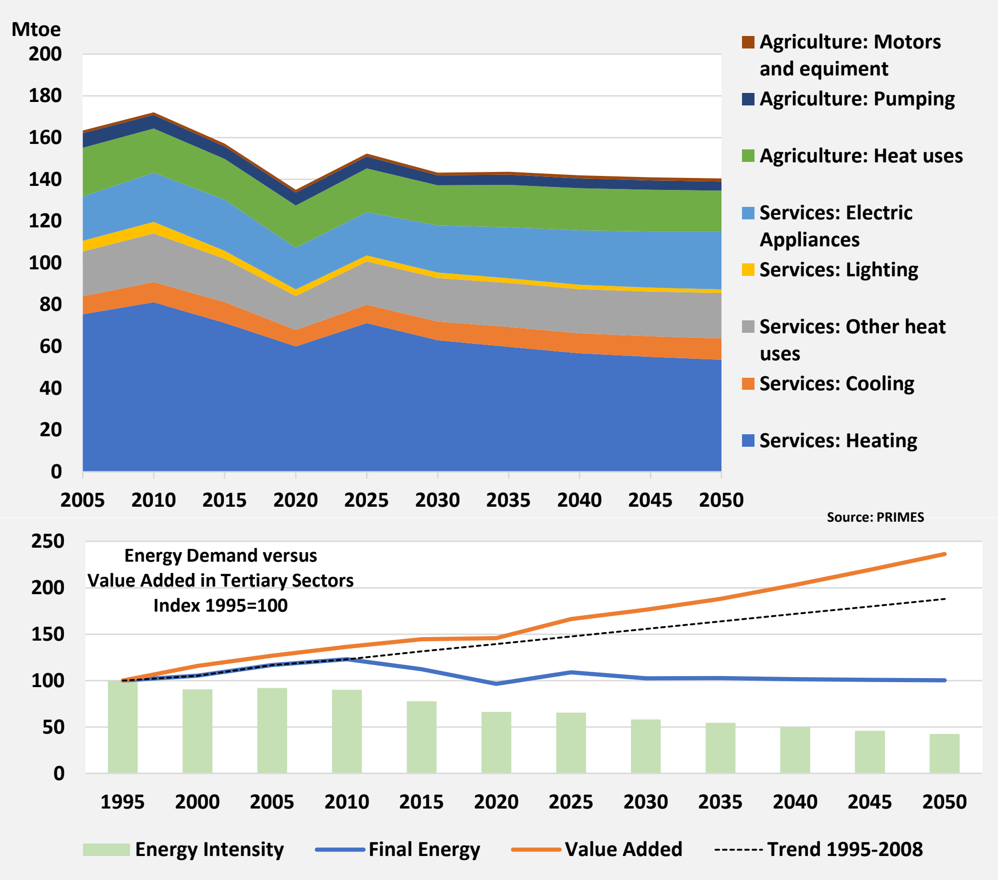
Source: PRIMES

3.1.3. Tertiary sector

As in the residential sector, projections of final energy demand in the tertiary sector point to a decoupling of demand from economic activity (Figure 29). In the services sector, energy efficiency improvements are significant, while in agriculture energy efficiency gains are less prominent. Policies for energy efficiency, ecodesign and energy performance of buildings bring about remarkable energy efficiency gains. These gains offset the effects of growing sectorial activity towards 2030 and drive final energy demand below 2010 peak levels throughout the projection period.

Distinct efficiency progress is observed in heating and in electric non-heating uses, which brings energy consumption down between 2020 and 2030. Space heating in particular continues to be the single largest energy use. Final energy used for space heating drops however over time due to energy efficiency improvements. Specific electric uses exhibit the highest increase reflecting technology trends, including the development of data centres, increased stock and use of electric appliances. In agriculture, energy efficiency improvements, as well as potential for renewables, are projected for space heating purposes (greenhouses mainly). Beyond 2030, where no additional energy efficiency policies are implemented, total final energy consumption decreases at a slow pace.

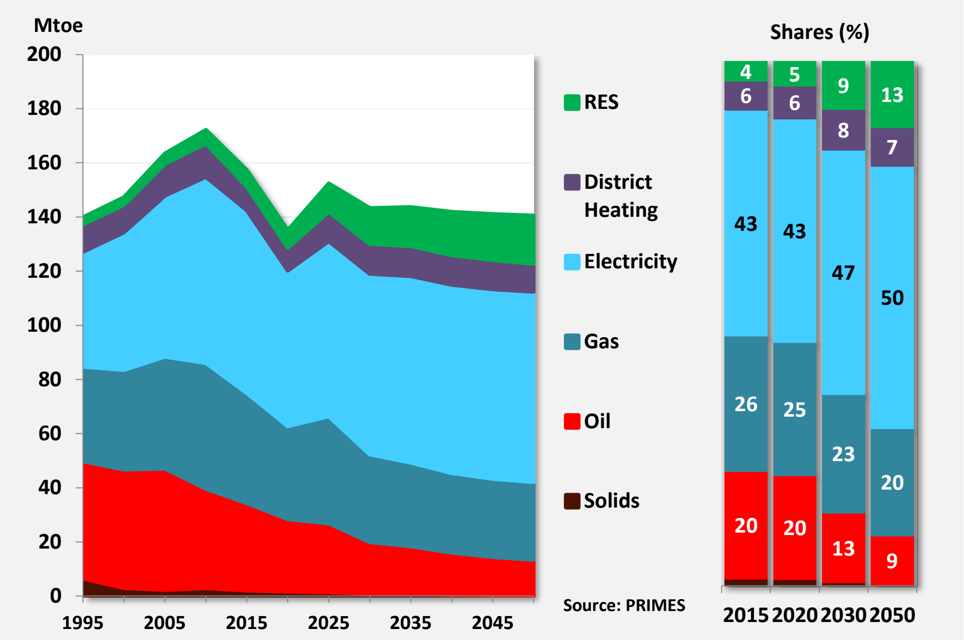
Figure 29: Final energy demand by use in the tertiary sector



Source: PRIMES

The fuel mix used in buildings of the tertiary sector is marked by two main trends: the significant decline of solids and oil due to substitutions by gas in the medium term and electricity in the medium and long term; and electrification, which increases from 43% in 2015 to 50% in 2050, driven by the rise in specific electricity uses and in heat pumps. RES shares grow steadily in the course of the projection period, driven primarily by the increased penetration of geothermal energy, already widely used in commercial buildings in many Member States and for which significant untapped potential exists.

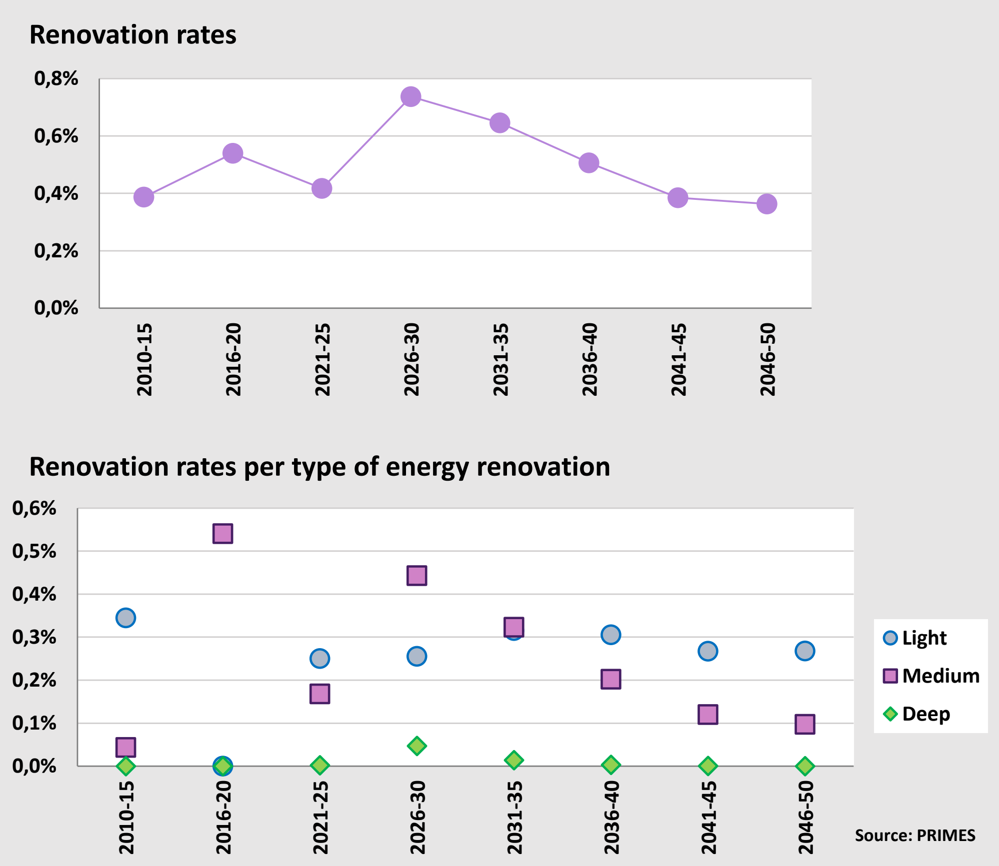
Figure 30: Final energy demand by fuel in the tertiary sector



Source: PRIMES

In general, renovation rates are lower in the buildings of the services sector, but the share of demolitions and new buildings is higher. All new buildings are assumed to comply with the country-specific building codes and be more efficient than existing buildings. The role of energy efficiency policies is noteworthy, causing renovation rates to double in the period 2026-2030, a trend that discontinues afterwards.

Figure 31: Renovation rates of services buildings



Source: PRIMES

Policies for the energy upgrading of public buildings trigger medium and to a lesser extent deep renovation until 2030. The obligations under Art.5 of the Energy Efficiency Directive on the exemplary role of public buildings push renovation rates in the non-market sector upwards. Commercial buildings, though not getting renovated as often since energy bills take up a small share of company costs, when they do, they reach higher energy savings. Therefore, although more rarely renovated, commercial buildings provide a stronger economic interest for deeper renovation, due to higher total energy bills and a possibly more rational investment appraisal.

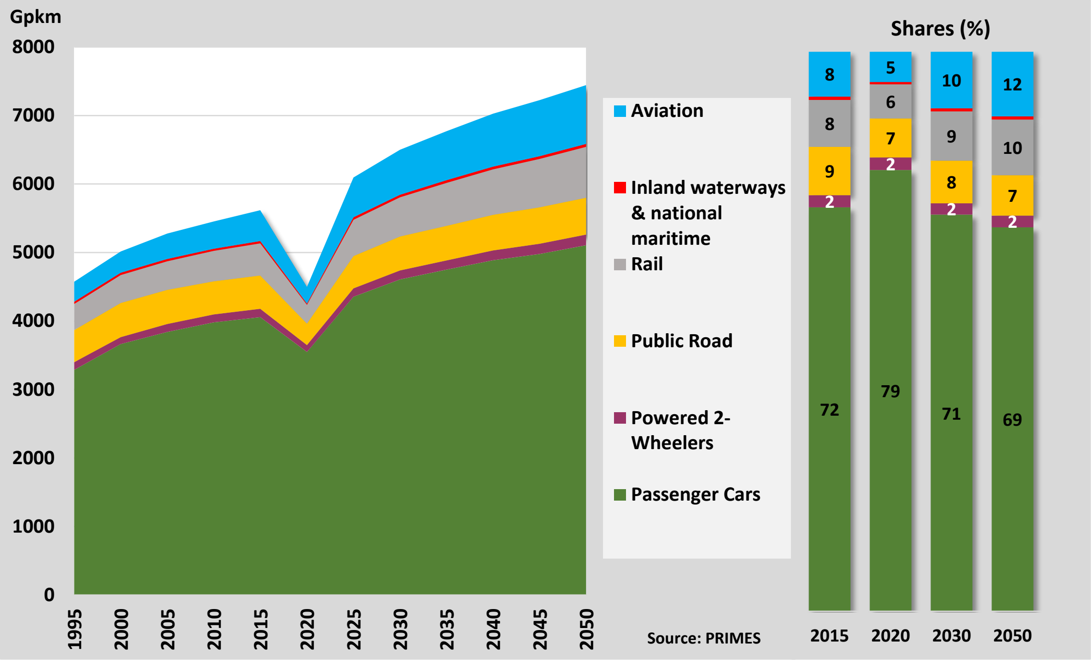
3.1.4. Transport sector

Transport activity

Transport activity for passenger and freight is projected to grow throughout the projection period, with freight growing faster than passenger transport activity. Following the significant decline in activity in 2020 due to the COVID-19 pandemic, a rebound is envisaged for 2025-2030.

In passenger transport, cars are expected to maintain their dominant role (Figure 32). However, the share of cars activity is expected to slightly decline over time, while the share of intra-EU aviation is projected to increase considerably.

Figure 32: Passenger transport activity by mode



Source: PRIMES

Note: Aviation includes only intra-EU aviation

Passenger rail activity[90], mainly high-speed rail where investments are foreseen, increases its modal share and competes with road transport and air transport in some cases. High congestion levels and rising fossil fuel prices, supported by the completion of the core and comprehensive TEN-T network by 2030 and 2050, respectively, and by other policies like the Fourth Railways Package, improve the competitiveness of railways and shift part of the passenger road traffic to rail in the long term. Inland navigation transport, which refers here to inland waterways and national maritime, holds a marginal share of total passenger transport activity.

Intra-EU aviation, which takes place within the boundaries of one Member State or between Member States, is projected to be the second highest growing of all passenger transport modes (i.e., after high-speed rail), and increase its share from 8% in 2015 to 12% in 2050.

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[90] Passenger rail activity covers here conventional and high-speed rail, plus light rail, and tram/metro in urban areas.

Extra-EU aviation activity, which covers flights between Member States and third countries, is projected to increase by 90% between 2015 and 2050 – only slightly less than intra-EU air transport activity.

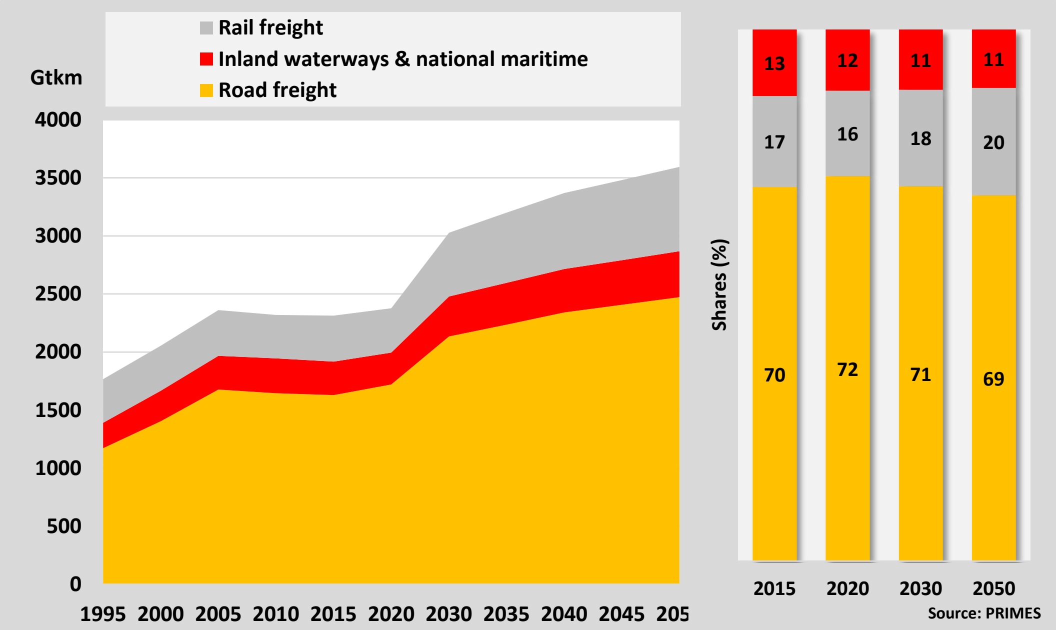
Table 8: Extra-EU aviation activity

Activity (Gpkm)	Reference Scenario			
	2015	2020	2030	2050
Extra-EU aviation	1,150	612	1,645	2,182

Source: PRIMES-TREMOVE

Freight transport activity is expected to grow significantly in the period 2015-2050 due to the increased economic activity and demand for transportation of goods (Figure 33). Road remains the dominant mode, representing 69% of total freight transport activity by 2050. Rail freight sees an increase in its shares from 17% in 2015 to 20% in 2050, which is driven by the completion of the TEN-T core and comprehensive network, supported by CEF. Inland waterways and national maritime traffic also benefits from the TEN-T core and comprehensive network completion, which includes further support for logistic functions and multi-modal integration, and from other policies promoting inland waterways and port services. However, the relatively stronger growth in road and rail traffic leads to a decrease in the modal share of inland waterways and national maritime, from about 13% in 2015 to 11% in 2050.

Figure 33: Freight transport activity by mode



Source: PRIMES

International maritime freight transport activity grows at a 1.2% rate annually between 2015 and 2030, and 1.1% annually between 2030 and 2050, which translates into 50% increase in maritime freight transport activity in 2050 compared to 2015 (Table 9). International maritime passenger transport activity is also projected to increase steadily by 2050, following the reduction in activity in 2020 due to the COVID-19 pandemic.

Table 9: International passenger and freight maritime transport activity

Activity	Reference Scenario			
	2015	2020	2030	2050
Passenger, Gpkm	1,962	1,186	2,426	3,052
Freight, Gtkm	14,269	11,327	17,075	21,444

Source: PRIMES-Maritime

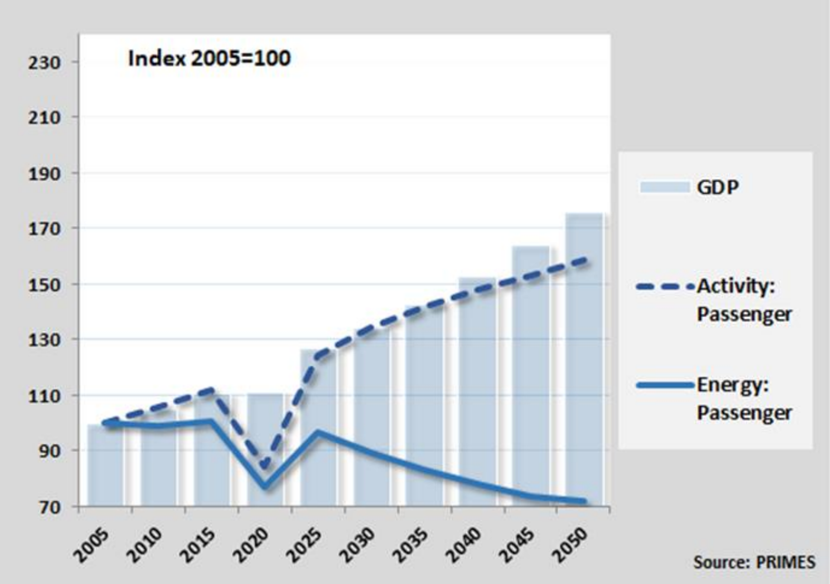
Energy demand: Analysis by transport mode

The growth of energy demand in transport has shown strong correlation with the evolution of transport activity over time. However, the projection indicates a significant decoupling of energy consumption from activity growth. In fact, the decoupling is far stronger compared to past trends for both passenger and freight transport.

This is attributed to a number of policies and technological trends, including: the CO_2 standards for LDVs and HDVs, policies favouring higher use of more sustainable transport modes and the electrification of rail, policies promoting the roll-out of recharging/refuelling infrastructure and other policies supporting progressive electrification of the road transport sector, remarkable technology progress that helps bring down the unit consumption of conventional technologies, improvement in the techno-economic performance of alternative power trains (in particular battery electric vehicles), etc.

Passenger transport activity is envisaged to recover post-2020 and to strongly decouple from the energy consumption by 2050 (Figure 34).

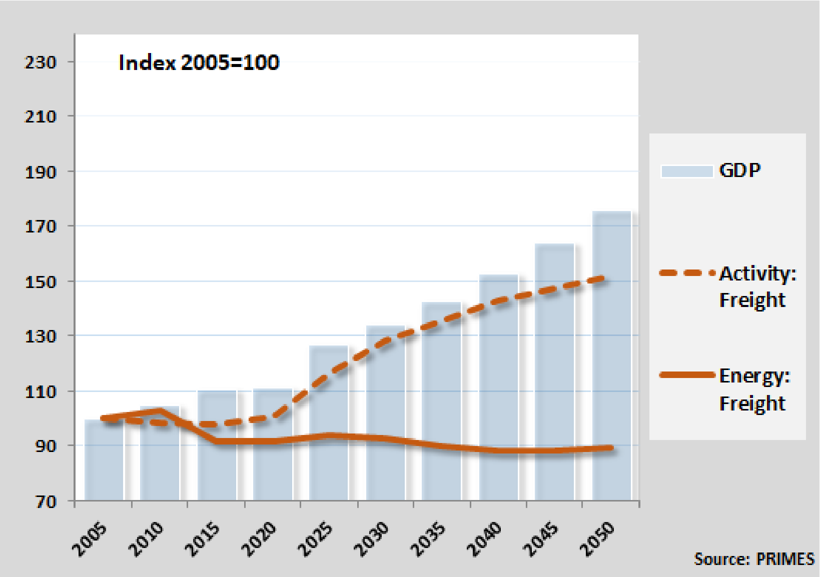
Figure 34: Trends in passenger transport activity and energy consumption



Note: Transport activity and energy use include intra-EU and extra-EU aviation but exclude international maritime.

Having suffered less than passenger transport from the pandemic, freight transport activity continues to grow in the future at a pace that roughly follows that of GDP. The completion of the TEN-T core network by 2030 and of the comprehensive network by 2050 is expected to provide support for logistic functions and improve multi-modal integration (road, rail, and waterborne transport) through innovative information management systems that are part of the network. Freight transport activity is also projected to strongly decouple from the energy consumption by 2050 (Figure 35).

Figure 35: Trends in freight transport activity and energy consumption

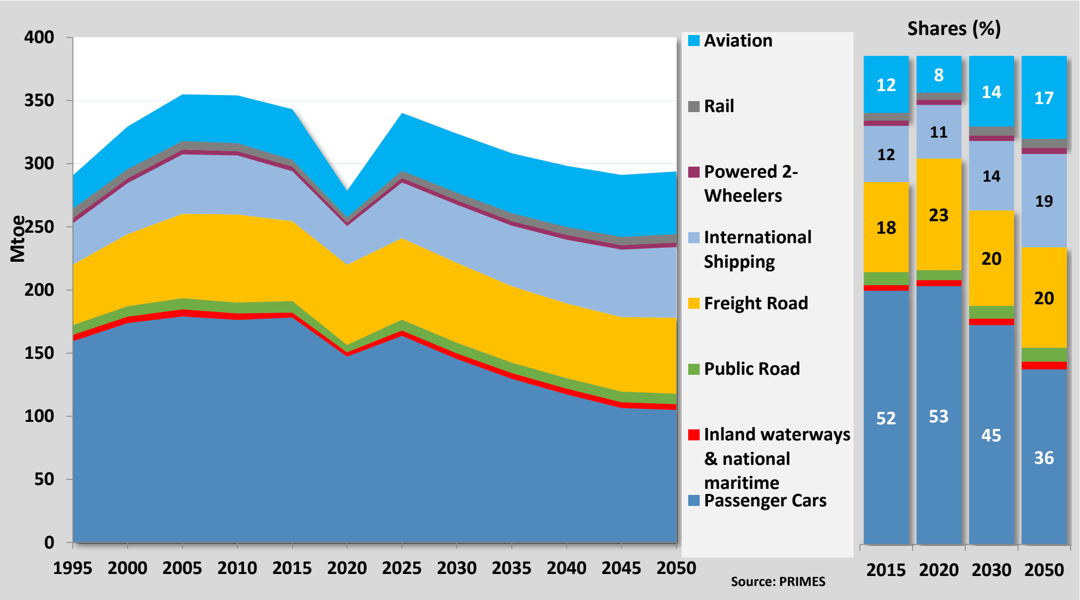


Source: PRIMES

Note: Transport activity and energy use do not include international maritime transport.

A rebound in energy use in transport is projected during 2020-2025, driven by the recovery in activity following the COVID-19 pandemic. Post-2025, EU level and national policies as well as techno-economic developments lead to a gradual drop in consumption. Energy demand from cars, responsible for more than half of total final energy demand in transport in 2015, is projected to decrease considerably by 2050 (Figure 36), due to notable energy efficiency gains brought by the introduction of CO_2 emission performance standards, the gradual renewal of the vehicle fleet, the emergence of advanced vehicle technologies and the increase in fuel prices in the long term.

Figure 36: Total energy demand in transport



Source: PRIMES

The picture is different in aviation where efficiency gains do not suffice to compensate for the increased activity levels resulting in growing energy demand. Other transport sectors such as rail, inland waterways and national maritime are projected to maintain their share in total energy demand throughout the years. Demand for energy also increases in international maritime transport (freight and passenger) between 2015 and 2030, a trend which persists also post-2030.

As said, the catalyst for the decoupling between activity and energy demand is the uptake of more fuel-efficient technologies and fuel substitution (Figure 37). In road passenger transport, energy efficiency of vehicles improves by 27% in 2030 and 52% in 2050 relative to 2015. Such development is the outcome of the implementation of the regulation on CO_2 emission standards for Light Duty Vehicles (LDVs), which covers new passenger cars and light commercial vehicles and is projected to lead to more fuel efficient LDVs being introduced into the market. The deployment of low- and zero-emissions vehicles is further supported by the roll-out of recharging/refuelling infrastructure, driven by the Directive on alternative fuels infrastructure (AFID).

Figure 37: Efficiency improvements by mode

Note: For aviation and total passenger transport, the figure reports the improvements in energy efficiency taking into consideration domestic, international intra-EU flights and extra-EU flights. Regarding the efficiency improvements in overall freight transport, the figure considers the improvements in international shipping.

In aviation, the improvement in specific fuel consumption is projected at 19% in 2030 and 35% in 2050 relative to 2015. Such developments are driven by high efficiency gains due to the introduction of more energy efficient aircrafts and the renewal of the fleet, as well as due to operation efficiency gains. Hence, even though aviation experiences strong growth in its activity, efficiency gains limit the increase in the energy consumption.

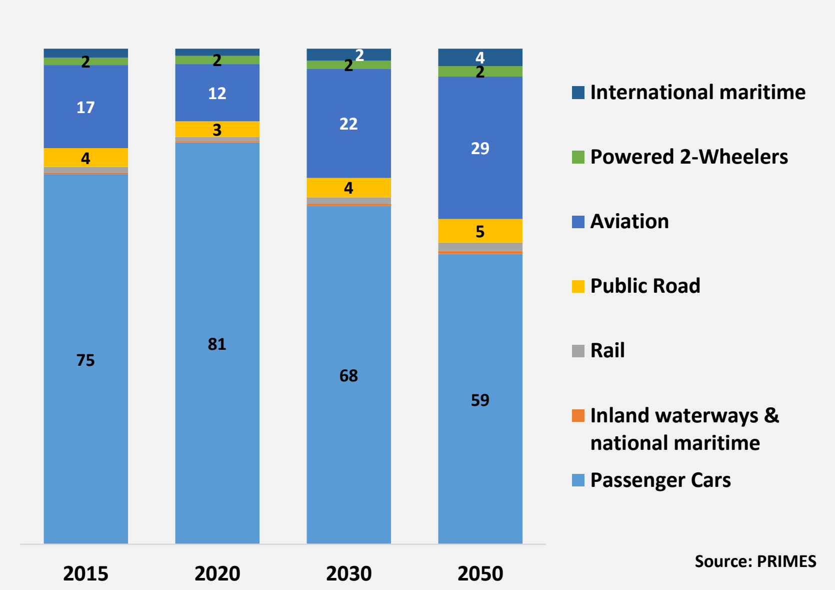
Efficiency improvements are less pronounced in passenger rail compared to road and aviation. This is because significant improvements have already taken place in the rail sector in the past and the remaining potential is more limited relative to other modes. Still, compared to past projections, switching from diesel to electricity in rail is becoming more prevalent, driven by policies.

Freight transport is also becoming increasingly efficient. CO_2 emission standards for HDVs and technological progress drive significant efficiency improvements in road transport throughout the projection period allowing manufacturers and fleet operators to reduce fuel costs, which make up a considerable amount of the operational costs of HDVs.

Similarly, freight rail sees moderate improvements in the average specific fuel consumption up to 2030, pushed by policies that support the growing electrification of railways. Freight inland waterways and national maritime achieve energy efficiency improvements in the order of 6% by 2030 and 11% by 2050 relative to 2015. International maritime is projected to see smaller improvements in fuel efficiency post-2015 in the Reference Scenario context. However, significant gains in the fuel efficiency (31%) have been already achieved during 2005-2015.

Energy efficiency improvements for passenger cars are expected to reduce the share of cars in energy demand for passenger transportation from 75% in 2015 to 68% in 2030 and 59% in 2050. On the contrary, the share of air transport rises to 29% in 2050 from 17% in 2015 due to the growing demand for jet fuels (Figure 38).

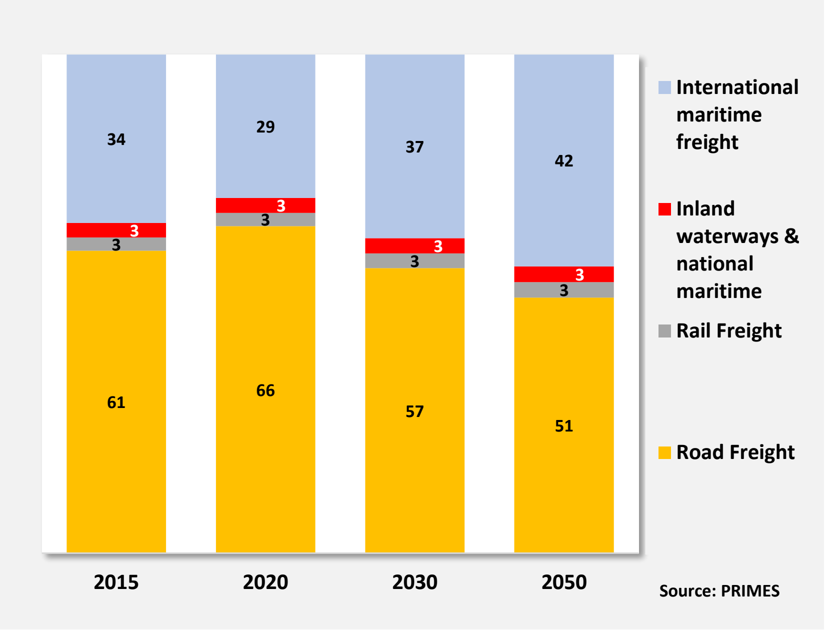
Figure 38: Shares of passenger transport modes in energy demand



Source: PRIMES

HDVs account for approximately 61% of the total energy demand from freight transport in 2015. Their share would decrease over time to 57% in 2030 and 51% by 2050, due to the introduction of CO_2 emission standards and increasing fossil fuel prices (Figure 39). Fuel for international freight shipping bunkers was reported to be roughly 35 Mtoe in 2015. This represents 34% of the energy demand from freight transport. Model estimates show a growth in the freight bunker fuels consumption, up to 50 Mtoe in 2050 (42% of the energy demand in freight transport), driven by the high growth in the international maritime transport activity. Rail freight, inland waterways and national maritime are projected to maintain a limited share of the energy demand from freight transport by 2050.

Figure 39: Shares of freight transport modes in energy demand



Source: PRIMES

Energy demand: Analysis by fuel

The efficiency improvements induced in the segment of passenger cars have been evident since 2010-2015, when manufacturers started to market low-emission vehicles. This trend is expected to intensify. The CO_2 standards for light and heavy duty vehicles, the 2030 RES target for transport, the deployment of alternative fuel infrastructure and particularly the recharging infrastructure and other national policies combined with significant reductions in the cost of batteries are changing the mix of technologies in the car fleet towards 2030, giving considerable impetus to the emergence of battery electric power trains (Figure 40).

Oil products, namely gasoline, diesel, kerosene, LPG and fuel oil, continue to represent the largest share in total energy consumption in transport, including international aviation and international maritime. From 95% in 2015, their share drops down to 87% in 2030 and 75% in 2050. The volumes of diesel and gasoline decrease over time, but the volume of kerosene increases, because of the increased air transport activity. Indeed, kerosene is projected to increase its share in the fuel mix over time. Only after 2035 bio-kerosene slowly starts to penetrate the aviation fuel mix (Figure 41)[91]. Natural gas increases its market penetration, but remains low in total volume terms. In particular, LNG develops in road freight, national and international maritime.

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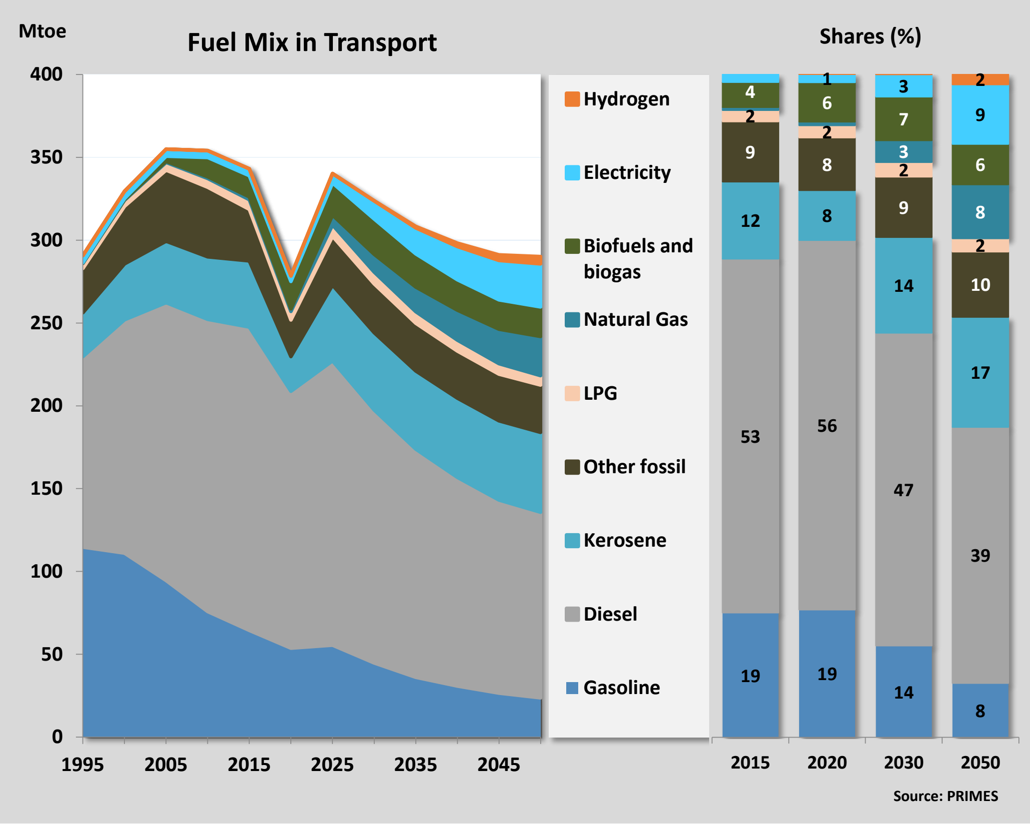
[91] Fuel mandates for the aviation sector are not included in the Reference scenario projection.

Figure 40: Total energy consumption in transport by fuel



Source: PRIMES

Note: Including international aviation and maritime.

The evolution of biofuel and biogas penetration in the EU energy mix is mainly driven by the legally binding target of 14% RES in the transport sector, including the dedicated sub-target of advanced biofuels covering 3.5% of energy consumption by 2030 (including the multipliers). Specific national mandatory blending regulations and incentives are considered in the Reference Scenario. The growth in biofuel and biogas consumption is projected to decelerate after 2030 due to absence of dedicated policies and the uptake of electric vehicles.

The total share of electricity increases over time and is projected to reach 9% by 2050. This development is mostly the result of electric vehicles penetration in road transport and partly driven by the substitution of diesel-powered with electric rolling stock in rail transport.

International maritime activity is projected to experience significant growth by 2050. Oil products continue to be the dominant energy source used for powering vessels. LNG and diesel oil, both fuels with low sulphur content thus in compliance with the Sulphur Directive and the SECA zones of EU waters, gradually penetrate the bunker fuels market and replace part of the fuel oil. The rollout of LNG infrastructure facilitates this process. Biofuels do not play a significant role under the Reference Scenario, in the absence of additional policies.[92]

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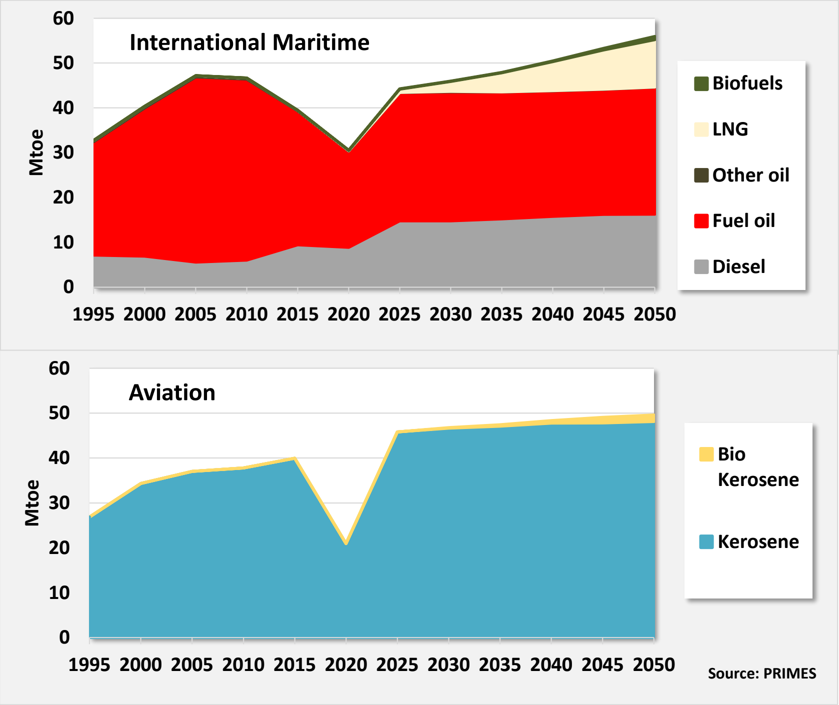
[92] Fuel obligations for maritime fuels are not included in the Reference scenario projection.

Figure 41: Energy demand in aviation and maritime by fuel



Source: PRIMES

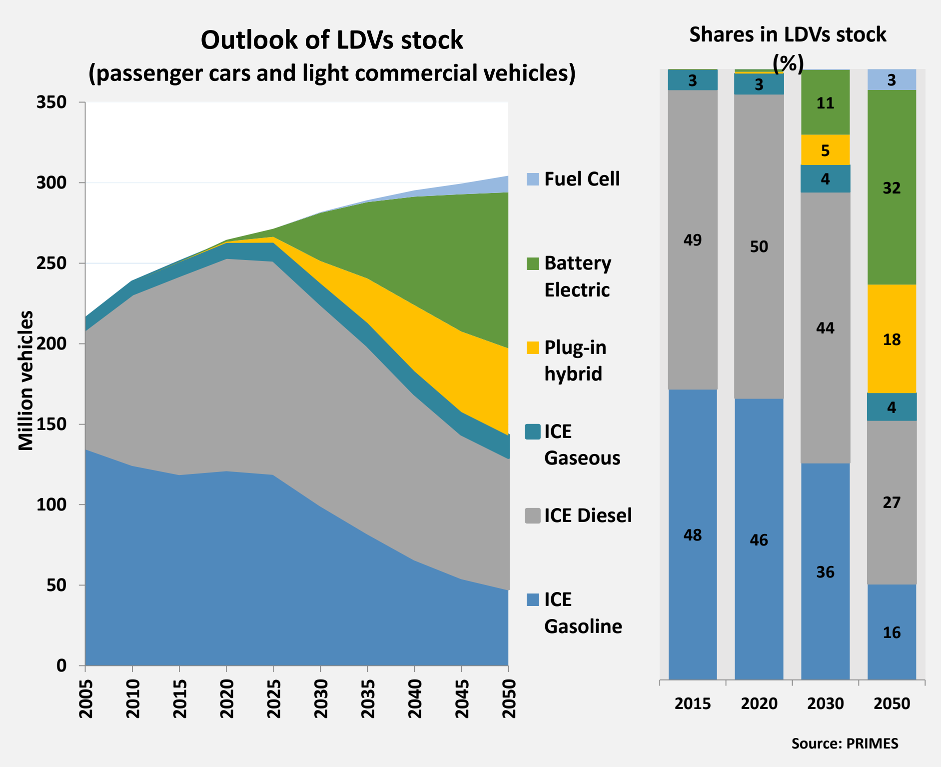
Outlook on Light Duty Vehicles and Heavy Duty Vehicles

The market segment of LDVs, which consists of private cars and light commercial vehicles, is projected to change significantly compared to historical trends driven by policies. The CO_2 standards for LDVs brings down the shares of ICE Gasoline to 16% of the total LDVs stock in 2050 from 46% in 2020 and those of ICE Diesel down to 27% from 50% in 2020. Car manufacturers are assumed to comply with the standards and promote vehicles that have a hybrid system on their powertrain, which become more appealing to consumers due to their lower additional costs.

Electric vehicles (EVs) represent a growing share of the market as a result of EU and national policies, incentive schemes, roll-out of recharging infrastructure and lower battery costs. Strong incentives introduced by specific Member States in the form of tax exemptions or subsidies make the purchase of EVs by urban commuters and early adopters easier. Battery Electric Vehicles (BEVs) present higher levels of maturity, particularly beyond 2030. Dropping battery costs assumed in the Reference Scenario bring capital costs of BEVs down, thus enabling their uptake. As a result, BEVs represent 32% and PHEVs 18% of total LDVs stock in 2050, respectively, in the Reference Scenario (Figure 42). Fuel cell vehicles still represent a niche market, reaching 3% at the end of the projection period due to their higher costs.

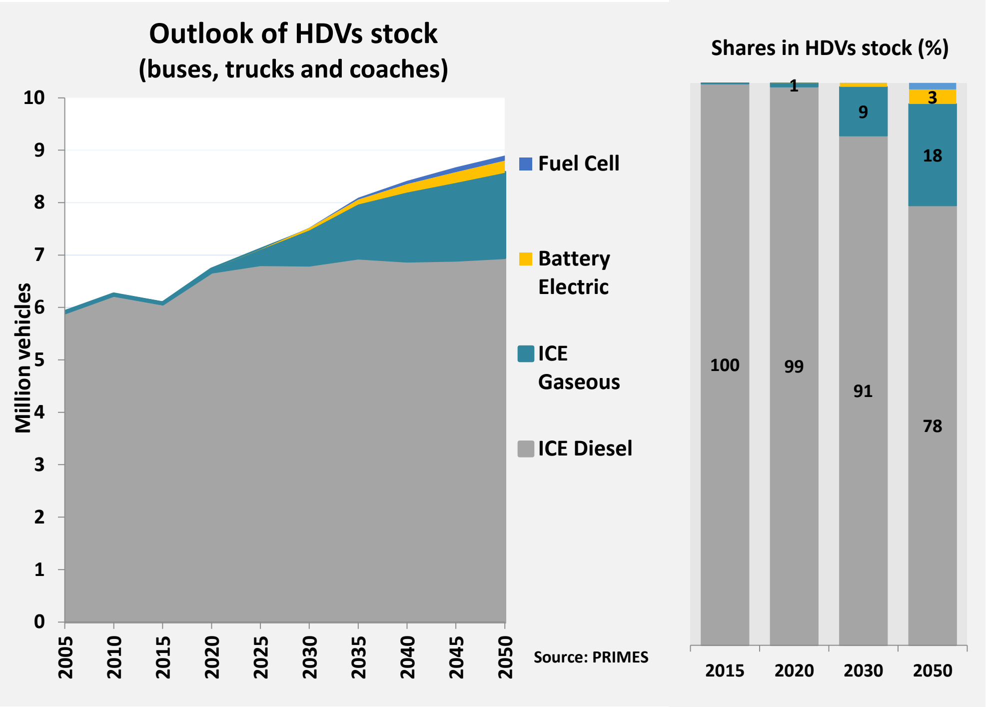
The modelling takes into consideration national support plans for advanced technology vehicles such as EVs and the roll-out of recharging/refuelling infrastructure. Incentives including subsidies, lower taxation, premiums etc. are treated as explicit drivers in the model. Countries that have such plans in place and support electrification of private road transport are expected to show higher penetration of electric vehicles (i.e., higher than the EU average). Other energy forms such as LPG and natural gas occupy a small share out of the total LDVs stock by 2050.

Figure 42: Outlook of LDVs stock by type and fuel



The market segment of HDVs, consisting of buses, trucks and coaches, undergoes moderate changes compared to historical trends. The introduction of CO_2 standards and the Clean Vehicles Directive, together with rising fossil fuel prices, cause ICE Diesel to drop to 78% in 2050 (from 99% in 2020) and ICE Gaseous to reach 9% in 2030 and 18% in 2050 from less than 1% in 2020 (Figure 43). The share of electric and fuel cell HDVs is projected to be more limited at around 4% of the total HDV stock by 2050. Electric buses would however represent around 20% of the bus stock by 2050, driven in particular by the Clean Vehicles Directive.

Figure 43: Outlook of HDVs by type and fuel



3.2. Energy supply

3.2.1. Power and heat production

The projections for power and heat production are derived from the relevant PRIMES sub-model, which models the electricity sector and market and their interaction with steam/heat demand, provided through combined heat and power (CHP) plants, district heating as well as industrial CHP and boilers. It is a very detailed model that has evolved significantly since the Reference Scenario of 2016.

One part of the model handles the optimisation of capacity expansion inter-temporally, looking at all existing power plants, one by one, in all countries. The model reflects different possibilities for refurbishment, investment (greenfield or brownfield) and non-linear potential cost curves for all resources. The database[93] of PRIMES further includes all planned investments that are currently known, including lifetime extensions as well as decommissioning.

Another part of the model performs unit commitment optimisation, by considering, in hourly resolution, the cyclical possibilities of power plant operation, the balancing of RES along with the role of storage and cross-border flows. These concern the EU as well as the UK, Norway, Switzerland, and the interactions with the Balkan region. The interconnections between countries of the ENTSOE 10-Year Development Plan are considered exogenously. Simultaneously with power sector optimisation, the model performs optimisation of co-generation, respecting the variation of loads of electricity, heat, and steam in a synchronised manner.

The key policy drivers underpinning the projections of power and heat production are summarised below.

An important first driver is the **EU ETS carbon price**, which is projected to reach, in the Reference Scenario policy context, 30 €/tn CO_2 in 2030. After 2030, the carbon price is projected to increase at a faster pace (see section 2.5.1).

Another crucial driver are **technology trends**, which confirm the cost-competitiveness of solar and wind power. Variable RES are assumed to experience a sustained investment pace, backed by support schemes in the short term and enabling conditions in the medium and long term. Such enabling conditions are reflected in the model in different ways: in the form of grid extensions that allow tapping RES potential in remote locations, enhanced rules for shortening licencing procedures, the formation of local energy communities etc.

Enabling conditions resolve the challenges associated with investing in RES, which is represented in the model by non-linear ascending cost curves country by country and technology by technology. In essence, it is about facilitating the investment without reducing the costs. These enabling conditions are assumed to intensify until 2030, helping Member States reach the 2030 RES target but phase down after 2030 in accordance with the Reference Scenario assumptions. However, the reduction in unit technology costs of wind and solar continues until the end of the projection period and, in combination with the rising EU ETS price, allow for the share of RES in the power mix to grow.

For variable RES to develop and integrate into the system, balancing and reserves are needed. Gas prices, which are assumed to remain rather stable especially until 2030, contribute in the development of CCGTs. CCGTs are important for they replace coal and offer balancing services to variable RES. Balancing services are also provided through storage technologies, which develop in the model projections after 2030. This combination

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[93] Data is retrieved from commercial databases (e.g., Platts) and plans of large companies in all Member States.

of gas and storage helps to deliver a secure and reliable power system with high penetration of variable RES.

Furthermore, the model considers provisions for excluding high-emitting plants from support schemes, as laid down in the Industrial Emissions Directive[94], the latest Electricity Directive[95] and Electricity Market Regulation[96]. It also accounts for the prospect of rising EU ETS prices and the ambitious **coal phase-out plans**, some of which were announced after the submission of final NECPs. Altogether, these elements are assumed to discourage the refurbishment of old coal power plants.

In the majority of cases **lifetime extension** of nuclear power plants takes place following refurbishment, while new constructions are in the pipeline in few Member-States. Lifetime extension is analytically assessed, based on a plant-by-plant survey of the age, construction type (generation) and national legislation. Building new power plants in new sites (i.e., in locations where there are currently no power plants) is considered very difficult due to challenges associated with public acceptance; information on the cost of recent nuclear projects[97] has been used to inform the modelling in this regard.

Electricity demand is projected to increase in the medium and long term after being stagnant in recent years. The main reason is the growing electrification in demand sectors, a persisting trend in the projection period. While higher efficiency partly balances out the share of electricity demand in buildings, additional electricity demand comes from the transport sector and to a lesser extent also from industrial processes.

Electricity generation

EU and national supporting policies as well as technology trends prompt a significant penetration of RES in power generation. By 2030, more than half of power generation comes from RES (59%) which is projected to reach 75% by 2050 under Reference Scenario conditions. In 2030, 42% of RES is projected to come from variable sources (wind and solar). Technology and investment trends confirm the cost-competitiveness of solar and wind power. However, in the absence of additional policies post-2030, further investments in RES are driven only by market forces, the ETS and the improved techno-economic characteristics of the technologies.

The biggest increase in the EU power generation mix comes from wind, which more than triples compared to 2015 reaching 30% of total net electricity generation in 2030. Wind installed capacity increases from 127 GW in 2015 to 349 GW in 2030 and 508 GW in 2050. Offshore wind capacity grows exponentially; from just 5.9 GW of installed capacity in 2015 to 95 GW in 2050. Most of wind offshore investments takes place until 2030 – a fourfold increase compared to 2020 – in line with Member State commitments in the NECPs and related projections.

The enabling policy framework between 2021 and 2030 and national commitments boost wind development. New sites are being exploited and wind turbines are progressively replaced by new, taller ones, with higher installed capacity. Without supporting policies in place after 2030, wind onshore growth is still considerable with 40% capacity being added to the grid until 2050.

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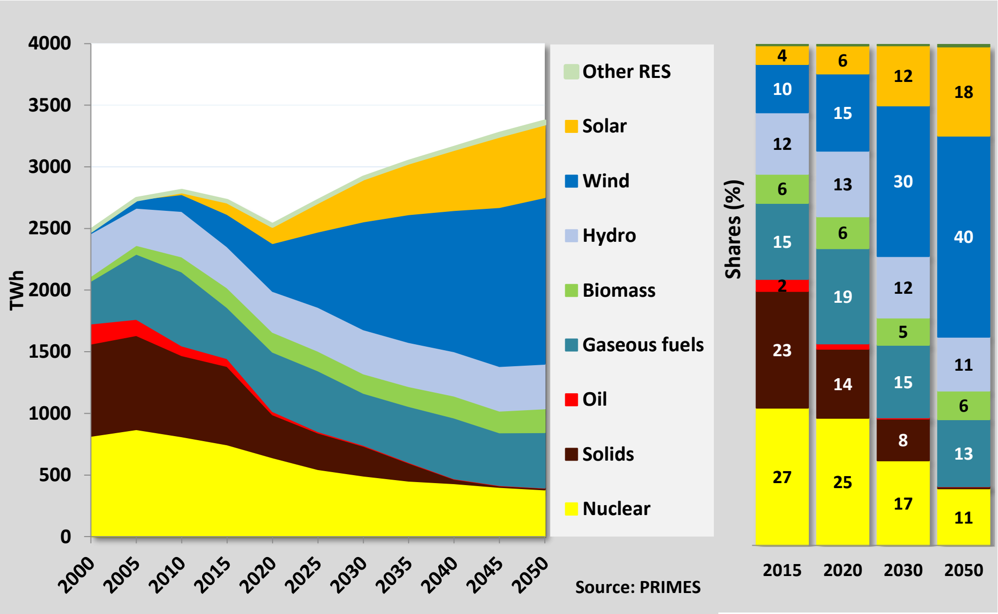
[94] Directive (EU) 2010/75

[95] Directive (EU) 2019/944

[96] Regulation (EU) 2019/943

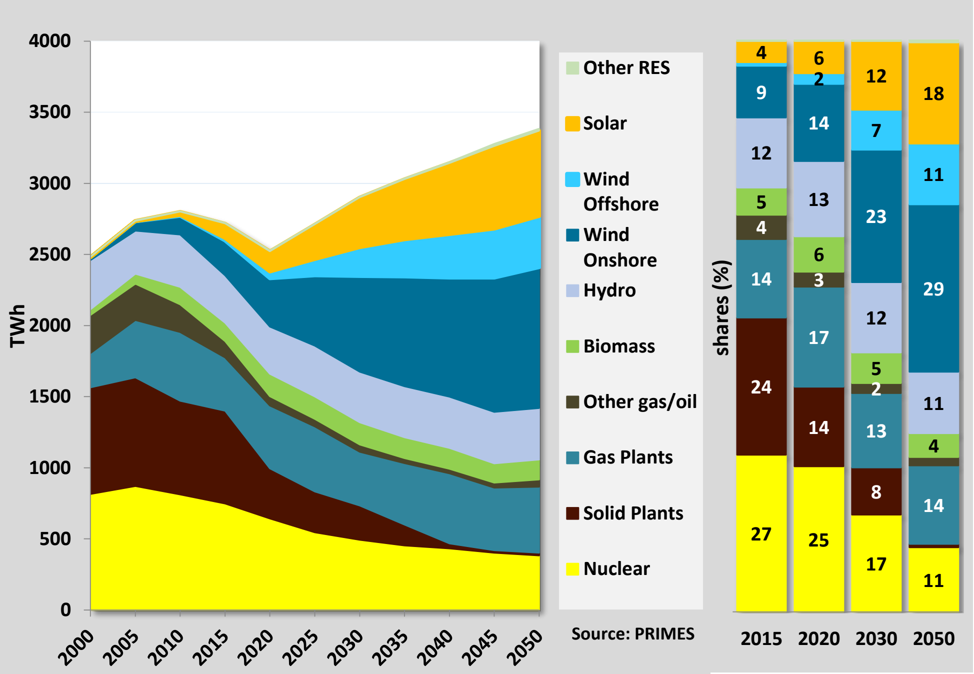
[97] Information was based on http://www.world-nuclear.org/ and related background links

Figure 44: Electricity generation by fuel type



Source: PRIMES

Figure 45: Electricity generation by plant type



Source: PRIMES

Solar power also expands from 87.8 GW in 2015 to 307 GW in 2030 and 513 GW in 2050. Investment in new solar capacity is driven mostly by support schemes in the short term, the decreasing costs of solar panels and high sector competitiveness. Under Reference Scenario assumptions solar PV covers 18% of electricity generation in 2050.

Biomass use increases slightly but the share of power generation from biomass remains between 5-6% throughout the projection period.[98]. Pure biomass/waste plant capacities (excluding co-firing) remain between 30 and 39 GW throughout the projection period.

Hydro generation remains rather stable. Net installed capacity increases by 8GW between 2015 and 2050 with 3.5 GW of investments in hydro-reservoirs planned until 2030.

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[98] Calculated following Eurostat definitions, i.e., excluding energy consumed by industrial sectors and refineries for on-site CHP steam generation.

Beyond this period the majority of investments are in small run-of-river plants. Geothermal, tidal and wave energy are not expected to develop before 2050.

The ambitious policies on coal phase-out is the main trigger for the rapid drop in solid fuels until 2030 along with their limited competitiveness vis-a-vis RES and natural gas, the lack of refurbishments and the EU ETS prices. Oil consumption almost vanishes, except in the non-interconnected islands.

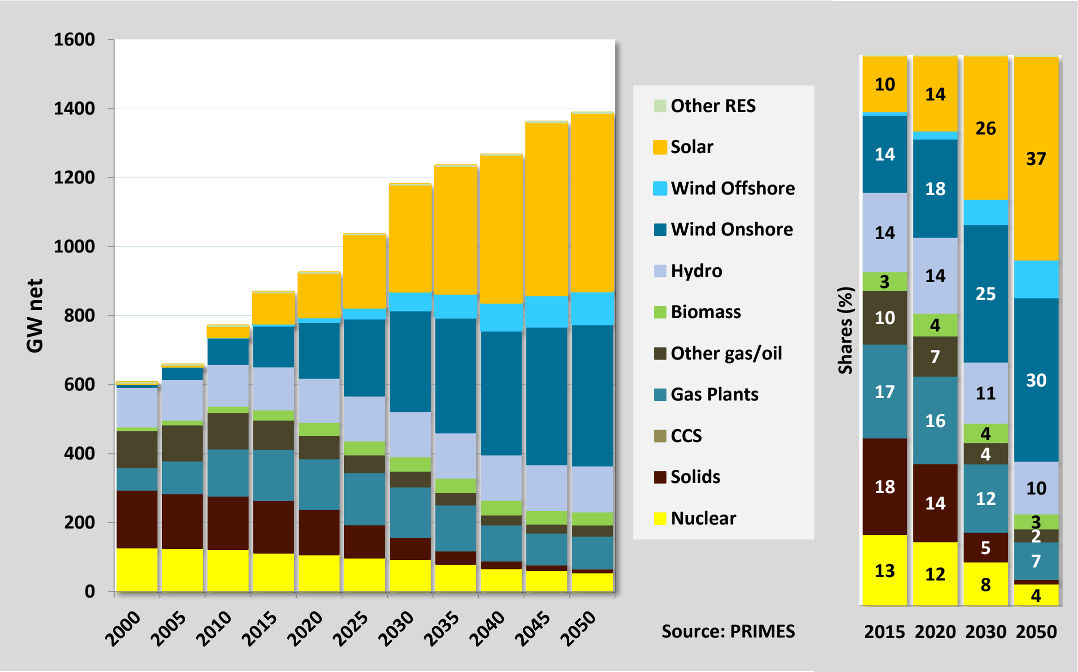
Natural gas continues to play a role in power generation throughout the projection period acting as bridge fuel. It has low carbon intensity relative to oil and solids and contributes to emission reduction. At the same time, gas units are flexible enough to deliver necessary balancing services that allow variable RES to boost their share in power generation. For this reason, gas-firing generation is projected to drop modestly until 2030 and increase marginally in 2050. Total net investment in gas-fired plants in the period 2020-2050 amounts to 290 GW. Capacities thus remain, mainly CCGT plants, as in a Reference Scenario context these represent the main flexibility options.

The share of co-generation in steam production, as well as in electricity production, remains at similar levels throughout the projection period.

Last, the decision for nuclear retirement in Germany before the end of 2022, the extended downtime of a number of units in countries like France and Sweden, and the delays in the commissioning of new-build nuclear plants, e.g., in Finland, coupled with acceptance issues, drive electricity generation from nuclear downwards throughout the projection period: starting with a capacity of approximately 107 GW in 2020, this declines to 94 GW in 2030 and 55 GW in 2050.

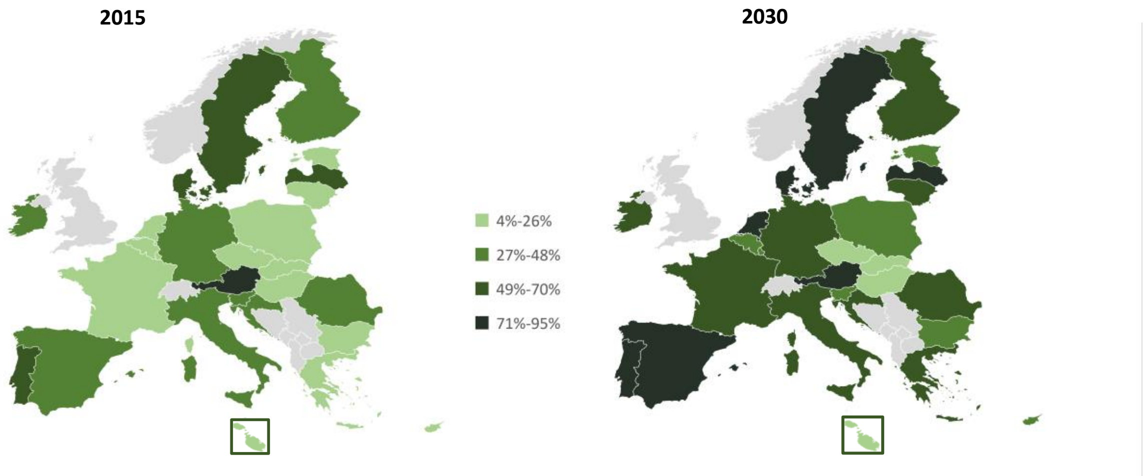
The projected investments in nuclear capacity mainly occur on existing sites or are lifetime extensions; there are very few projected investments in nuclear capacities on new sites. More specifically, the vast majority of investments in nuclear are planned until 2030 and concern the retrofitting of existing plants. Beyond 2030 there are some investments in new nuclear power plants. However, most of these are brownfield investments on existing sites; cumulatively in the period 2035 to 2050 37% of investments are retrofits and 68% of new investments are on existing sites and only in Member States which allow for nuclear investments.

Figure 46: Operating power capacities



Source: PRIMES

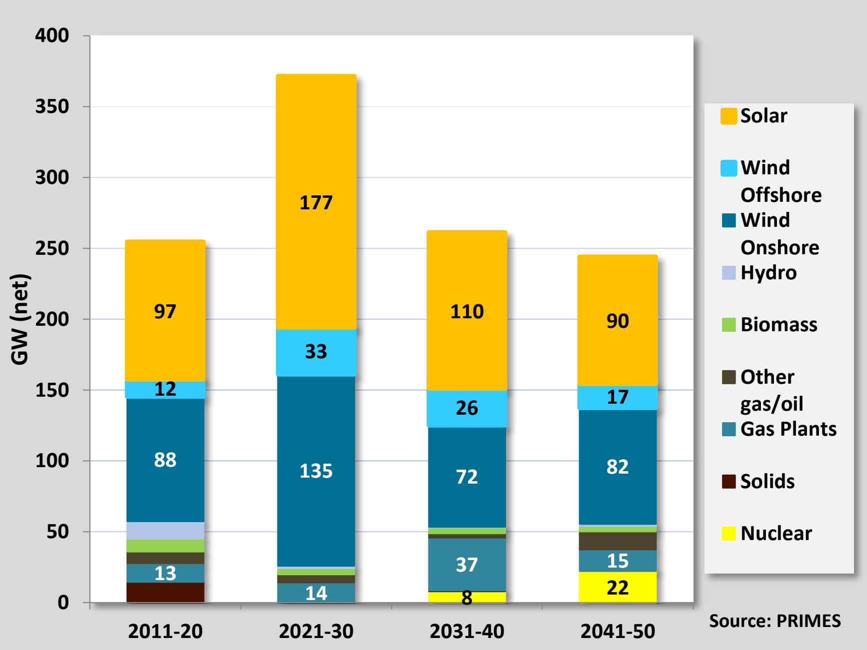
Figure 47: RES-E shares in Member States in 2015 and 2030



Investment patterns

Incremental system capacities come almost exclusively from RES, notably solar PV, and wind. As the share of non-dispatchable generation increases, the rate of use of capacities for CCGT and for the remaining coal plants drops. In the case of CCGT, it is because gas plants are increasingly used for flexibility and reserves purposes. Coal capacities on the other hand decrease due to lower competitiveness and phase-out plans.

Figure 48: Investment in new capacities

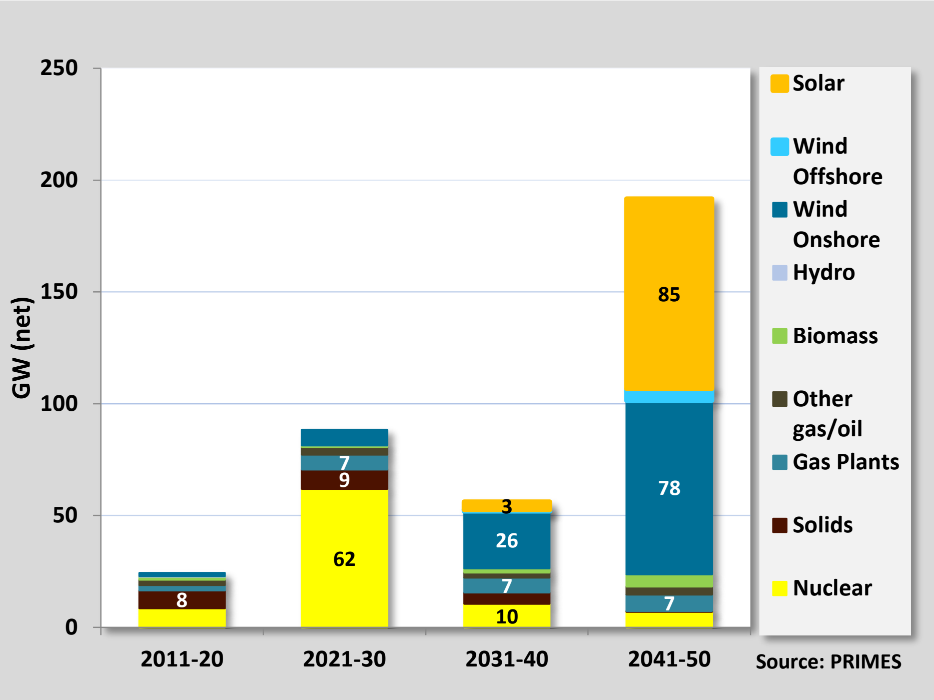


Source: PRIMES

The decade 2021-2030 is projected to be far more demanding in terms of new capacity investment compared to other periods (Figure 48). This correlates with the Reference Scenario assumption that Member States implement the NECPs and that no additional policies are introduced after 2030. Under these terms, solar PV and wind make up for the largest share of investment until 2030. Wind onshore develops strongly while wind offshore benefits from dedicated policies and attracts significant investment.

The absence of such policies after 2030 implies a slowdown of investment. Between 2040 and 2050 total investment in RES increases again, driven by the need to repower obsolete plants (Figure 49), high ETS prices and declining cost of RES technologies. The model assumes full possibility of repowering on existing sites.

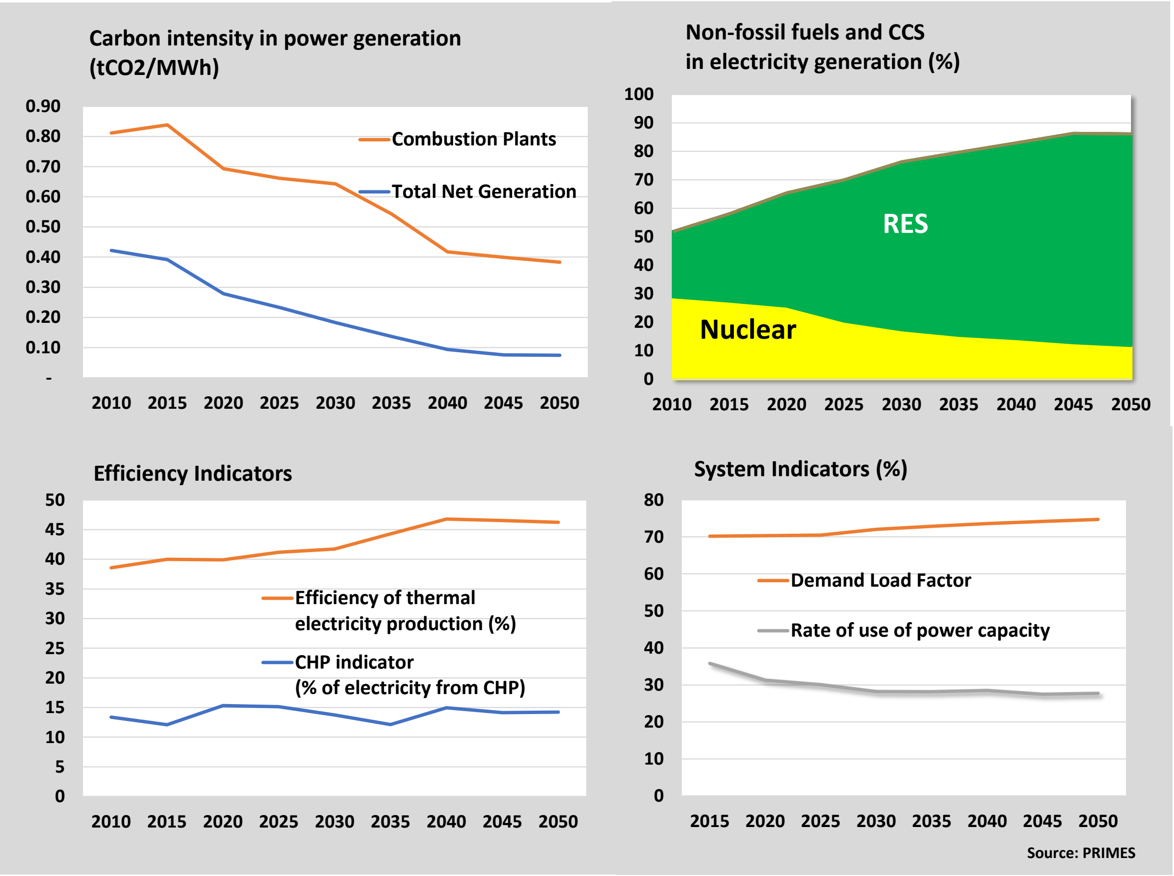
Figure 49: Investment in plant refurbishment



Source: PRIMES

That said, the carbon intensity of power generation (Figure 50) is set to decrease significantly. Key driver is the development of RES, given that nuclear is not expanding, complemented by the increase of thermal plants' average efficiency due to the new CCGTs and the coal phase-out.

Figure 50: Power sector indicators



Carbon intensity in power generation (tCO2/MWh)

Non-fossil fuels and CCS in electricity generation (%)

Efficiency Indicators

System Indicators (%)

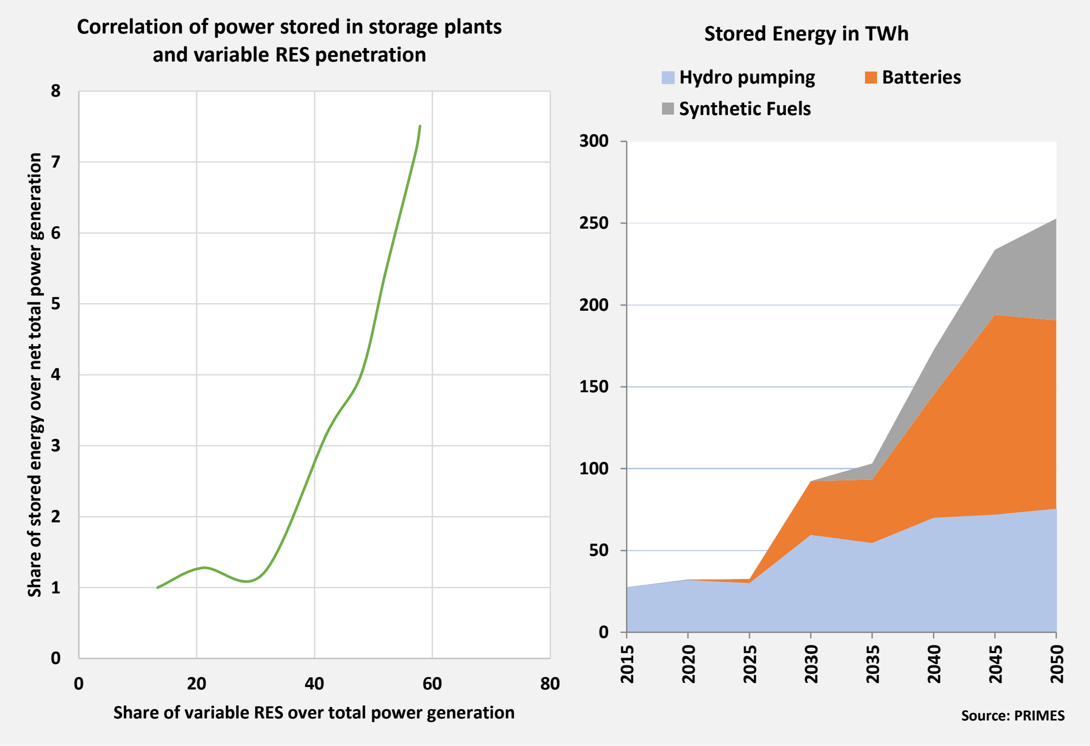
Source: PRIMES

CHP also leads to greater energy efficiency since it optimises the combined generation of electricity and heat from the same input fuel. However, CHP is projected to be roughly stable, a result of the almost stable demand in heat and steam.

Storage

As expected, the increasing penetration of variable RES implies a significant increase in flexibility services in the power system. Gas plants, cross-border flows and storage plants are the main balancing resources. Still, storage facilities undergo an increase by 2030, which accelerates afterwards (Figure 51): pumped storage, which develops further but has potential limitations; batteries that also develop considerably and benefit from decreasing costs over time; and power-to-X, which emerges in the longer-term. As hydrogen makes little inroad under Reference Scenario assumptions, power-to-X has a small contribution to total storage, even in the long-term.

Figure 51: Storage plants and energy



Source: PRIMES

Electricity trade patterns

Over time the volume of trade in electricity is influenced by a number of factors. On the one hand, the full development of the internal market leads to higher NTCs, which, all else equal, increases trade flows; on the other hand, the higher penetration of decentralised RES leads to the construction of flexible capacities close to the demand centres. All else equal, this leads to a reduction of the trade volume. Finally, the harmonisation of electricity prices also tends to a reduction of trade volumes.

These effects can be observed inTable 10 which shows the evolution of volume of trade. EU countries are grouped in regions, and each region includes countries that are well-interconnected and form a relatively “closed” system. Looking at the trade flows, it can be seen that in the 2020-30 period, there is a decrease in total trade flows, while post-2030, the factors that increase trade volume overweigh, and total trade flows end up increasing until the end of the projection period. At the same time,Table 10 reveals a very slight “opening” of the regional systems, as they increase trade with other regions relative to trade within the regions. In particular, in 2020 trade flows between different regions represents 45% of total trade flows; this figure increases to 48% in 2030 and then stays almost stable for the remainder of the projection period reaching 49% in 2050.

Looking more closely at the results for each region: the Iberian region appear to increase its trade with the Central West region; on the other hand, trade of the Central West with other regions (and in particular the Central East region) decrease. Southeast Europe remains a closed system due to the relatively limited developments in interconnection capacity assumed.

Table 10: Volume of trade flows by region over time (MWh)

2020	Central West (C/W)	Iberian (IB)	North (N)	Central South (C/S)	Central East (C/E)	Baltic (BA)	South East (S/E)
C/W	73	15	7	33	24	0	0

IB	1	7	0	0	0	0	0
N	7	0	31	0	3	8	0
C/S	0	0	0	4	0	0	9
C/E	4	0	0	0	27	7	1
BA	0	0	2	0	1	10	0
S/E	0	0	0	0	4	0	1
Total							**279**
Interregional trade as % of total							**45%**

2030	**Central West (C/W)**	**Iberian (IB)**	**North (N)**	**Central South (C/S)**	**Central East (C/E)**	**Baltic (BA)**	**South East (S/E)**
C/W	78	8	4	26	18	0	0
IB	15	6	0	0	0	0	0
N	13	0	17	0	7	5	0
C/S	3	0	0	4	0	0	3
C/E	5	0	1	0	16	3	3
BA	0	0	1	0	4	11	0
S/E	0	0	0	1	3	0	2
Total							**257**
Interregional trade as % of total							**48%**

2050	**Central West (C/W)**	**Iberian (IB)**	**North (N)**	**Central South (C/S)**	**Central East (C/E)**	**Baltic (BA)**	**South East (S/E)**
C/W	10	6	19	21	0	0	82
IB	7	0	0	0	0	0	15
N	0	16	0	4	3	0	12
C/S	0	0	4	1	0	1	8

C/E	0	3	0	19	4	2	13
BA	0	4	0	3	12	0	0
S/E	0	0	3	4	0	3	0
Total							**280**
Interregional trade as % of total							**49%**

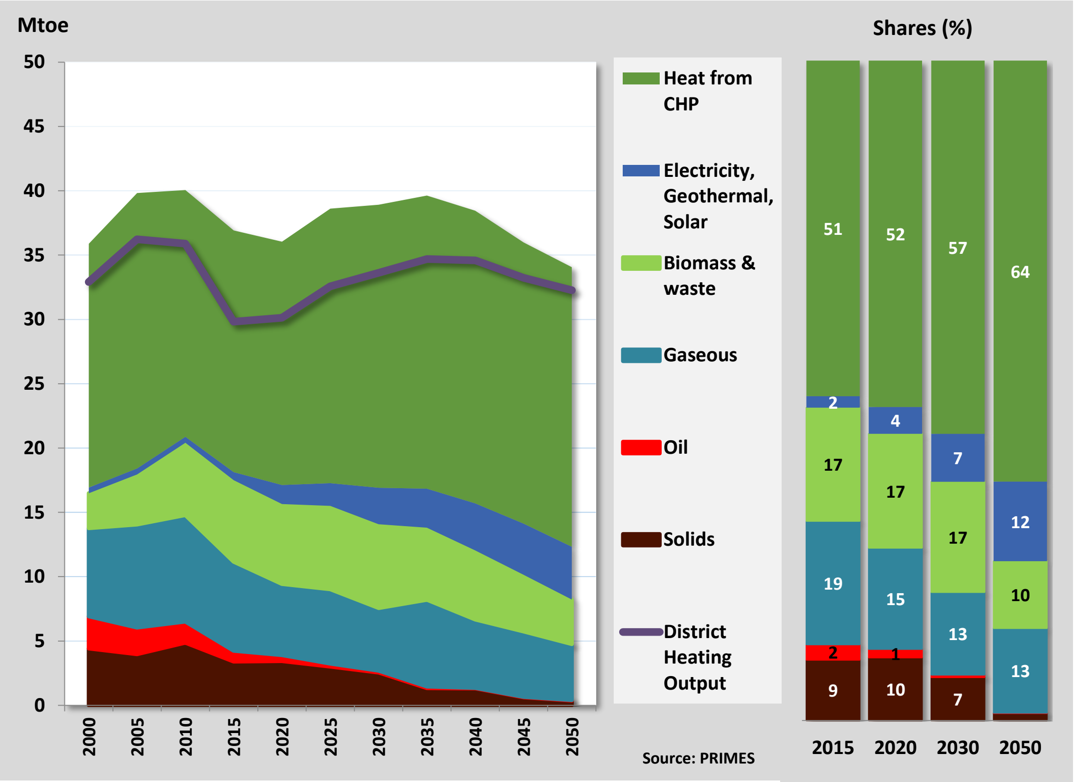
3.2.2. Steam and heat supply

The demand for heat/steam remains relatively stable throughout the projection period.

The share of CHPs in electricity remains similar in the mid-projection period before increasing in the longer term. For steam generation the share between district heating boilers and CHPs remains stable over time. In district heating boilers there is a gradual shift away from solids, oil and (in the long term) gas towards biomass, waste and other emerging renewables and electricity technologies, e.g., heat pumps, solar thermal, and geothermal.

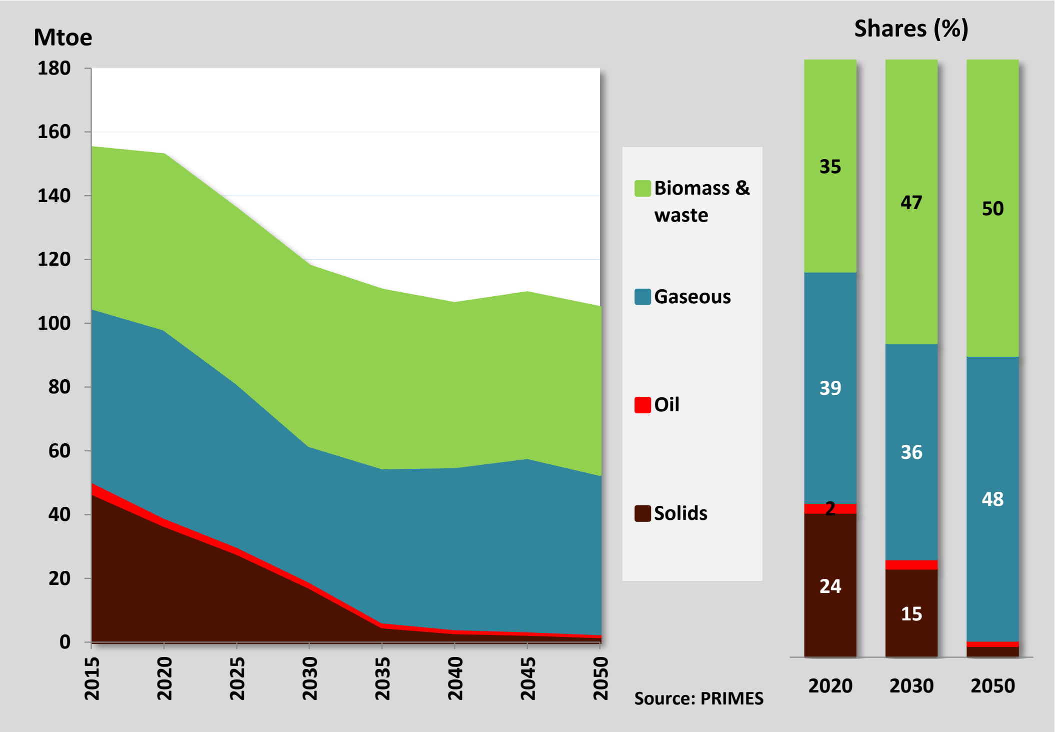
Electricity boilers, heat pumps, geothermal energy and solar thermal penetrate the district heating market and get a significant share in the long term. This is attributed to the high ETS prices, since district heating is covered by the EU ETS, which acts as market and technology driver.

Figure 52: Fuel input to district heating



Source: PRIMES

Figure 53: Fuel input to CHP plants (all plants)

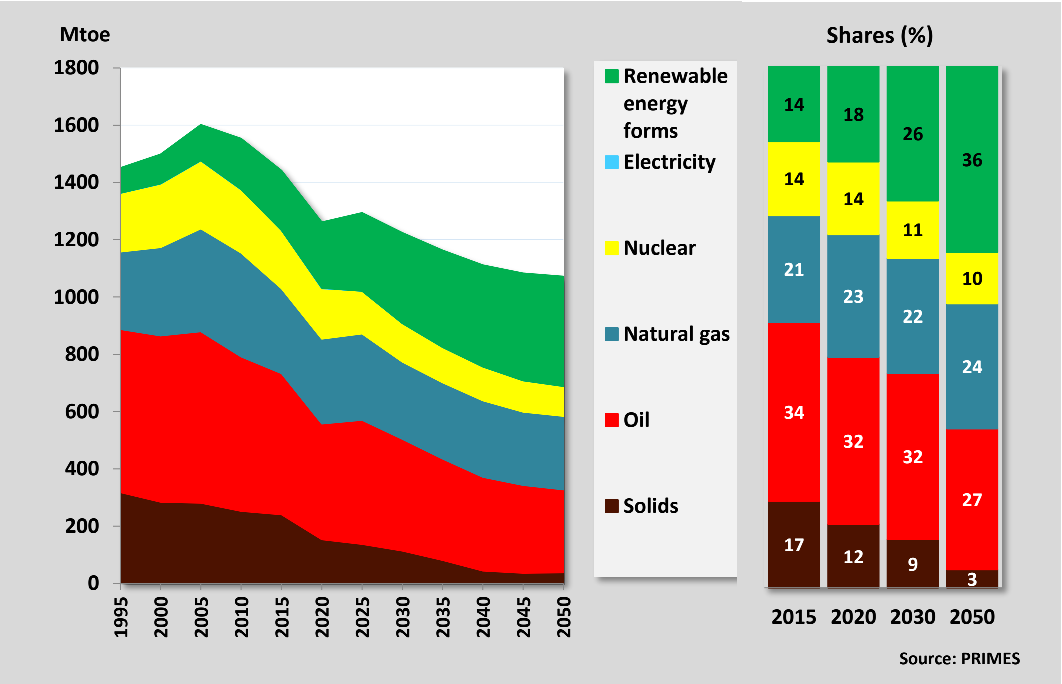


Source: PRIMES

3.2.3. Primary energy supply

Total primary energy supply declines after 2030 due to increased levels of energy efficiency, which brings primary energy demand down (Gross Inland Consumption). RES share more than doubles between 2015 and 2050 owing to the growing electrification of demand sectors. Oil maintains a large share due to limited substitution in the transport sector. Solid fuels decline as a result of coal phase-out in the power sector, while gas maintains its share and is widely used in all stationary and energy supply sectors (Figure 54).

Figure 54: Gross inland consumption



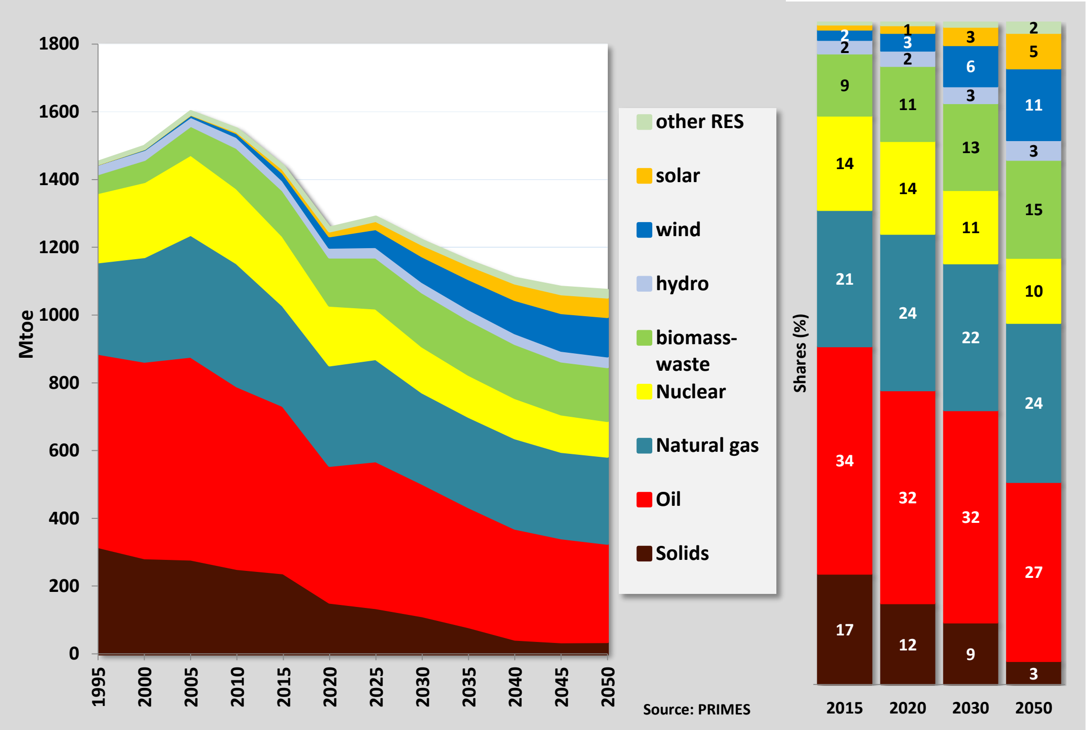
Source: PRIMES

Primary energy requirements are increasingly covered by RES. RES achieve the largest share in the long run, driven by an impressive development in the power sector. RES increase by a factor of 1.8 in 2015 from 2005 levels and by a factor of 3.3 in 2030. The pace of growth slows down after 2030 and in 2050 RES are 4.6 times above their levels in 2005.

Biomass, mainly traditional solid biomass, represents more than half of total RES followed by wind; wind onshore is projected to develop rapidly in the medium term, whereas wind offshore grows faster in the long term. Solar energy exhibits an impressive growth until 2030, which decelerates afterwards.

The shift towards RES contributes significantly to lower primary energy intensity since, in statistical terms, RES are accounted using an efficiency factor of 1, as opposed to alternative fossil fuel or nuclear technologies, which are accounted using energy conversion factors below 1.

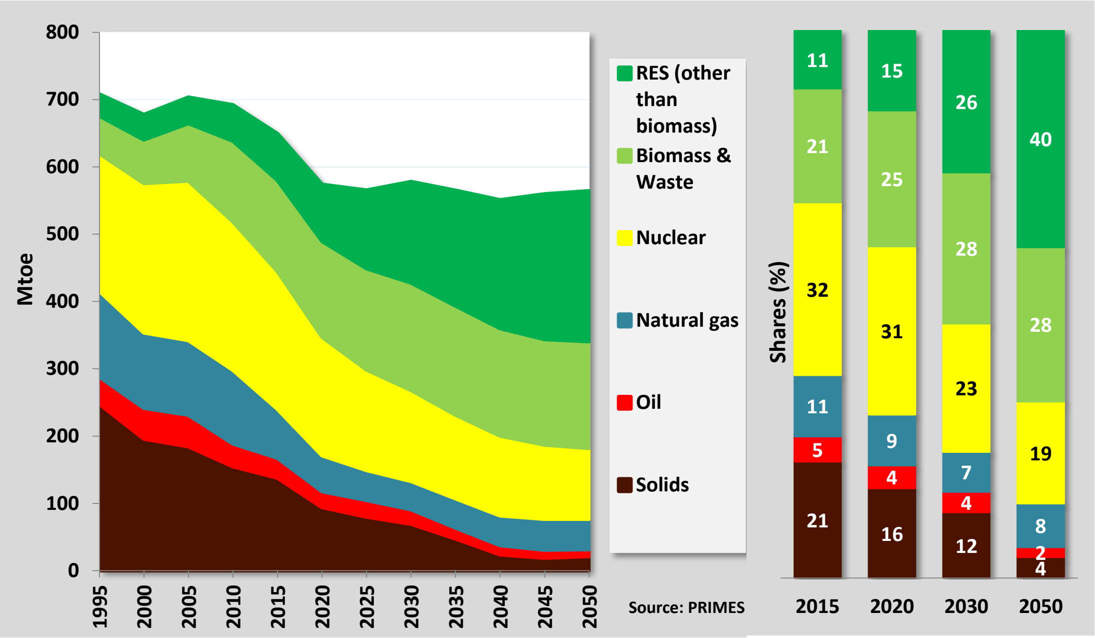
Figure 55: Breakdown of RES shares in Gross Inland Consumption



Source: PRIMES

Primary energy production follows the declining trend of primary energy demand for solid fuels and the exhaustion of reserves for oil and gas. Moreover, the mix in primary energy production changes considerably over time, with RES, including biomass, becoming dominant by 2050 (Figure 56) and almost compensating the reduction of indigenous fossil fuel production.

Figure 56: Primary energy supply



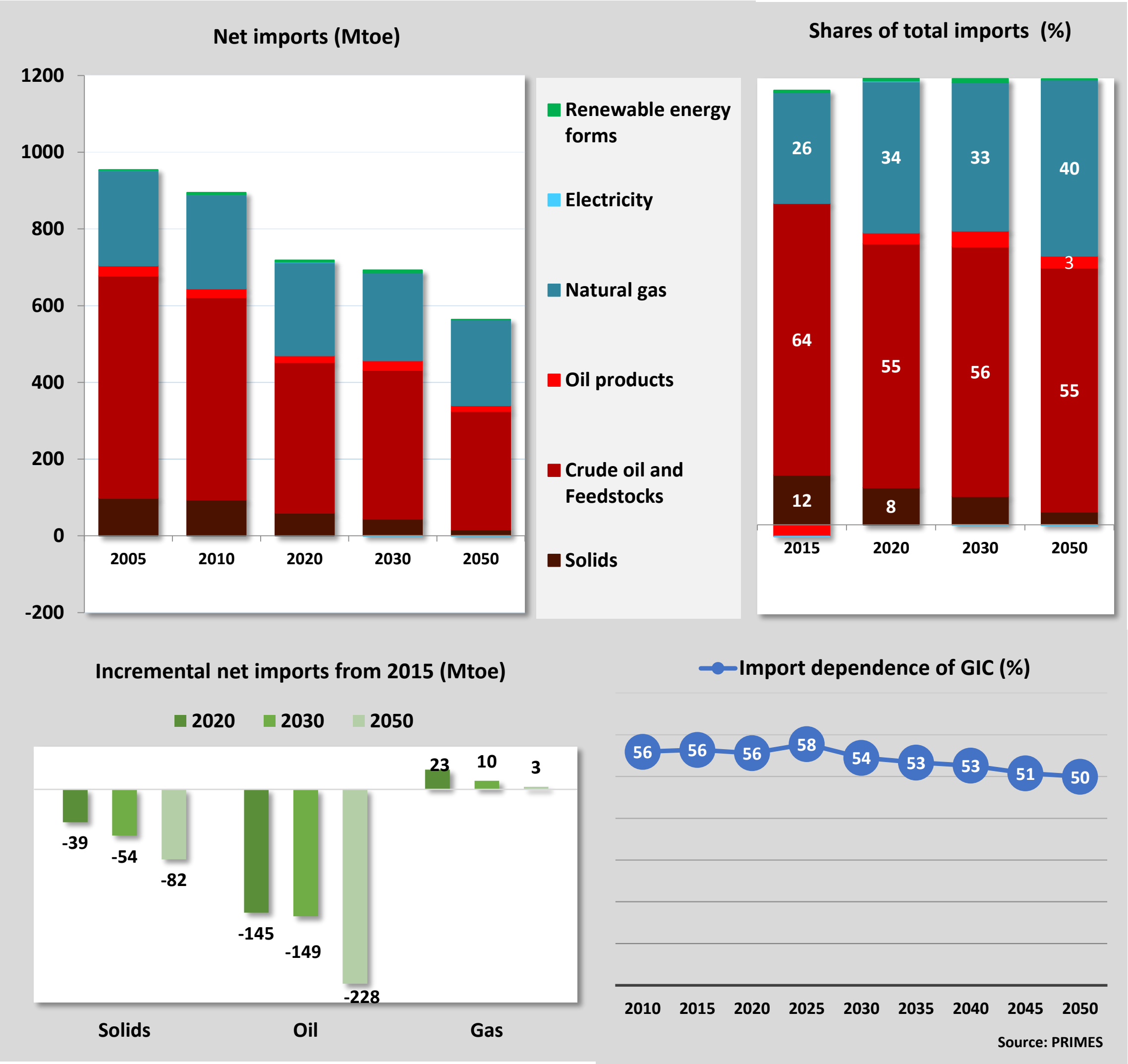
Source: PRIMES

3.2.4. Import dependence

Import dependence remains roughly stable over the projection period. Despite the dropping shares of fossil fuels in final energy demand and the decrease of overall net imports including crude oil, the limited domestic resources lead to an increase in imports of natural gas and oil products. A potentially stronger increase in imports is however mitigated by RES deployment, energy efficiency improvements and stable nuclear production. As a result, import dependence peaks in 2025 at 58% before dropping to 50% in 2050 (Figure 59).

Nonetheless, the absolute level of imports is on decline, even as domestic resources are diminishing. Imports of solids and crude oil and feedstock decrease, while oil slightly increases. Natural gas net imports increase slightly in the long term, reaching approximately 223 Mtoe in 2050.

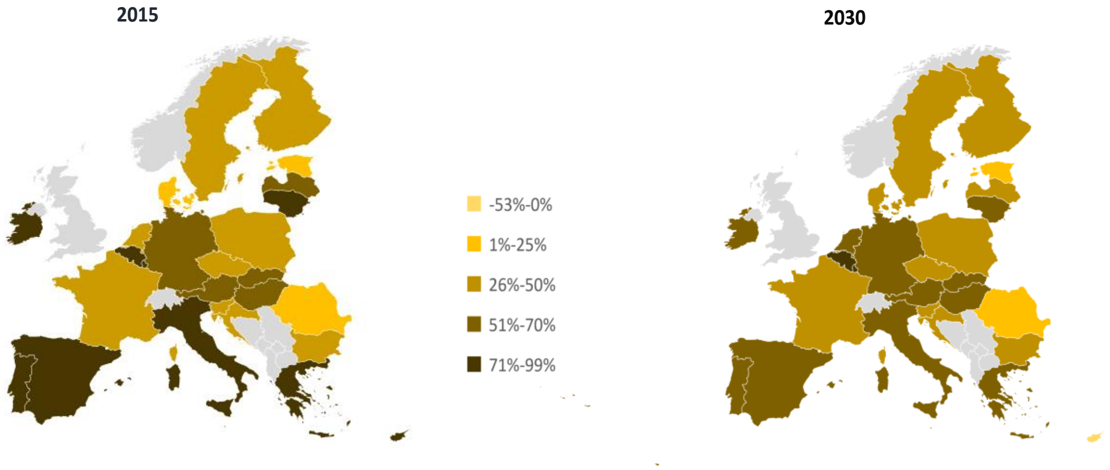
Figure 57: Net imports by fuel



Source: PRIMES

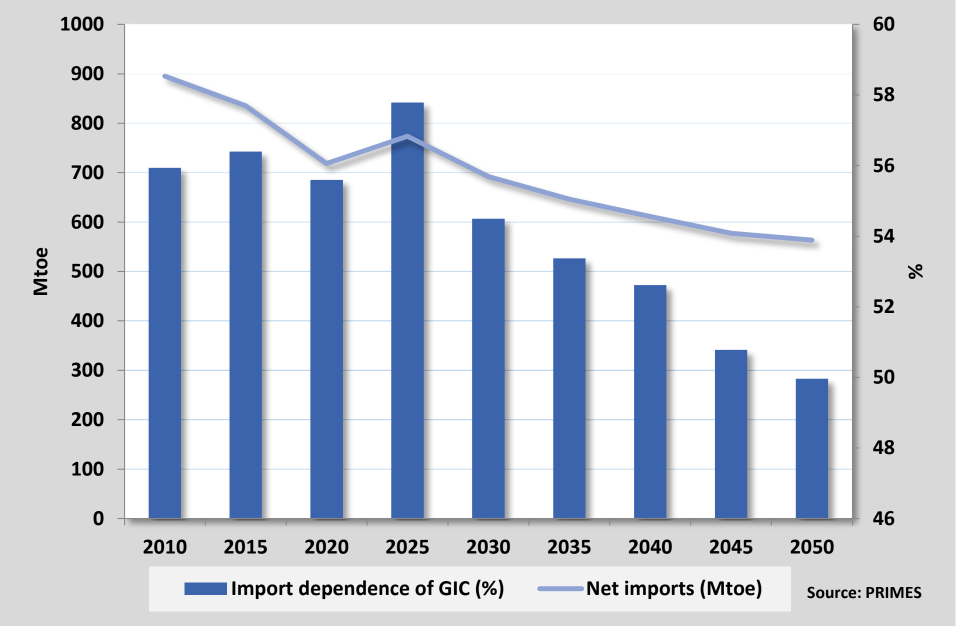
In 2030 import dependence in most Member States is projected to be lower than 2015, while Cyprus becomes a net exporter (of gas). In all other Member States energy import dependence decreases or remains constant. The external fossil fuel bill of the EU is projected to rise in constant prices by 14.5% between 2015 and 2030 and by 36.3% until 2050, reaching around 279 bn €'15 and 332 bn €'15 in 2030 and 2050, respectively.

Figure 58: Energy import dependence by Member State in 2015 and 2030 (%)



RES deployment, combined with energy efficiency improvements and nuclear production (which remains stable), help mitigate the potentially stronger increases in import dependence. Incremental net imports relative to 2005 are negative for all fossil fuels, including natural gas, while oil continues to represent the largest share in total imports of energy. Therefore, the import dependence indicator remains roughly stable over the entire projection period.

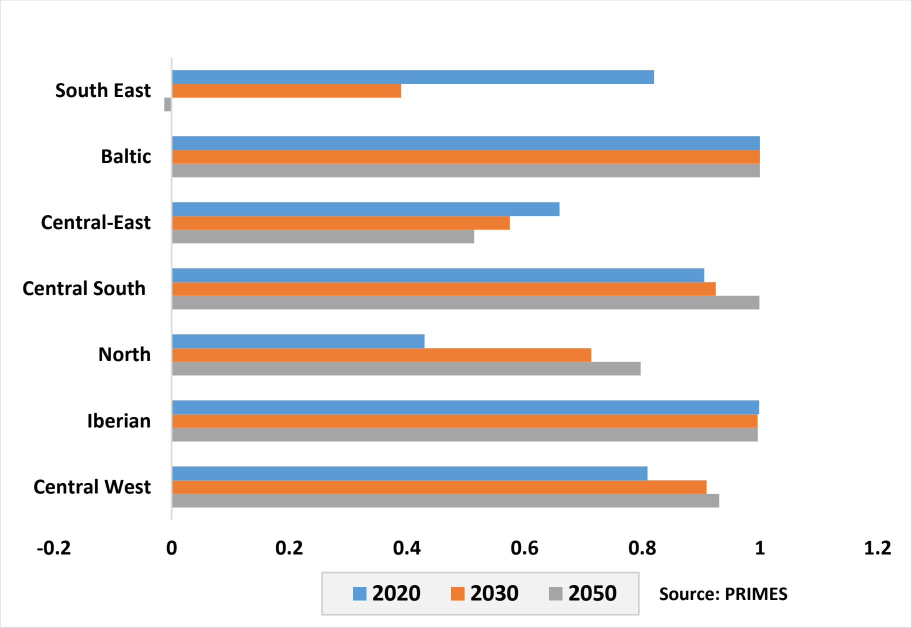
Figure 59: Primary energy imports (% / Mtoe)



Source: PRIMES

Figure 60 shows gas import dependence projections in EU Member States grouped by region on the basis of geographical proximity and energy/gas system characteristics. The highest increase in import dependence between 2020 and 2030 occurs in North Europe (Denmark, Finland, Sweden) followed by Central West (Austria, Belgium, France, Germany, Ireland, Luxembourg, and the Netherlands). In regions with no gas resources and hence no production prospects (Iberian Peninsula and Baltics) net import dependence remains 100% over the period 2020-50.

Figure 60: Natural gas import dependence (%)



Source: PRIMES

3.3. Energy policy indicators

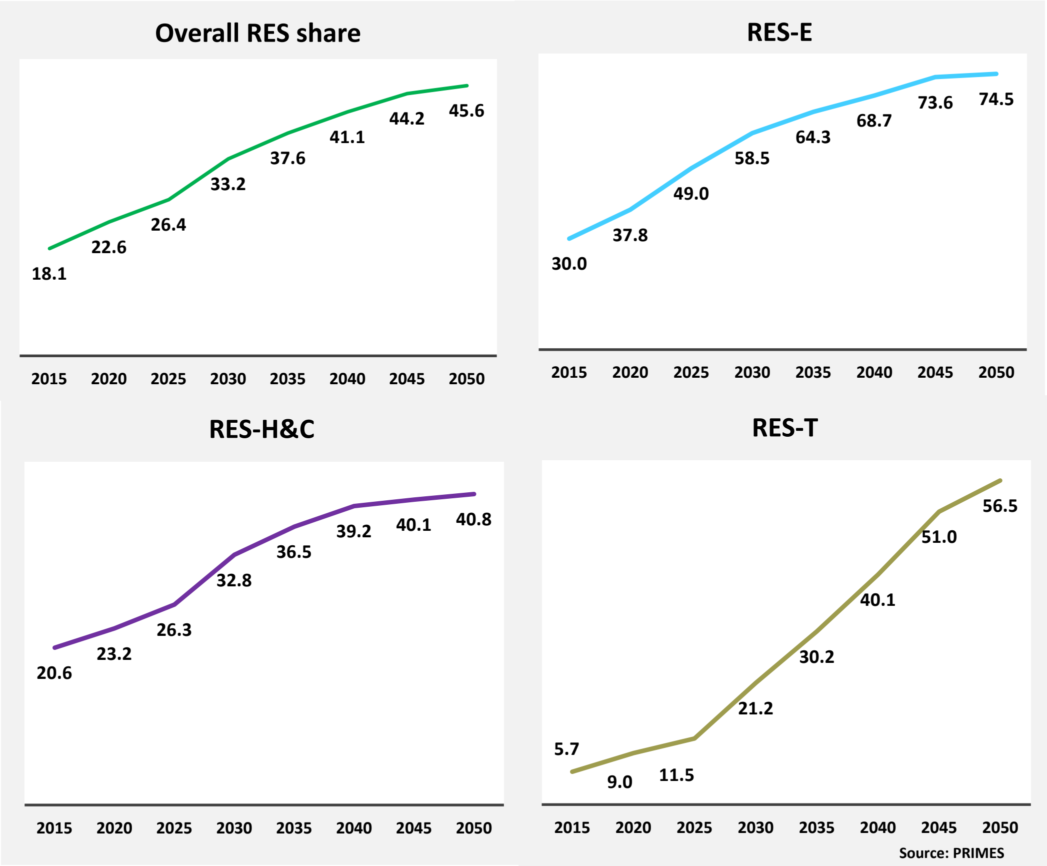
3.3.1. RES target

The overall EU RES target for 2030 is slightly over-achieved (Figure 61). According to projections, the growth of RES share is significantly higher in the second half of the decade (2025-2030) compared to the first half. A slow-down is foreseen after 2030 in the absence of additional policies. This is particularly relevant for RES share in heating and cooling.

The shares of RES in electricity continue to increase after 2030 – albeit slower than before – owing to the strong policies in place, the planned investments for 2030 and the market forces.

RES-T is projected to increase significantly after 2030, due to the increase in electrification brought by the CO_2 standards, the recharging infrastructure development, and the decrease in battery costs. The multipliers included in the current RES-T formula lead to the strong increase of the RES-T share post-2030, as calculated according to the current legislation.

Figure 61: RES policy indicators



Source: PRIMES

RES-E

In the RES-E share, the numerator represents total gross electricity generation from RES and the denominator represents electricity demand[99].

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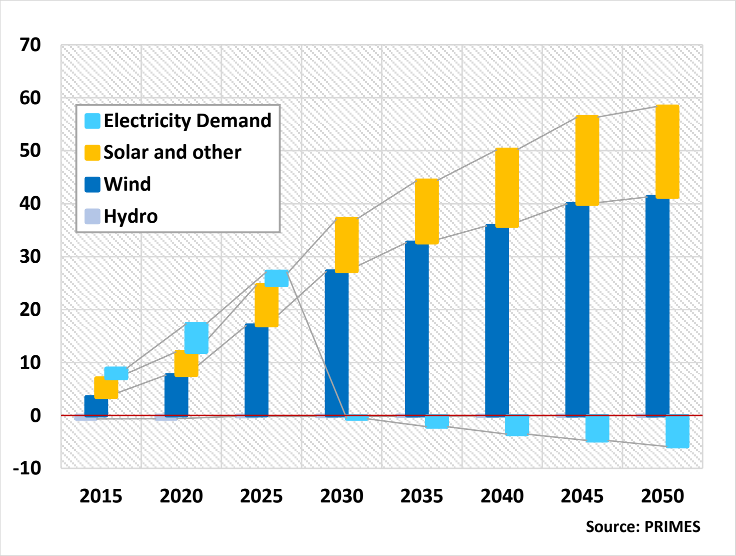
[99] Whenever the denominator decreases and the numerator does not change, then RES shares increase, without however RES changing as an absolute amount.

Between 2021 and 2030 energy efficiency policies curb demand for electricity, which brings about an additional (to what results from the increase in absolute amounts of renewable electricity) increase in RES-E share. In the long term, electrification of final demand sectors combined with a slower penetration of RES in power generation make it so that electricity demand (denominator) grows slightly faster than total RES (numerator), resulting in a slower increase of the RES-E share (after 2030). Wind followed by solar power drive the increase in RES-E share over time; hydropower increases modestly and has a small contribution.

Figure 62: Decomposition of RES-E change relative to 2010 (in %)



Source: PRIMES

RES-H&C

Heating and cooling includes space heating, and all heat uses in buildings, industry, as well as the production of heat, i.e., the fuels used to produce heat in co-generation and in district heating/heat-only plants.

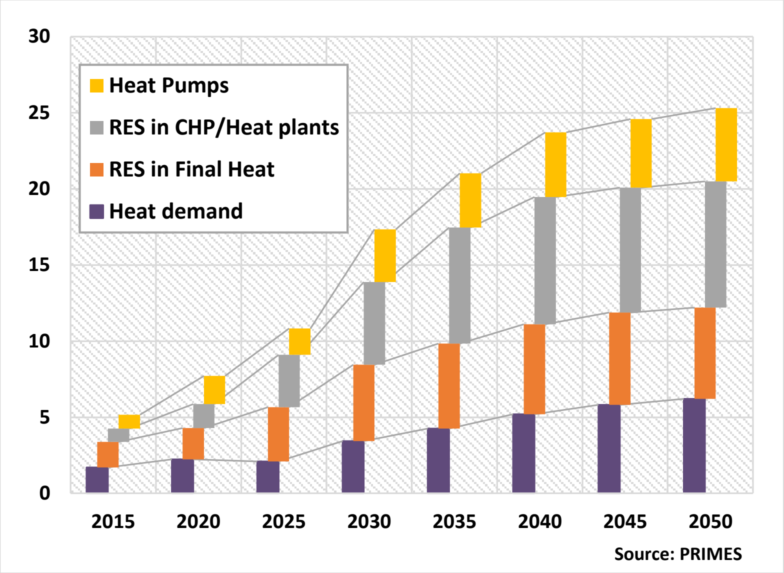
According to the projections, energy efficiency of heat uses, through e.g., insulation of buildings and efficiency in industry, improves substantially. Cutting back the demand for heat (denominator) in all final demand sectors pushes the RES-H&C share strongly upwards until 2035. In the absence of further strengthening of policies for energy efficiency this trend slows down.

Equally important in the growth of the RES-H&C share is the increased absolute use of RES in heating – both in final demand sectors and in supply (cogeneration and district heating). The numerator sums together the direct use of RES in final heat demand, RES share in co-generation, and the penetration of heat pumps. Evidently, all three play a positive role in boosting in the RES-H&C share.

Supported by strong policies RES extend their share in final heat demand in 2021-2030 and remain stable for the rest of the projection period. In contrast, RES in cogeneration and heat-only plants continue to increase also post-2030 as a large part of the production coming from these plants is subject to the EU ETS, which is the main driver of RES development in 2030-2050 period. The electrification of heating via the penetration of heat pumps supported both by energy efficiency and RES policies has also a positive impact on the RES-H&C share through the ambient heat calculation. However, the projection for the use of heat pumps under Reference Scenario assumptions is rather conservative compared to climate neutrality scenarios, which tap fully on their vast potential.

Put together, the absolute use of RES in final demand and in supply and the deployment of heat pumps have a combined positive effect on RES-H&C share, which is much greater than the effect of energy efficiency improvement.

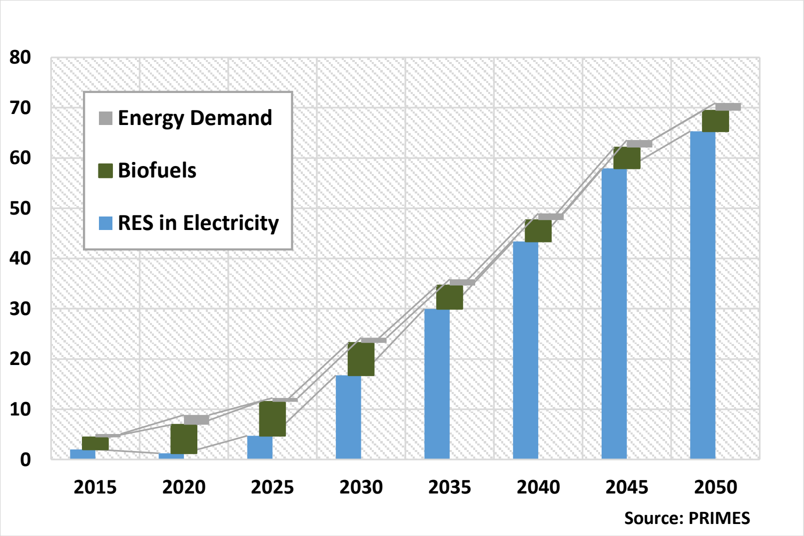
Figure 63: Decomposition of RES-H&C change relative to 2010 (in %)



RES-T

The evolution of the RES-T share depends on three factors: energy demand, the use of biofuels and RES electricity combined with transport electrification. As the electrification of transport advances and the share of RES in power generation increases, the two combined, together with the multiplier used in the RES-T formula, exert the strongest influence on the RES-T share.

Figure 64: Decomposition of RES-T change relative to 2010 (in %)



Under Reference Scenario assumptions the contribution of biofuels peaks in 2030. After 2030 the demand for biofuels in transport remains relatively stable. Demand decreases in the passenger car segment, where electrification proceeds over time, and remains relatively stable in freight road transport. Biokerosene starts making inroads into aviation in 2030-2035 but it maintains a limited share by 2050. The share of biofuels in the maritime sector remains very limited by 2050. In relative terms, the contribution of biofuels to the increase in the RES-T share decreases over the projection period, due also to the way the formula is calculated.

3.3.2. Energy efficiency target

Energy consumption measurement follows the 2020-2030 scope as defined by the current legislation (Table 11), under which international EU aviation and blast furnaces are included in final energy demand. The targets are expressed accordingly.

The Reference Scenario projects that the sum of NECPs fails to meet the EU 2030 target of 32.5% savings in final energy demand with regards to the respective year value of PRIMES 2007 baseline projection. In contrast, the primary energy savings EU 2030 target is achieved due to the combined effects of the energy efficiency policies and the plans of Member States to phase out coal and nuclear in several countries and replace them by RES[100] and more efficient gas in the power sector.

Table 11: Key policy indicators for the energy efficiency target

Key policy indicators (Scope Europe 2020-2030)	**2020**	**2025**	**2030**
Gross inland consumption (Mtoe)	1260.6	1300.6	1229.6
Non Energy consumption (Mtoe)	84.5	91.3	98.7
Primary Energy Consumption (Mtoe)[101]	1176.1	1209.3	1130.9
Final Energy Consumption (Mtoe)	868.8	930.5	882.6
Primary Energy Savings with regards to the respective year value of PRIMES 2007 baseline projection	-28.3	-27.4	-32.4
Final Energy Savings with regards to the respective year value of PRIMES 2007 baseline projection	-27.5	-24.5	-29.6

3.4. Electricity prices and costs

In PRIMES electricity prices are calculated in such way that allows recuperating all costs, including those related to RES policies (e.g., feed-in-tariffs), grid costs, charging infrastructure for EVs and investment costs including stranded investments, back-up, and reserve costs as well as profit margin. The PRIMES model differentiates electricity prices by sector reflecting load profiles, generation, and grid costs.

Weighted average electricity prices, decomposed by cost items, tend to modestly increase until 2030. This is explained mainly by two factors. First, the application of carbon pricing and taxes, i.e., ETS allowance payments. And second, the higher grid costs due to infrastructure development to support grid expansion and new interconnections. Grid costs increase over time due to the growing share of RES and particularly variable distributed RES. Although not geographically defined, PRIMES uses functions to determine grid costs based on the share of distributed generation, mainly wind and solar. The function has been econometrically estimated based on the requirement for high, medium, and low voltage grid requirements. In the period to 2030, grid costs increase

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[100] Wind and solar are accounted by a factor of 1 in primary energy, whereas thermal combustion uses the efficiency of the power plants and nuclear uses a statistical factor of 0.3. This explains the significant primary energy savings when coal or nuclear is substituted by RES in power generation.

[101] Primary Energy Consumption = Gross inland consumption – Non-energy consumption

both due to the increase of distributed RES as well as to the grid development of the TYNDP of ENTSOE.

A small increase in capital costs by 2030 is linked with RES development. After 2030, capital costs of RES decrease thanks to learning by doing and falling technology costs. Also, after 2030, the fuel cost component remains stable despite the increase in fuel prices, due to the decreasing share of combustion plants.

Calculation of electricity prices in PRIMES

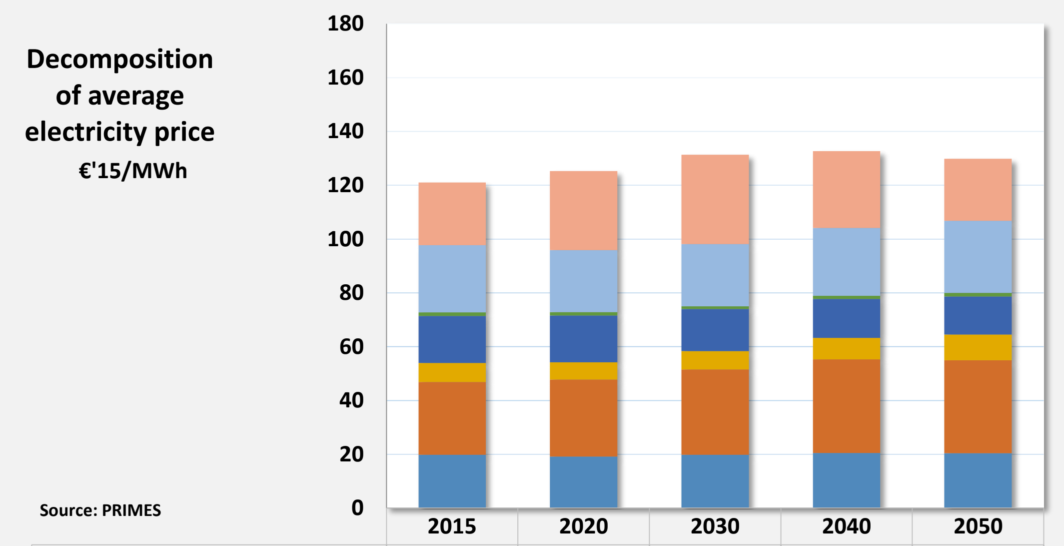
The electricity prices in PRIMES are calculated in order to recuperate all costs including those related to renewables (such as feed-in-tariffs), grid costs, recharging infrastructure for EVs and investment costs including stranded investments, back-up and reserve costs, profit margin etc. The process to determine the electricity prices in PRIMES can be divided into four steps:

- Determination of total system costs under least cost unit commitment and least cost expansion conditions mimicking well-functioning markets.
- Simulation of wholesale markets by country and estimation of marginal system prices reflecting long run marginal costs.
- Matching of load profiles of customer-types with the duration curve of long term marginal prices with customers sorted in descending order of their load factor mimicking bilateral contracting.
- Calculation of prices by sector based on price levels by customer type are calculated to recover the total power system budget including variable generation costs and annuity payments for capital costs, recovery of additional costs for RES and cost of grid differentiated by voltage type.

Grid cost recovery is based exclusively on load payments at average grid tariffs determined as levelised costs of regulated asset basis.

The pricing approach corresponds to the Ramsey-Boiteux methodology and allows for the differentiation of electricity prices by sector.

Figure 65: Cost components of average electricity price

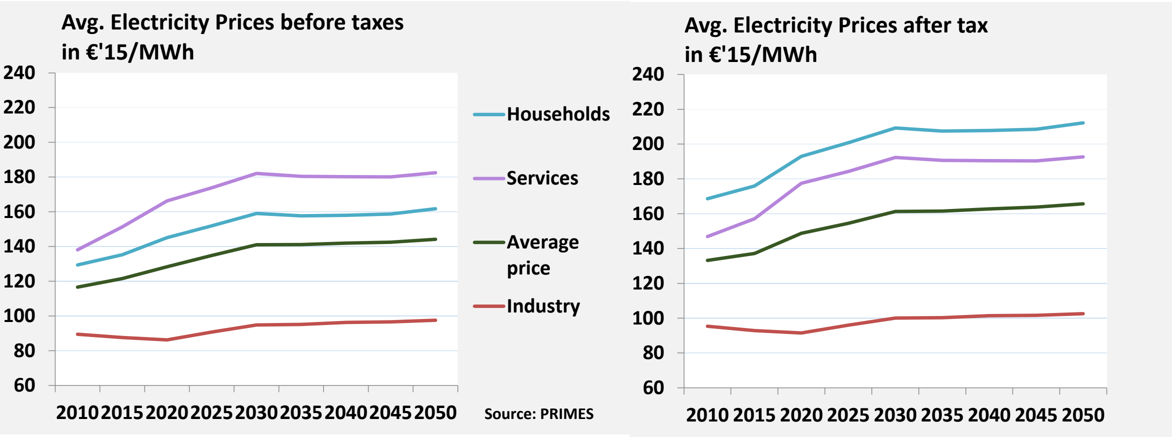


	2015	2020	2030	2040	2050
Annual capital cost	23	29	33	29	23
Fixed costs	25	23	23	25	27
Variable costs	1	1	1	1	1
Fuel costs	18	17	16	15	14
Tax on fuels and ETS payments	7	6	7	8	10
Grid costs	27	29	32	35	34
Excise tax and VAT on electricity	20	19	20	21	20
Average price of electricity (after tax)	146	151	158	159	161

Overall, prices of electricity across the EU Member States tend to converge towards the EU average in the projection period. This convergence is driven by a combination of factors including the elimination of subsidies where these are still present, an increased penetration of RES in all countries, as well as deeper market coupling.

Prices for services and households increase moderately in the medium term and remain stable in the long term. Industrial prices remain stable or reduce over time, as industry maintains base-load profile and is charged for a fraction of grid costs. As far as taxes are concerned, these apply mainly on prices for households and services.

Figure 66: Electricity prices by sector



Source: PRIMES

3.5. Greenhouse gas emissions and removals

3.5.1. CO_2 emissions (excluding LULUCF)

This section presents the projected evolution of CO_2 emissions, emitted from the combustion of fossil fuels in the various sectors of the economy and from industrial processes.

Total CO2 emissions

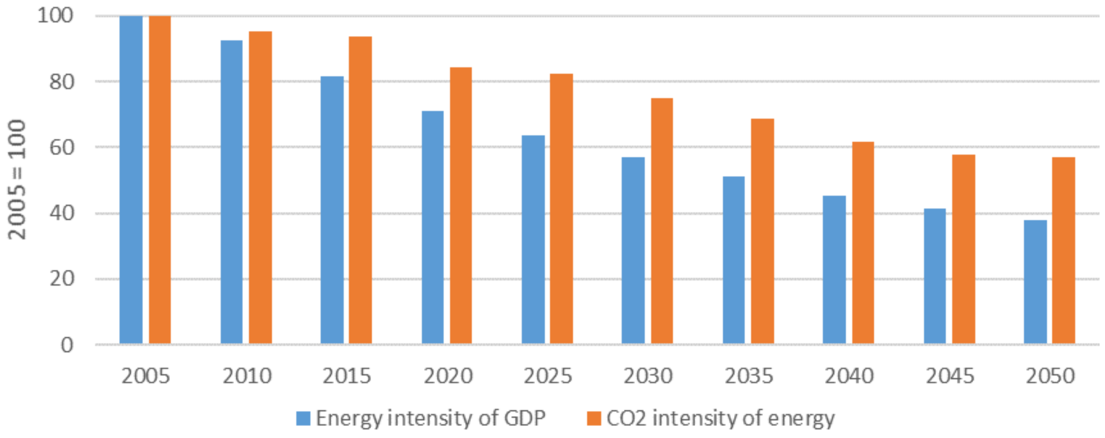
The energy projections presented in the previous sections point to a progressive decoupling of energy demand from GDP growth and a decoupling of CO_2 emissions[102] from energy demand by 2030, strengthening the trend observed since 2005 (see Figure 67).

It must be noticed that 2020 is an exceptional year, with a drop in GDP growth and in CO_2 emissions due to the pandemic. Both GDP growth and CO_2 emissions are projected to bounce back by 2025, close to pre-COVID-19 levels.

The implementation of energy efficiency policies is an important driver of the projected trend of reduction of the energy intensity of the GDP until 2030, which is complemented by carbon intensity savings of the energy mix as the result of coal phase-out policies and the further deployment of renewables in power generation and the other sectors.

The improvement of the energy intensity slows down after 2030, in particular due to the lack of additional energy efficiency policies.

Figure 67: Evolution of the energy intensity of GDP and of the carbon intensity of energy for the EU



Note: The intensities are calculated using the Gross Inland Consumption of energy, the GDP is expressed in EUR2015. Source: PRIMES model

Figure 68 shows the comparison of the carbon intensity of GDP in 2015 and 2030 by country, which reflects a general improvement, although for some countries, the persistence of coal use maintains a fairly high level of carbon intensity still in 2030.

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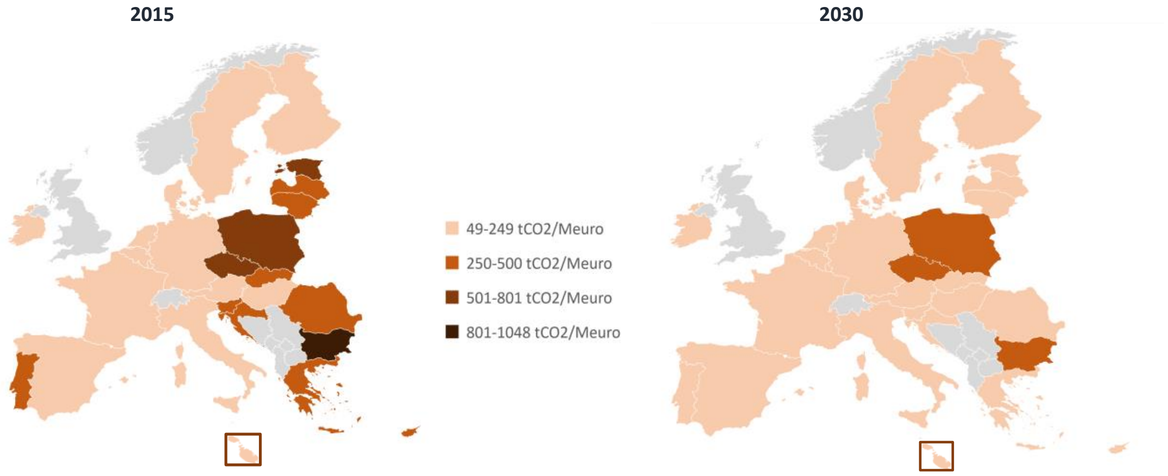
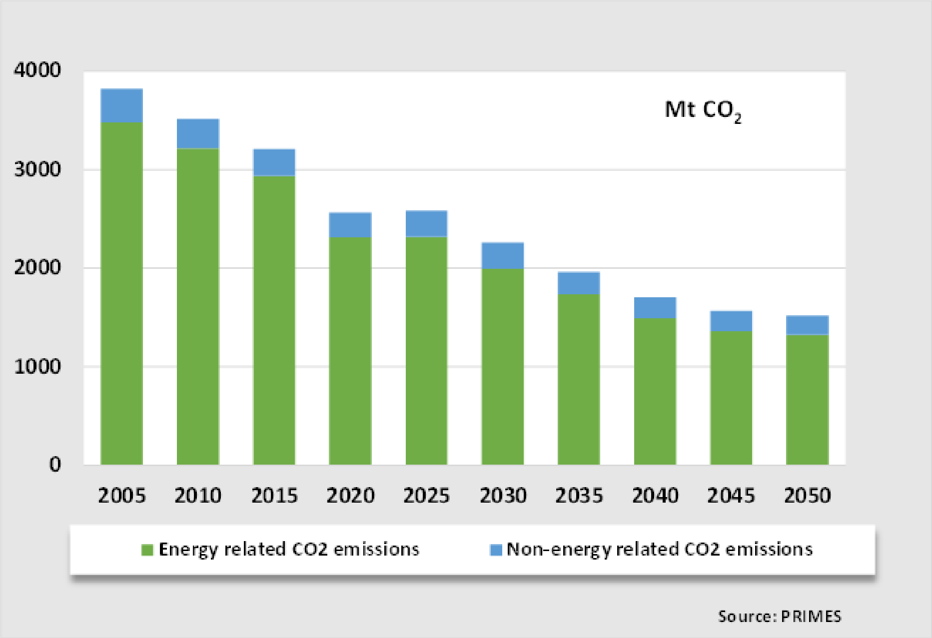
[102] The PRIMES model computes endogenously energy-related CO_2 emissions from the combustion of fossil fuels applying the emission factors of the Regulation on the monitoring and reporting of greenhouse gas emissions (601/2012 and updates thereof). This also concerns emissions for historical years, where these emission factors apply to energy balances calibrated on historical Eurostat energy balances. Matching of energy-related CO_2 emissions with emission inventories is done through the calculation of residuals. In the particular case of the iron and steel sector, the process-related CO_2 emissions are calibrated so that the sum of emissions of the different steps of the industrial process do match the sum of the following categories of the EEA GHG data viewer: 1.A.2.a - Iron and Steel, 1.A.1.c - Manufacture of Solid Fuels and Other Energy Industries, 2.C.1 - Iron and Steel Production.

Figure 68: Carbon intensity of GDP in 2015 and 2030



Falling energy and carbon intensity imply a steady decline in CO_2 emissions throughout the projection period (Figure 69).

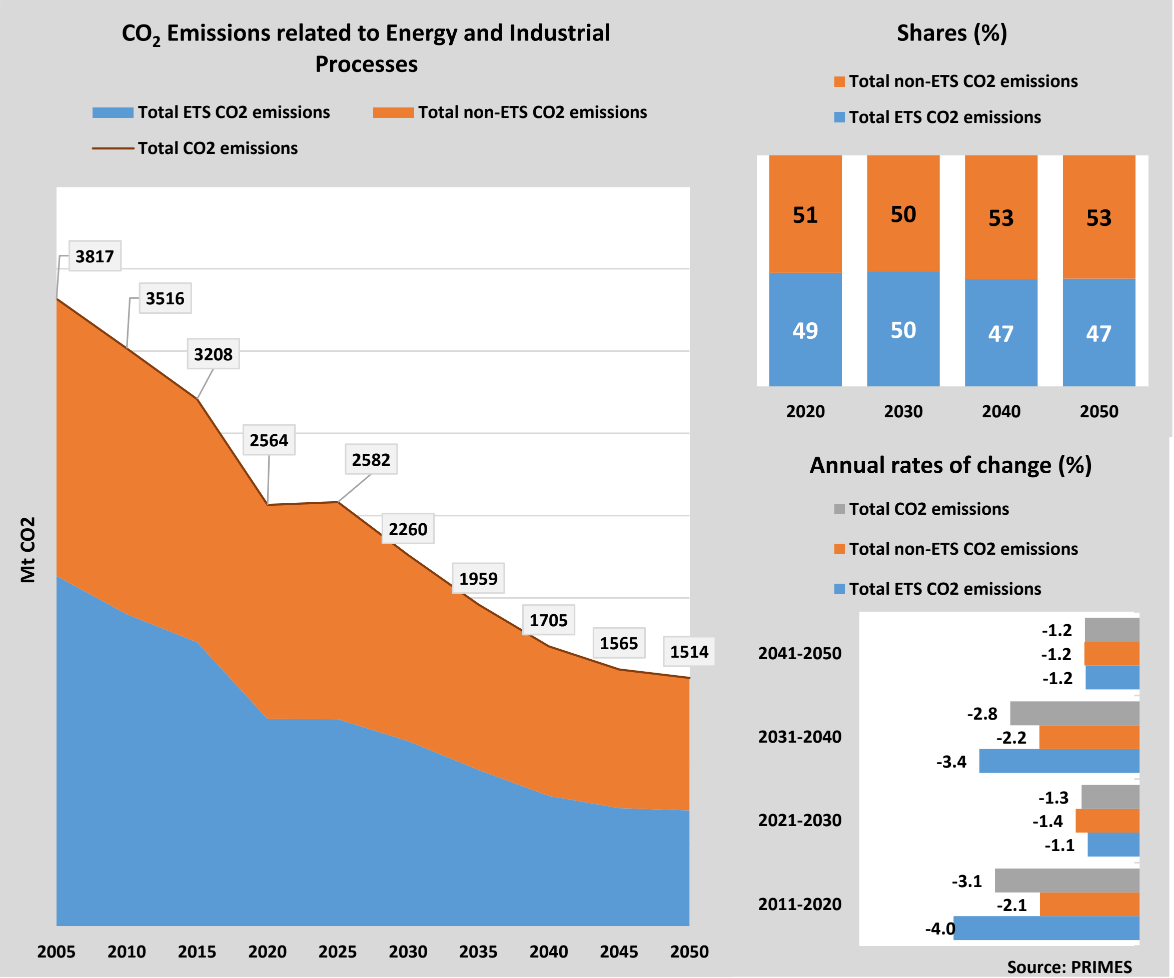
Figure 69: Evolution of CO_2 emissions (excl. LULUCF)



Source: PRIMES

Emissions reduction continues from 2030 to 2040, since in that decade coal phase-out is completed, high RES shares in power generation are established and energy efficiency policies continue to have an impact. Post 2030, emissions reductions are relatively stronger in the ETS sectors compared to the non-ETS sectors, since the ETS is a strong policy driver that continues to apply over the period and affects emission reductions in the longer term (Figure 70).

Figure 70: Decomposition of energy-related CO_2 Emission reduction relative to projection with CO_2 intensity of GDP frozen to 2010 levels



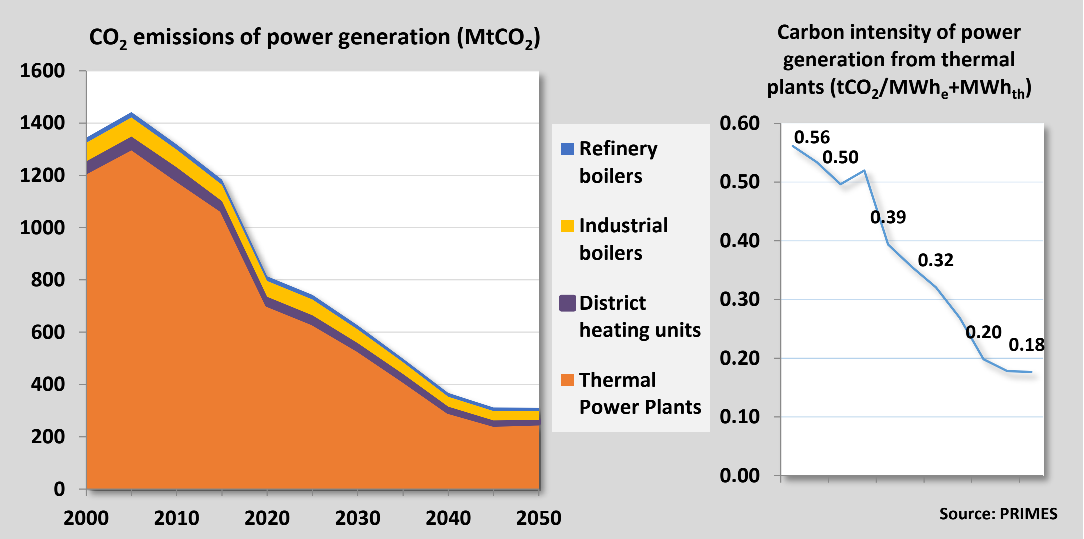
Source: PRIMES

CO2 emissions in the power sector

In particular, and as shown in Figure 71, emissions in the power sector decrease by 50% in 2030 and 75% in 2050 compared to 2015, without however reaching carbon neutrality in the long-term in the Reference Scenario context. This is primarily attributed to the ETS carbon price signal, the technology improvements (contribution of renewables, increased efficiency of CCGT plants) and national coal phase-out policies. Emissions in the power sector decrease by 50% in 2030 and 75% in 2050 compared to 2015, without however reaching carbon neutrality in the long-term in the Reference Scenario context. This is primarily attributed to the ETS carbon price signal, the technology improvements (contribution of renewables, increased efficiency of CCGT plants) and national coal phase-out policies.

District-heating units also see a reduction in emissions, whereas emission reductions in refinery and industrial boilers are relatively small.

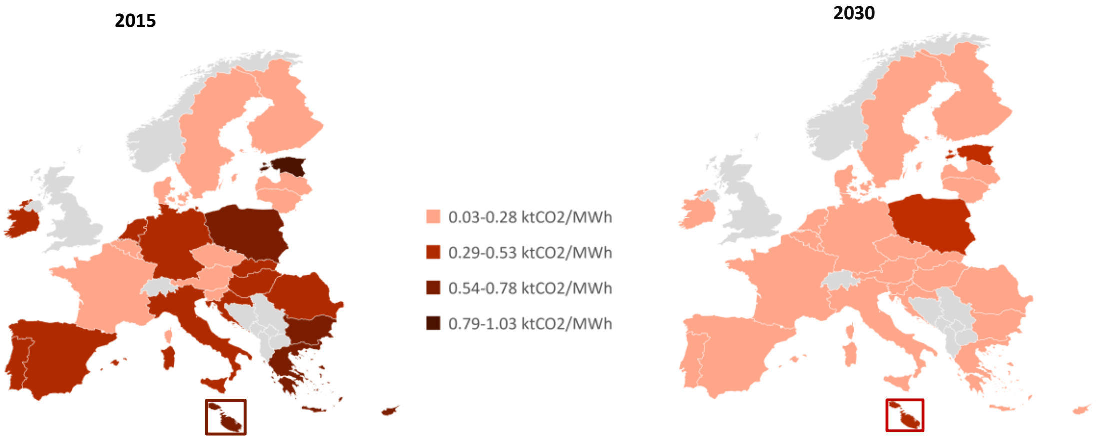
Figure 71: CO_2 emissions in power and steam supply



Source: PRIMES

Until 2030, the carbon intensity of power generation (Figure 72) is projected to decline in all countries driven by the decisions to phase out coal, the development of RES and/or the reliance on nuclear. Few countries which continue to use coal and lignite have higher carbon intensity in power generation.

Figure 72: Carbon intensity of power generation by Member State in 2015 and 2030



CO2 emissions in final energy consumption sectors

In final energy consumption sectors the reduction of direct CO_2 emissions is in general driven by the reduction of energy demand, complemented by fuel switching.

This is for instance the case in transport, where CO_2 emissions (including international aviation, but excluding international maritime) are lower by 15% in 2030 and 36% in 2050 compared to 2015. Unlike the other transport modes, aviation undergoes an increase in emissions by 2030 driven by the growth in transport activity which leads to higher energy consumption met primarily by fossil fuels. CO_2 emissions from international maritime also increase in the Reference Scenario, by 14% by 2030 and 32% by 2050 relative to 2015[103].

Emissions in the transport sector are the most difficult to abate. CO_2 standards for light and heavy duty vehicles contribute significantly to lower the carbon intensity for the total fleet of LDVs and HDVs and reduced emissions by 2050. This is complemented by other

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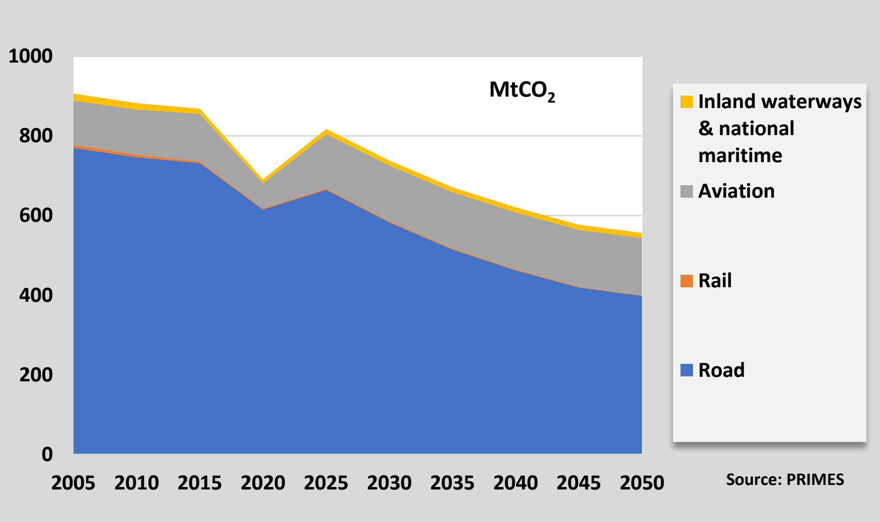
[103] By 2050, the CO_2 emissions from international maritime would stabilise to the levels of 2008.

policies leading to improvements in transport system efficiency, by making the most of digital technologies and smart pricing and further encouraging multi-modal integration and higher use of sustainable transport modes.

Still, while electrification develops, fuel switching by 2030 remains limited in the transport sector in the Reference Scenario (see section 3.1.4). A shift to alternative fuels is mainly projected in the longer run for the passenger cars segment (mainly electricity), and for road freight and maritime transport (e.g. LNG). Also, the role of biofuels is limited post-2030 in the context of the Reference Scenario. Under these conditions, fossil fuels in transport persist.

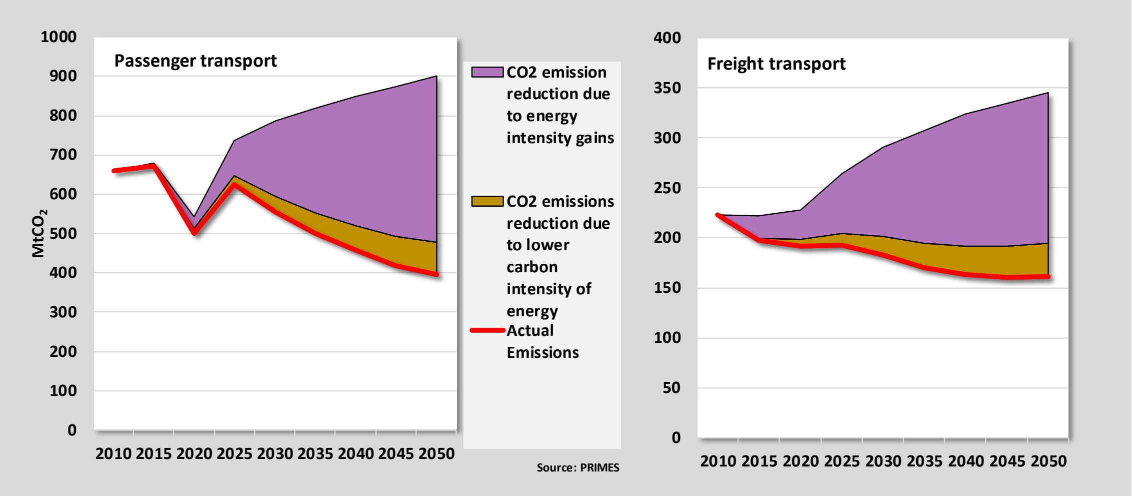
Figure 73: Evolution of CO_2 emissions in transport (excluding international maritime)



Source: PRIMES

Emissions from passenger transport go down by 17% in 2030 and 41% in 2050 compared to 2015 levels whereas emissions from freight transport reduce by 7% in 2030 and 18% in 2050, respectively.

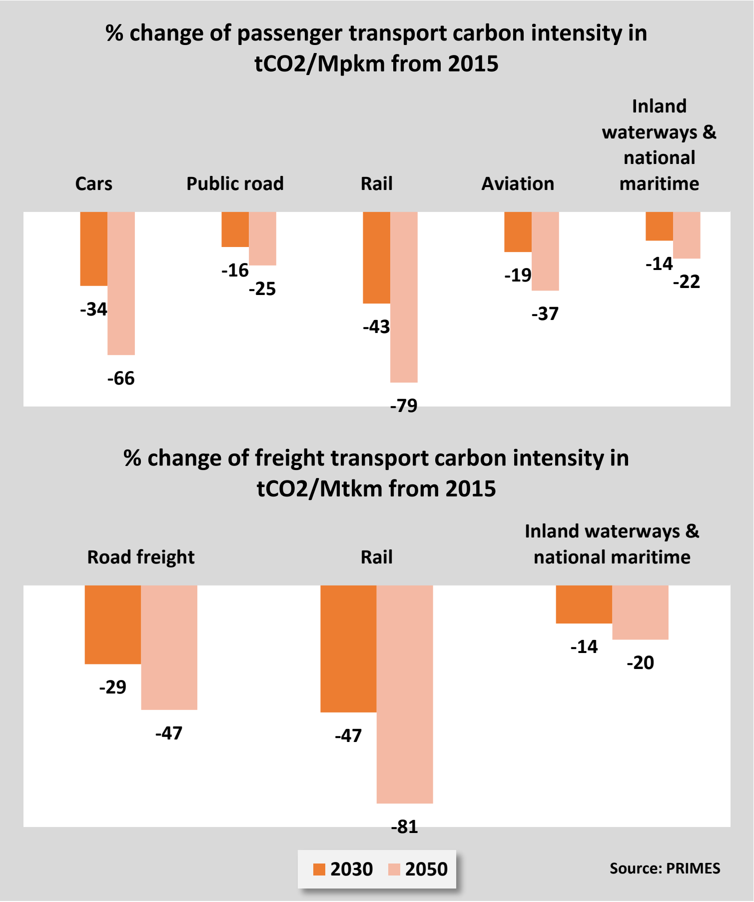
Figure 74: Energy-related CO_2 emissions in transport



Source: PRIMES

In both freight and passenger transport, the biggest drop in carbon intensity among transport modes is projected to come from railways. This is mainly due to the electrification of the rolling stock and the related infrastructure, a trend that will unfold until 2030 and beyond, enabled also by the TEN-T Regulation. Cars follow suite, representing the second highest reduction in carbon intensity. This is mainly due to the growing market share of low- and zero-emission vehicles by 2030. Road freight is also expected to reduce its carbon intensity, attributed to the market penetration of LNG trucks and efficiency improvements in the fleet brought about by the introduction of CO_2 standards for manufacturers (Figure 75).

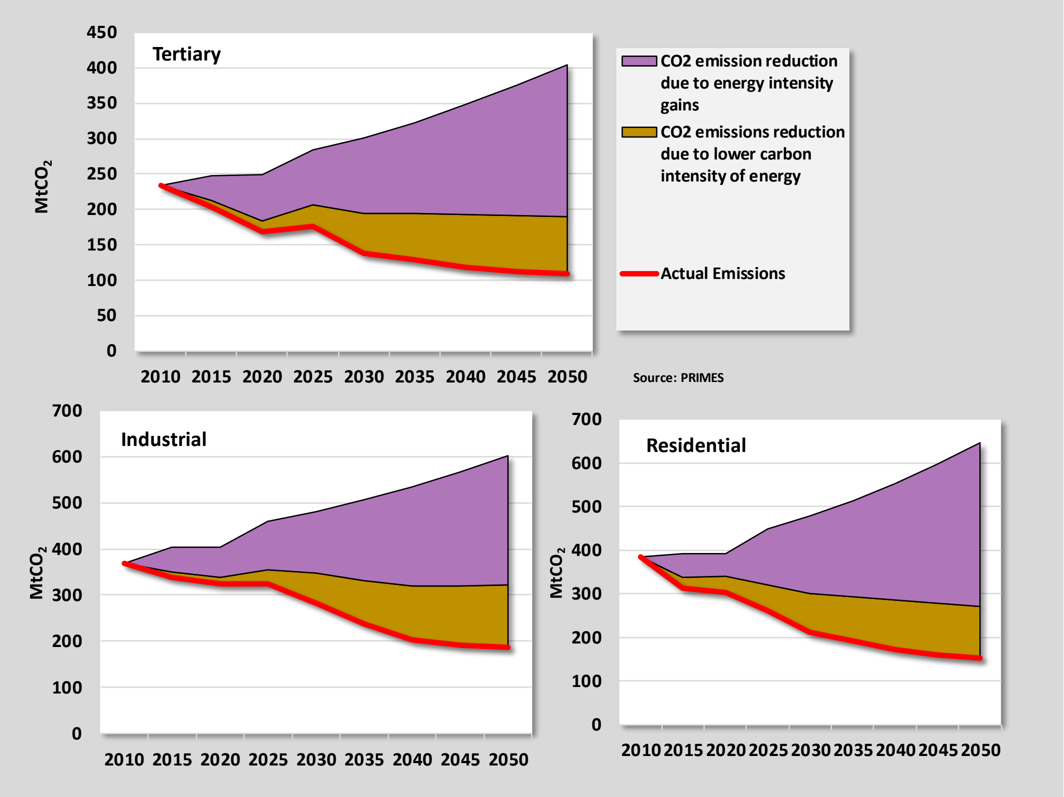
Figure 75: Carbon intensity by transport mode



In the industry, process emissions in 2030 are projected to be at their 2015 level, with technologies for emission abatement difficult to adopt in the Reference Scenario context. On the other hand, emissions from energy uses decrease compared to 2015, with the EU ETS driving a shift towards less carbon intensive fuels (see section 3.1.1) and accompanying the movement from energy-intensive products towards higher value-added and less energy-intensive products. Compared to 2015, energy intensity and carbon intensity gains are projected to bring energy-related CO_2 emissions in industry down by 17% in 2030 and 27% in 2050.

Finally, in buildings (including both residential and services), fuel switching and electrification along with energy efficiency policies bring emissions down by 33% in 2030 and 52% in 2050 compared to 2015. Energy intensity drops, in particular due to energy efficiency policies, with a shift in favour of less carbon intensive energy vectors in the long term (see section 3.1.2 and section 3.1.3).

Figure 76: Energy-related CO2 emissions in demand sectors (excl. transport)



3.5.2. Non-CO_2 emissions and their drivers

In 2015, the EU emitted non-CO_2 greenhouse gases are equivalent to 778 $MtCO_2$-eq when converted using global warming potentials (GWPs) over 100 years from IPCC's Fifth Assessment report (2014)[104]. Just over half of these emissions can be attributed to the agricultural sector, about a fifth to the waste and wastewater sectors, and the rest primarily to fossil fuel production and use and to cooling. Figure 77 illustrates how emissions in non-agricultural sectors have declined by 30% since 2005 and are projected to continue to decline reaching 53% by 2030 and 67% by 2050. The reasons for the decline can be referred to existing policies to address non-CO_2 emissions e.g., the EU directives regulating the waste sector and the F-gas regulations. In contrast, the agricultural sector has seen emission reductions of only 5% since 2005, and with modest continued reductions expected, amounting to 8% by 2030 and 11% by 2050. Details on the drivers for and estimation of sector-level non-CO_2 emissions in the Reference Scenario are presented in this section.

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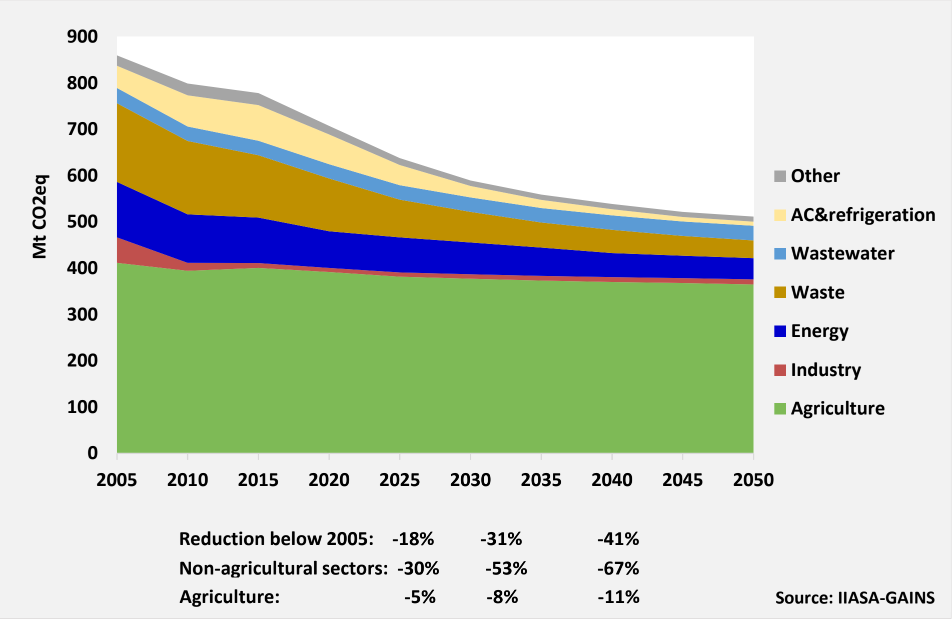
[104] See Commission Delegated Regulation (EU) 2020/1044 supplementing Regulation (EU) 2018/1999 with regard to values for global warming potentials.

Figure 77: Evolution of EU non-CO_2 greenhouse gas emissions

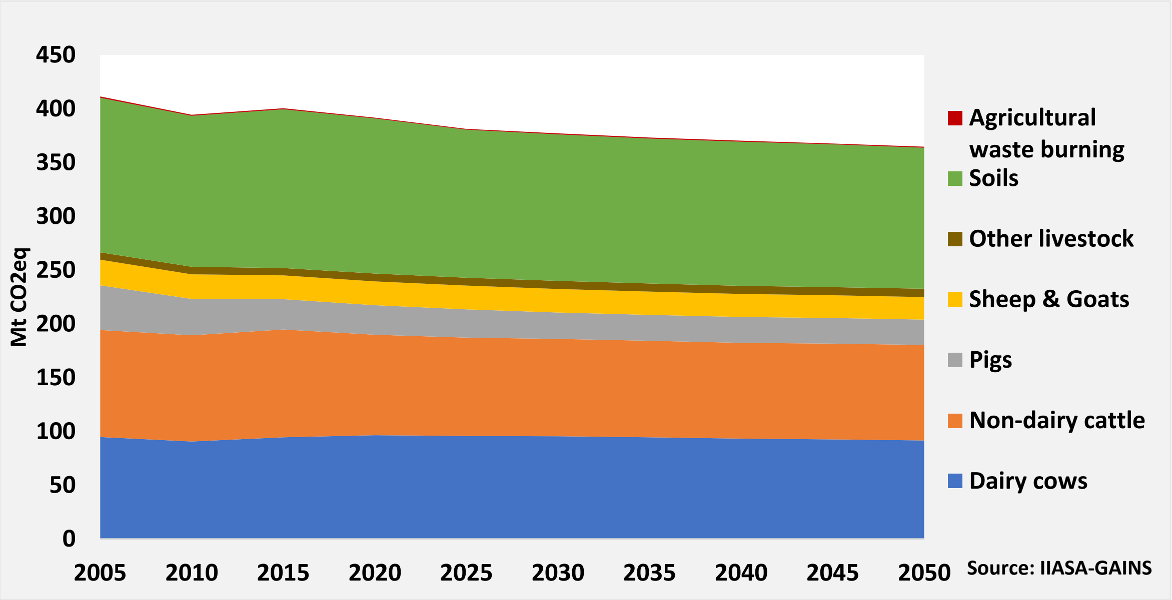


Source: IIASA-GAINS

Agricultural sector

Livestock is the primary source of agricultural non-CO_2 emissions. Over three quarters of livestock emissions come from dairy cows and non-dairy cattle systems (see Figure 78), with CH_4 formation during enteric fermentation processes in the digestive system of ruminants contributing the most, with smaller contributions coming from manure management. Just over a third of agricultural emissions are releases of N_2O from agricultural soils, which is closely linked to the amount of nitrogen (N) added from fertilizers. Finally, there is a small contribution of CH_4 emissions from the burning of crop residues left on fields.

Figure 78: Evolution of non-CO_2 GHG emissions from the EU's agricultural sector (excl. LULUCF)

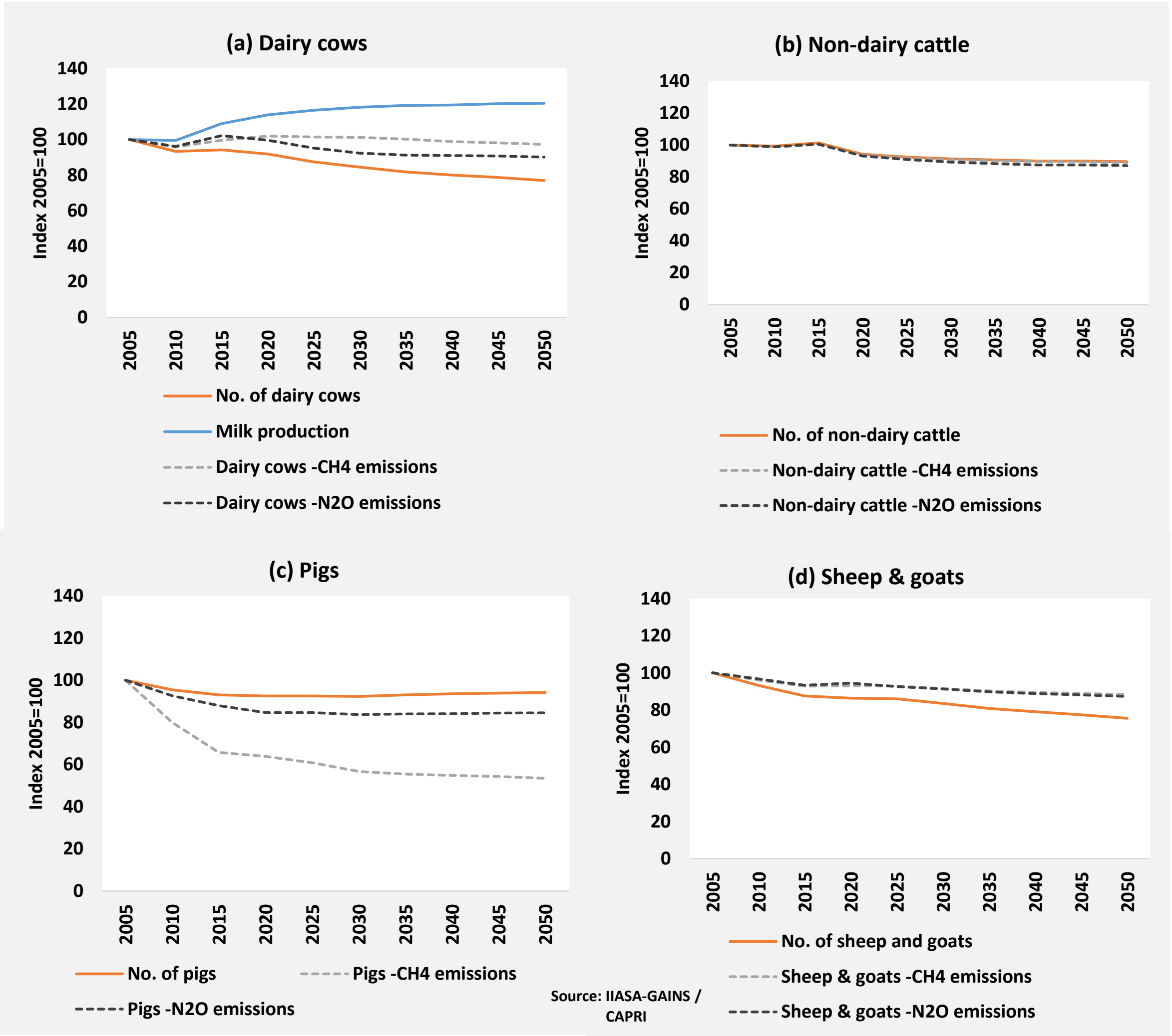


Source: IIASA-GAINS

Drivers used in GAINS for the future development of livestock emissions are animal numbers and milk production in the case of dairy cows, with emissions further affected by the prevalence of technologies and practices that limit non-CO_2 emissions. Figure 79 (panel a) shows how the EU stock of dairy cows is expected to decline by 10% between 2015 and 2030, but due to simultaneous increases in milk yield, CH_4 emissions drop by only 1.6% over the same period. Both CH_4 and N_2O emissions from non-dairy cattle are expected to follow closely a decline in the animal stock by about 10% between 2015 and

2030 (panel (b). There is no foreseen drop in pig numbers between 2015 and 2030 and only a limited decline in N_2O emissions. CH_4 emissions from pigs are estimated to have declined by 12% between 2005 and 2015 due to installations of farm capacity to treat manure in anaerobic digesters. These serve both as a source of biogas and as a way to reduce manure volumes and mitigate bad odour. With increased demand for RES, as estimated by PRIMES, the installation of anaerobic digesters is expected to continue, resulting in additional reductions in pig CH_4 emissions by 14% between 2015 and 2030. At the EU level, CH_4 and N_2O emissions from sheep and goats follow closely a declining trend in animal numbers.

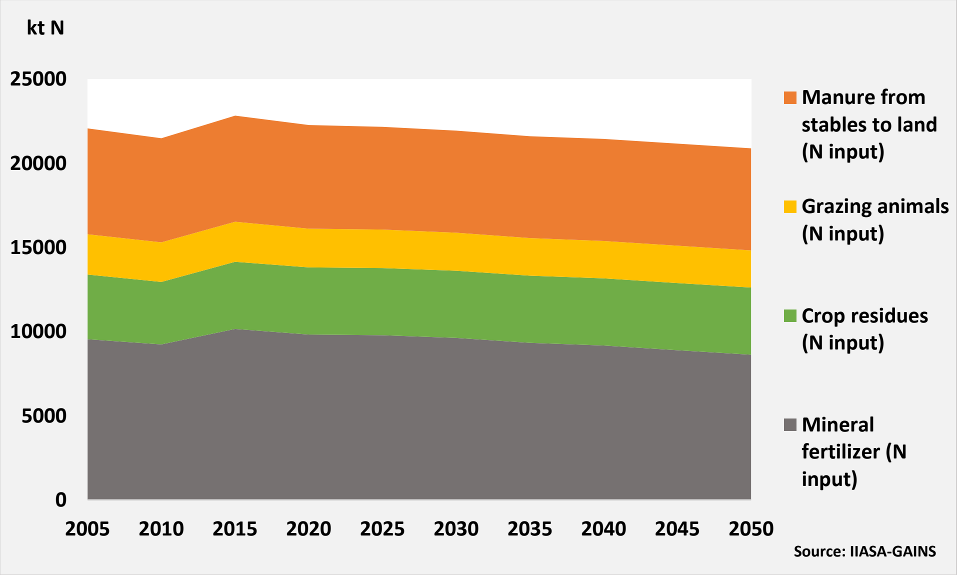
Figure 79: Evolution of EU livestock numbers and associated non-CO_2 emissions



Source: IIASA-GAINS / CAPRI

Figure 80 shows the expected evolution in nitrogen input on agricultural soils in the EU. Policies implemented to control nitrogen emissions, e.g., the EU nitrate directive, provide continued incentives to reduce the use of mineral fertilizers and are expected to translate into an 8% reduction in N_2O emissions from soils between 2015 and 2030.

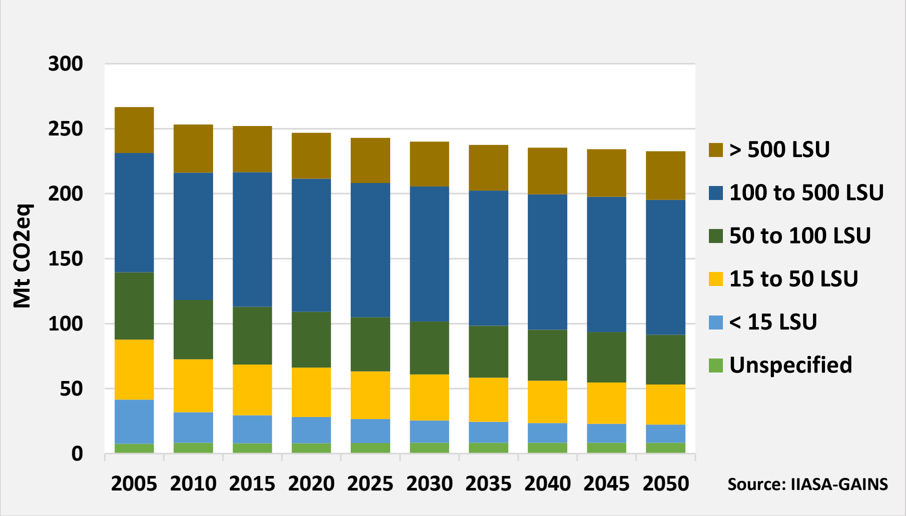
Figure 80: Evolution in nitrogen input on EU agricultural soils



Source: IIASA-GAINS

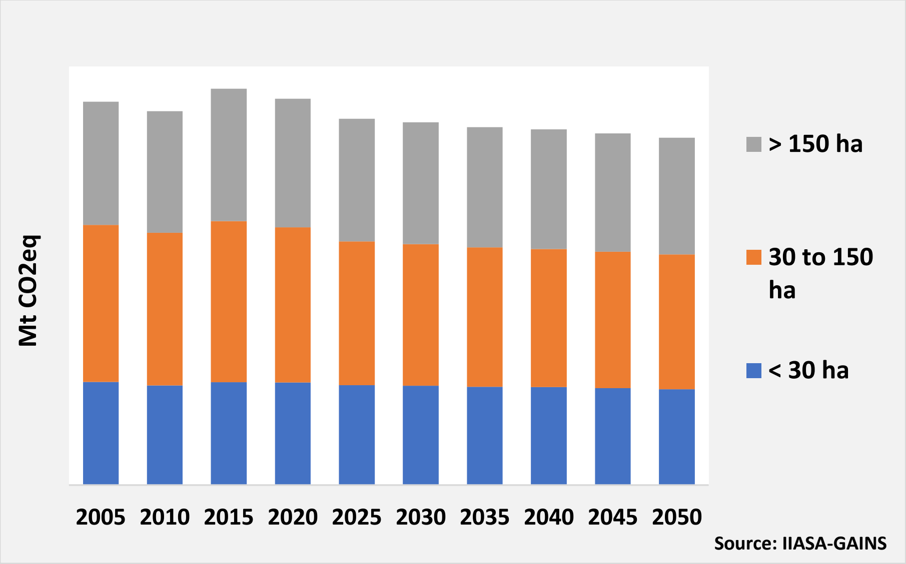
The GAINS model attributes non-CO_2 emissions from livestock by farm size ranges and from soils by farm area ranges. This reveals that 55% of EU livestock emissions are currently emitted from large farms with more than 100 LSU (see Figure 81), while one third of emissions from soils are released from the largest farms with more than 150 ha (Figure 82). These findings are of interest as large farms can utilize economies-of-scale in abatement and therefore often have lower unit abatement costs than smaller farms.

Figure 81: Livestock non-CO_2 emissions by farm size for the EU (LSU=livestock units)



Source: IIASA-GAINS

Figure 82: N_2O emissions from EU agricultural soils (excl. histosols) by farm area



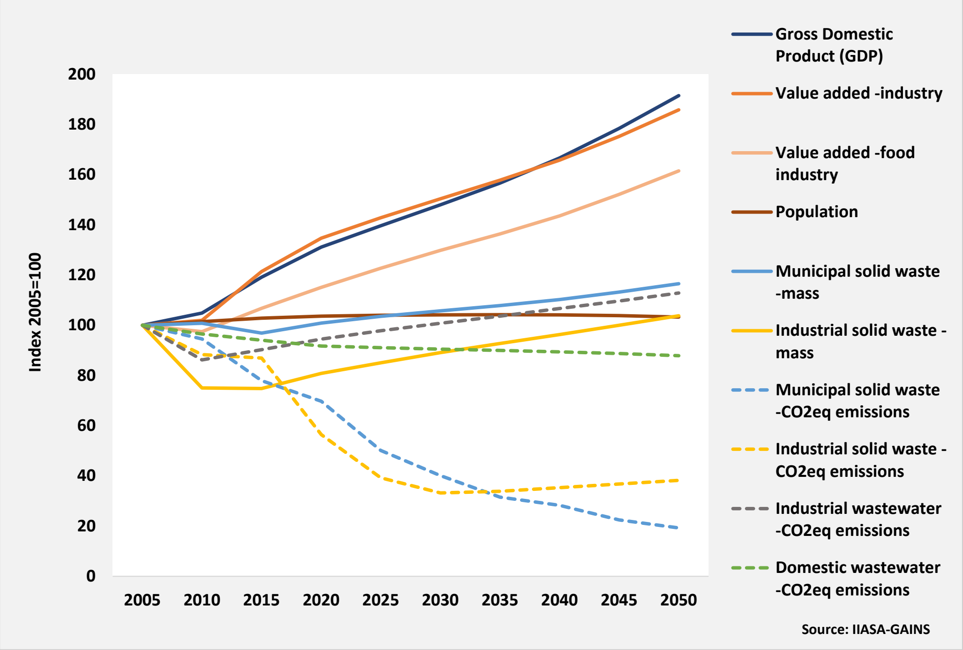
Source: IIASA-GAINS

Waste and wastewater sectors

Drivers used in GAINS for generation of municipal solid waste (MSW) are GDP per capita, population, and changes in urbanization rate. The driver for industrial solid waste generation is growth in value-added of the respective industry. Figure 83 shows how the expected increase in GDP coupled with a relatively constant population size, results in a modest increase in the gross (pre-treatment) generation of MSW by 9% between 2015 and 2030, with the assumed composition of the waste shown in Figure 83. Over the same period, industrial solid waste generation is expected to increase by 19%. Due to policies implemented over the last two decades to address waste sector emissions, e.g., the EU Landfill and Packaging directives, emissions have declined by 20% between 2005 and 2015 and are expected to be halved in the period 2015 to 2030. Due to the continued diversion of MSW away from landfills foreseen by the 2018 amendment of the Landfill directive (see Figure 83), emissions from MSW continue to decline also after 2035.

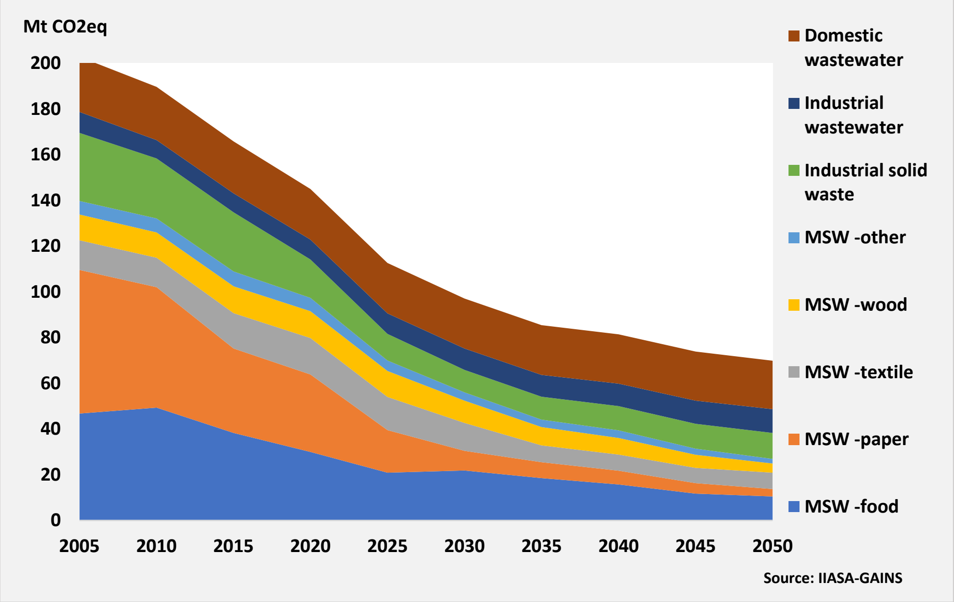
Driver in GAINS for CH_4 emissions from industrial wastewater is the chemical oxygen demand (COD) content of the wastewater. This is in turn assumed to be driven by the development in the value-added of the relevant industries and results in an expected increase in CH_4 emissions from this source by 12% between 2015 and 2030. CH_4 and N_2O emissions from domestic wastewater are driven by population growth but are also affected by on-going extensions of centralized sewage systems and upgrades of such systems to secondary/tertiary treatment. This results in a steady but modest decline in emissions, amounting to 4% between 2015 and 2030.

Figure 83: Development in major drivers for EU non-CO_2 emissions in the waste and wastewater sectors



Source: IIASA-GAINS

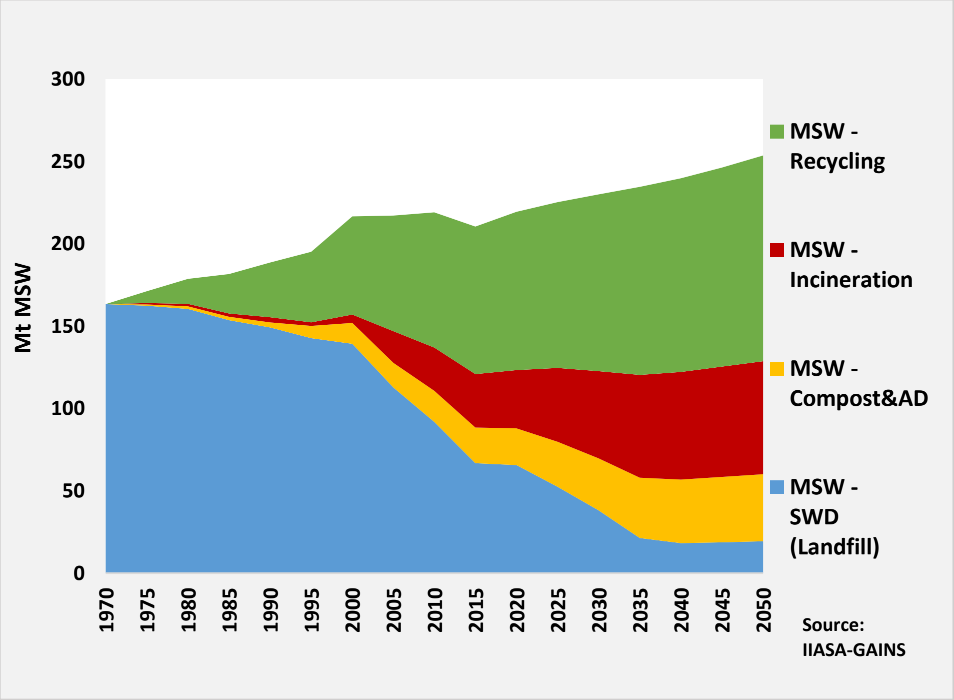
Figure 84: EU non-CO_2 GHG emissions from waste



Source: IIASA-GAINS

Source: Data for 1990-2015 from EUROSTAT; extrapolations to other years performed in GAINS

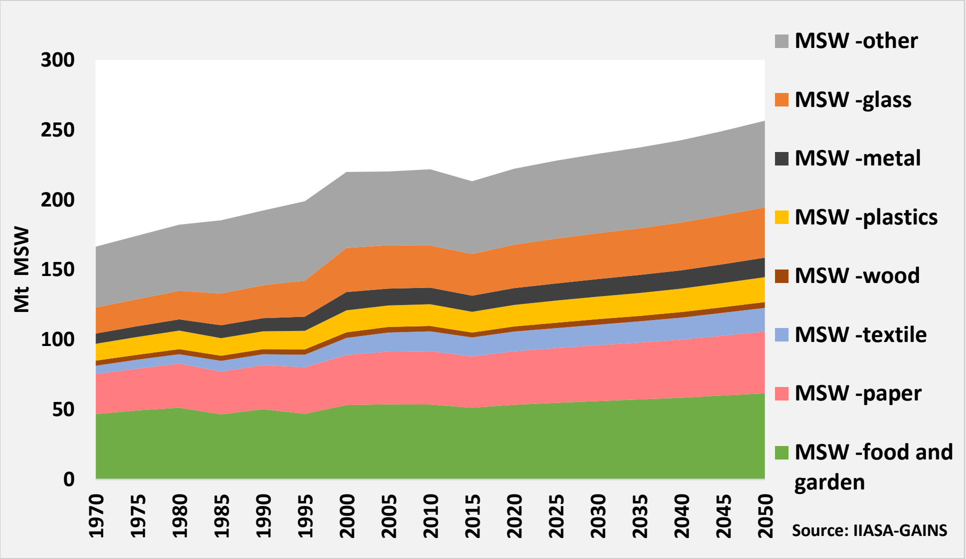
Figure 85: EU waste treatment pathway to meet the 2018 Landfill Directive targets



Source: IIASA-GAINS

Overall, non-CO_2 emissions from the waste and wastewater sectors have seen reductions of 18% between 2005 and 2015 (see Figure 86). Significant additional reductions of 41% are expected between 2015 and 2030 due to already implemented policies.

Figure 86: Evolution of non-CO_2 emissions from the EU waste and wastewater sectors

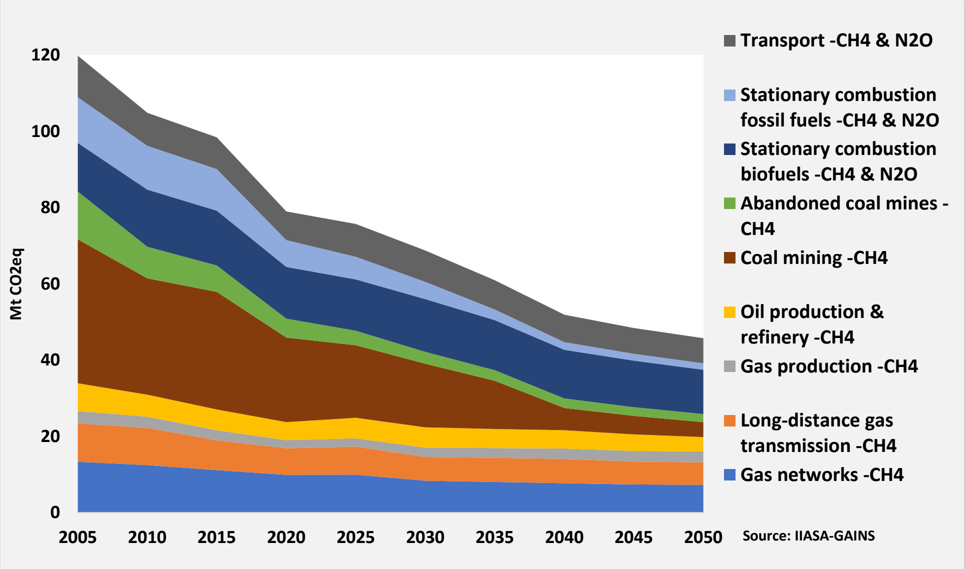


Source: IIASA-GAINS

Energy sector

Energy sector activity drivers are imported in GAINS from the PRIMES model. The phasedown in EU production of coal, oil and natural gas projected by the PRIMES Reference Scenario is the primary reason for reductions in energy sector non-CO_2 emissions, estimated at 18% between 2005 and 2015 and with expected additional reductions by 30% between 2015 and 2030 (see Figure 87). Reduced use of fossil fuels in stationary combustion adds to reductions in emissions. Continued combustion of biomass in stationary sources and increased use of gas of non-fossil origin in the PRIMES energy projections, translate in GAINS into maintained levels of non-CO_2 emissions from biomass combustion and modest reductions in overall leakage from the gas storage and transportation systems.

Figure 87: Evolution of non-CO_2 GHG emissions from the EU energy sector



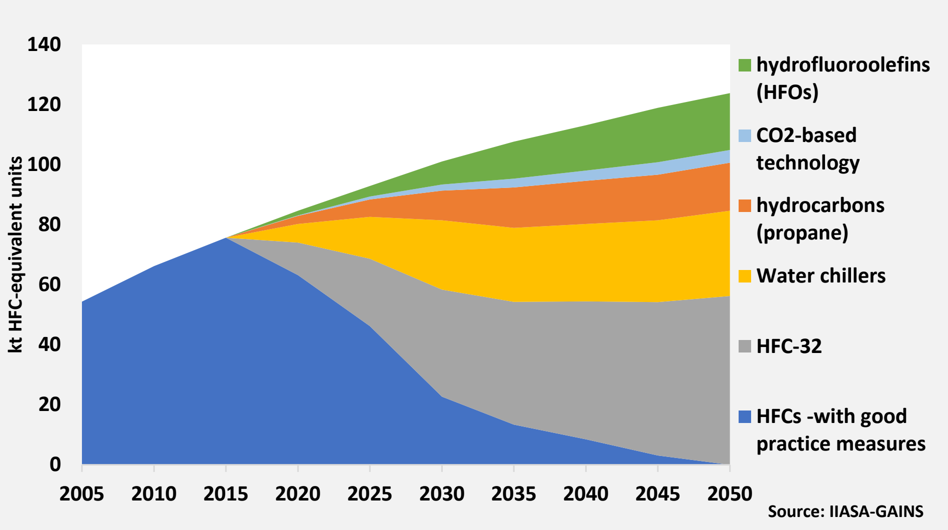
Source: IIASA-GAINS

HFC source sectors

The activity driver used for estimations of hydrofluorocarbons (HFCs) emissions in GAINS is the amount of HFCs used in different source sectors. Starting from the current use of HFCs, the evolution of a future fictive demand for HFCs, driven by economic, climate change and other factors, is first derived under the assumption that no replacement of HFCs with alternative substances takes place. Thereafter, an alternative pathway is developed in which the fictive demand for HFCs in different applications is replaced by the various alternatives to HFCs that are expected to be taken up in response to existing F-gas regulations.

Figure 88 shows how EU demand for coolants in stationary air conditioners (ACs), expressed in HFC-equivalent units, is expected to increase by 34% between 2015 and 2030. For residential ACs, the increased demand for cooling is driven by a growing fraction of households owning ACs, which in turn is a function of changes in income (GDP per capita) and the average number of annual cooling degree days (CDDs). The latter reflect expected temperature increases in response to climate change impacts. Similarly, the demand for coolants in commercial ACs is driven by changes in GDP per capita and commercial floor space area. Existing F-gas regulations are expected to replace HFCs with propane, CO_2-based technology, HFOs and HFC-32 in small commercial ACs, water chillers primarily in large commercial ACs, and HFC-32 and propane in residential ACs. Between 2015 and 2030 the use of HFCs (excluding HFC-32) in stationary ACs is expected to drop by 70%.

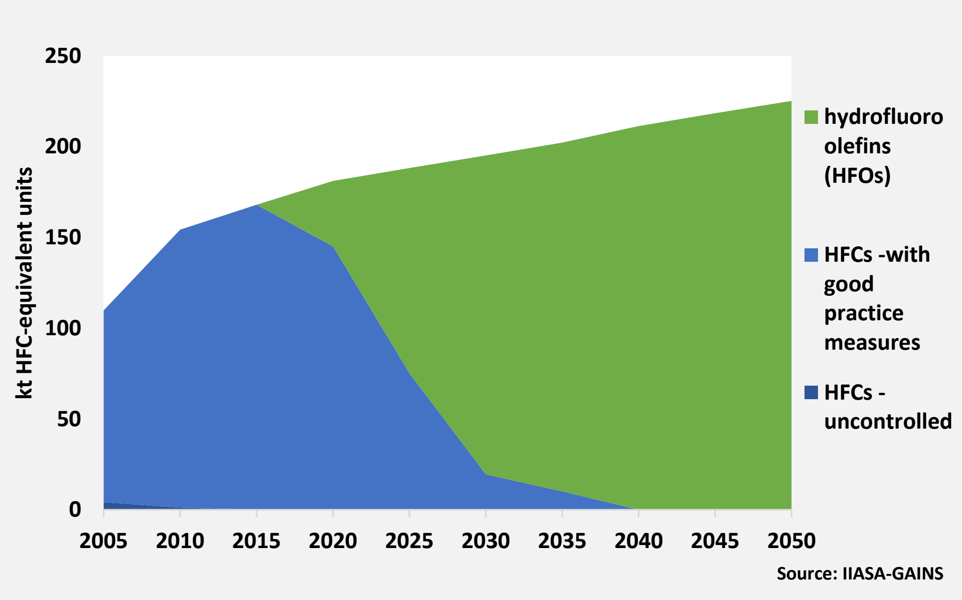
Figure 88: Phase-in of alternatives to HFC use in stationary air conditioners (residential & commercial) in EU



Source: IIASA-GAINS

Figure 89 shows how EU demand for refrigerants in mobile air conditioners (MACs), expressed in HFC-equivalent units, is expected to increase by 16% between 2015 and 2030. The increased demand is driven by expected changes in the numbers and composition of the vehicle fleet in terms of transport modes, e.g., buses, cars, trucks, vans etc. The EU MAC directive is expected to effectively replace all current use of HFC-134a in MACs with HFO-1234yf by 2040, with a close to complete replacement achieved already by 2030.

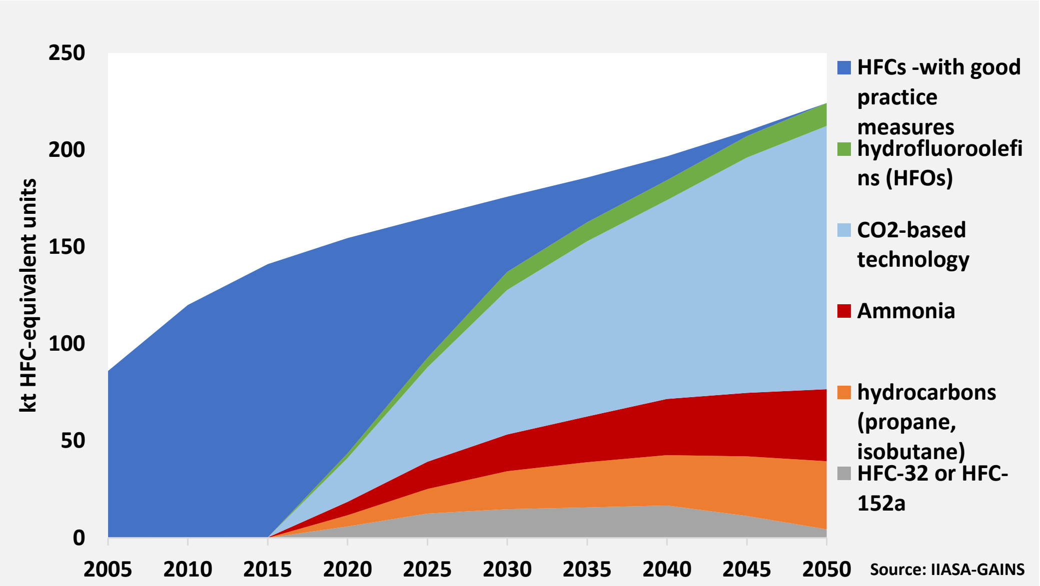
Figure 89: Phase-in of alternative to HFC use in mobile air conditioners in the EU



Source: IIASA-GAINS

Figure 90 shows how EU demand for refrigerants, expressed in HFC-equivalent units, for use in domestic, industrial, commercial and transport refrigerators is expected to increase by 25% between 2015 and 2030. The increased demand is for commercial refrigeration driven by the development in commercial sector value added and for industrial refrigeration by the development in industry value added. For domestic refrigeration, demand for refrigerant is driven by changes in GDP per capita and saturation rates for household refrigerator ownership, while for transport refrigeration it is driven by the growth in GDP per capita. Existing F-gas regulations are expected to phase-down current use of HFCs in refrigeration by 73% between 2015 and 2030. The use of HFCs in domestic refrigeration is expected to be completely replaced by hydrocarbons (isobutane) by 2030. In commercial refrigerators, the use of HFCs is expected to drop by three quarters between 2015 and 2030, replacing HFCs in large refrigerators primarily with CO_2-based technology and in small refrigerators primarily with propane. In industrial refrigeration, the current use of HFCs is expected to drop by 64% between 2015 and 2030, replacing HFCs primarily with ammonia and some HFOs, but also some use of CO_2-based technology in smaller units. The use of HFCs in refrigerated transport is expected to drop by 73% between 2015 and 2030, replacing HFCs with CO_2-based technology or propane.

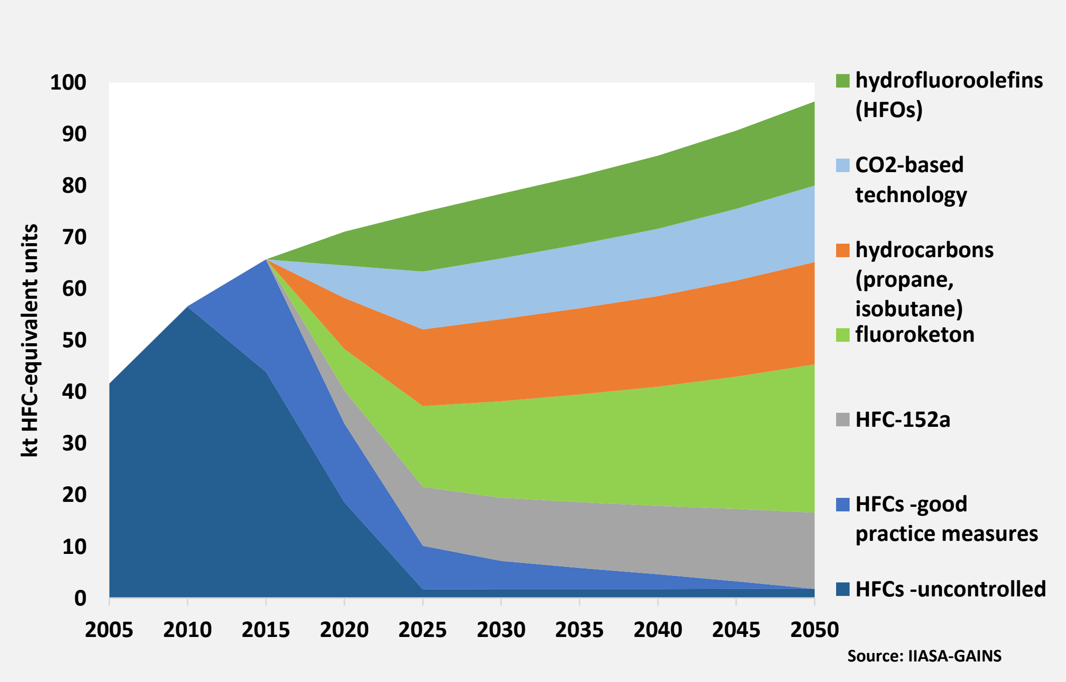
Figure 90: Phase-in of alternatives to HFC use in commercial and industrial refrigeration and refrigerated transport in the EU



Source: IIASA-GAINS

Figure 90 shows how EU demand for the services currently offered by HFCs in other types of applications, i.e., foams, aerosols, heat pumps and fire extinguishers, is expected to increase by 19% between 2015 and 2030. The demand for these services in foams, heat pumps and fire extinguishers is in GAINS driven by the development in GDP. The driver for future use of HFCs in aerosols for medical dose inhalers (MDIs) and purposes other than decorative and entertainment (which has been prohibited since 2008), is the expected growth in population. The F-gas regulation is expected to phase-down the current use of HFCs in these applications by 89% between 2015 and 2030. The use of HFCs as blowing agent for foams is expected by 2030 to be fully replaced by other alternatives, i.e., CO_2, hydrocarbons (propane or butane), HFOs or HFCs with low global warming potential (e.g., HFC-152a). The current use of HFCs in fire extinguishers and heat pumps is expected to decrease by three quarters in 2030 and be completely replaced by 2050. The use in fire extinguishers is expected to be replaced by fluoro-ketone (FK-5-1-12), while the use in heat pumps is expected to be replaced by HFO-1234yf, propane or HFC-152a. For 2015, 34% of the reported use of HFCs in aerosols was attributed to MDIs, while 66% was reported used for other purposes. In GAINS is assumed that by 2025 the use of HFCs in aerosols for other purposes than MDIs is phased out and replaced by propane.

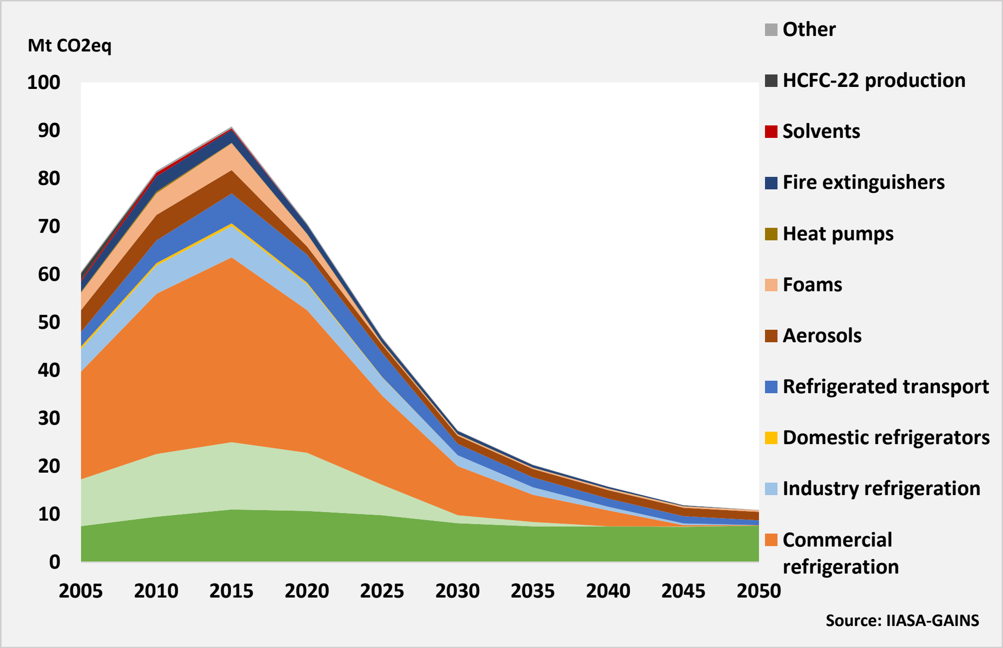
Figure 91: Phase-in of alternatives to HFC use in aerosols, foams, heat pumps and fire extinguishers in the EU



Source: IIASA-GAINS

To summarize, GAINS projection for the Reference Scenario indicates that HFC emissions in the EU drop by 70% between 2015 and 2030 on a CO_2-equivalent basis (see Figure 92). This is a result of measures implemented to comply with existing F-gas regulations. Emissions remaining in 2030 can primarily be referred to the use of HFC-32 in commercial refrigeration and residential air conditioning.

Figure 92: Evolution of HFC emissions in the EU

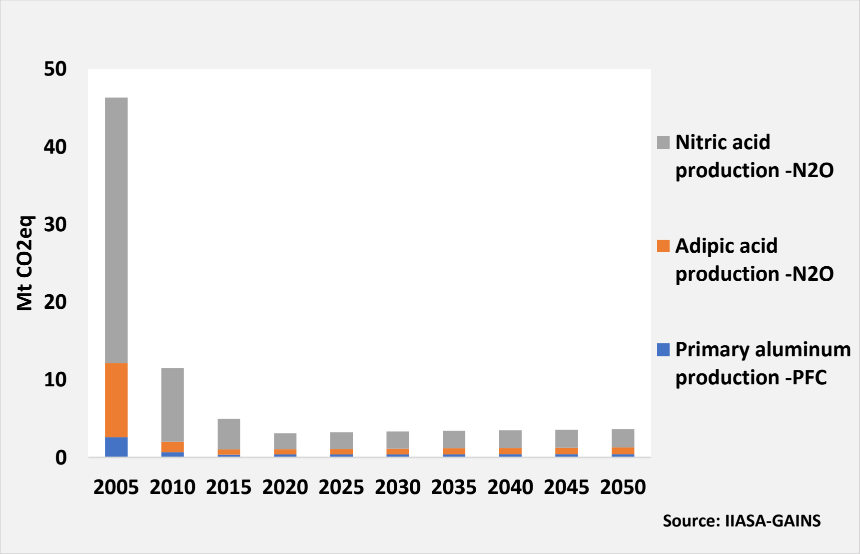


Source: IIASA-GAINS

Industry and other non-CO_2 source sectors

Non-CO_2 GHGs are emitted from a number of industrial processes and are partly included under the EU-ETS. Figure 93 illustrates how drastically N_2O emissions from nitric and adipic acid production and PFCs from primary aluminium production fell in response to these sectors becoming subject to requirements to hold emission permits.

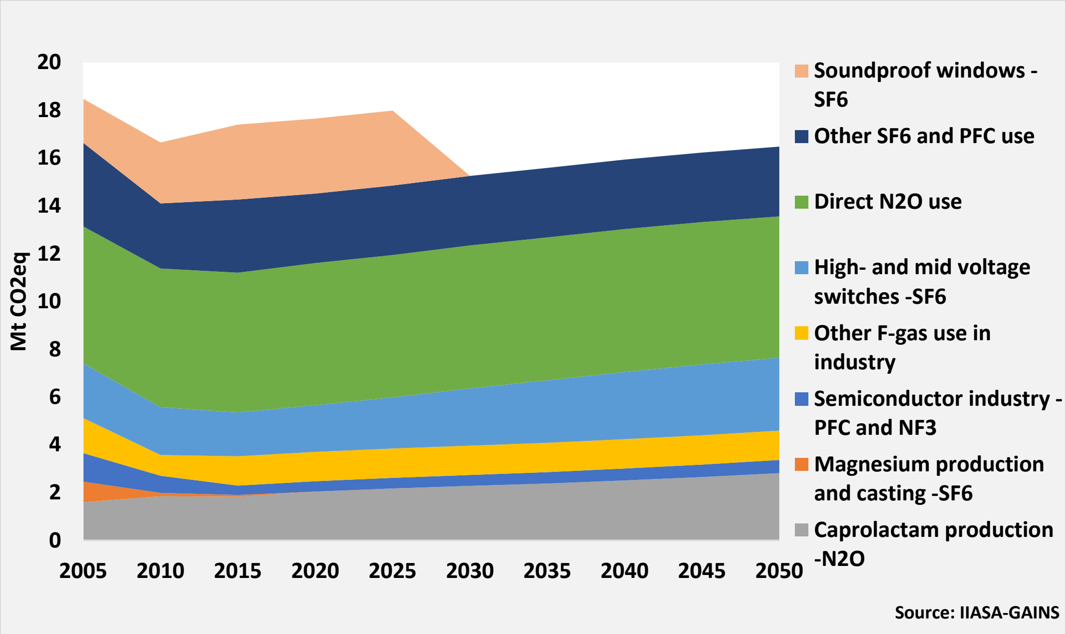
Figure 93: Evolution of non-CO_2 GHG emissions from ETS sectors in the EU



Source: IIASA-GAINS

Figure 94 shows the projected evolution of non-CO_2 emissions in industry applications not covered under the EU ETS and other smaller source sectors. These refer to N_2O from caprolactam production and direct use of N_2O in hospitals, food industry and combustion applications. They also refer to the use of SF_6 and PFCs in various industrial processes, as well as in high- and mid-voltage switches and soundproof windows. Driver for the development in future use of these gases in industrial applications is value added in industry. Since 2006, the F-gas regulation bans the use of SF_6 in soundproof windows. The amount of SF_6 reported by countries to the UNFCCC as still used in soundproof windows in 2015, is in GAINS assumed to remain until 2025, but then be quickly phased-out by 2030 as windows come to the end of an assumed lifetime of 25 years. Reported PFC emissions from the semiconductor industry have declined by 70% between 2005 and 2015, mostly as a result of the voluntary agreement introduced by the industry. No suitable alternative to the use of SF_6 in high- and mid-voltage exists. Emissions from this source therefore remain and are expected to increase with a future increased demand for electricity.

Figure 94: Evolution of non-CO_2 GHG emissions from industry and other (non-ETS) applications in the EU

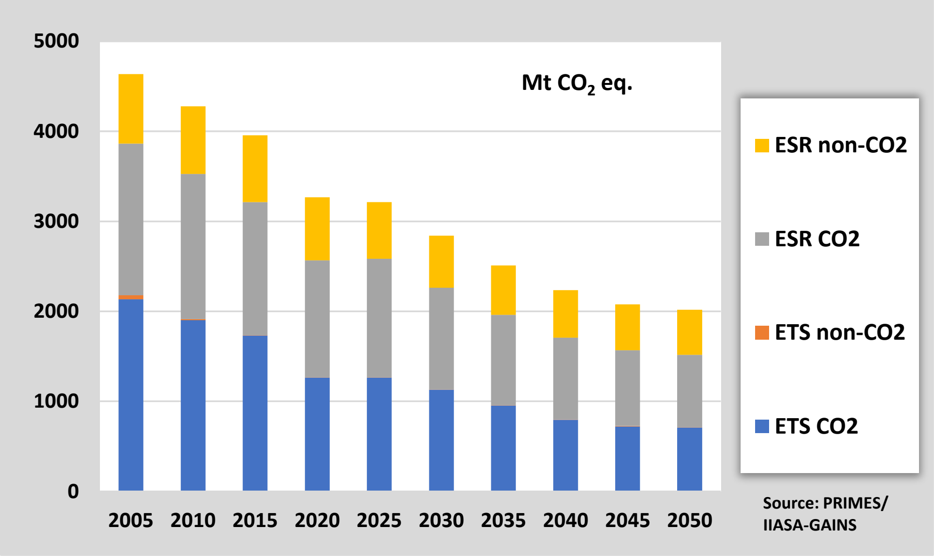


Source: IIASA-GAINS

3.5.3. Total GHG, ETS, ESR emissions (excl. LULUCF)

Figure 95 shows the evolution of GHG emissions over the projection period. In 2030, the total reduction in GHG emissions is 42.8% compared to 1990.

Figure 95: Evolution of total GHG emissions



Source: PRIMES/ IIASA-GAINS

ETS sector emissions reduce faster than overall emissions: coal phase-out policies are the main driver in the time period to 2030 whereas in the longer term it is the rising ETS prices. GHG emissions in the ETS drop by 48.2% in 2030 relative to 2005.

ESR sectors also see a decrease in emissions but not as strong, i.e., by 30.7% compared to 2005[105], and the national existing 2030 ESR targets are projected to be achieved domestically in the majority of countries. This is the result of stronger reduction trends in sectors like waste and HFCs and lower reduction trends in other sectors, notably agriculture, transport, and wastewater. The decreasing trend in emissions also beyond 2030 is well pronounced, especially for the power generation sector, driven by the continuous decrease of the ETS cap in line with current legislation.

For 2050, in lack of additional policies post-2030, emissions reduce to 60.4% compared to 1990. Compared to 2005 levels, ETS emissions are projected to reduce by 68.5%, and the non-ETS sectors by 48.1%.

Therefore, while showing considerable improvements compared to historical trends, the Reference Scenario projects a significant gap to achieve the new 2030 target of net 55% emission reduction in 2030 compared to 1990 and the climate neutrality objective by 2050.

3.5.4. LULUCF emissions and removals and their drivers

The LULUCF sector in the EU is at present a net carbon sink as it sequesters more carbon than it emits. Since the year 2000, the EU LULUCF sink was estimated to fluctuate at around -309 $MtCO_2$-eq per year (including harvested wood products and non-CO_2 emissions from LULUCF); in recent years, however, it shows a trend towards a slightly declining sink in the UNFCCC inventory[106]. While it is not possible to match all individual years with GLOBIOM-G4M, the average and the trends have been replicated closely. Differences in individual years are related to uncertainties in the models and datasets, as well as different modelling and reporting approaches applied.

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[105] Compared to 2005 GHG emissions as per PRIMES-GAINS models.

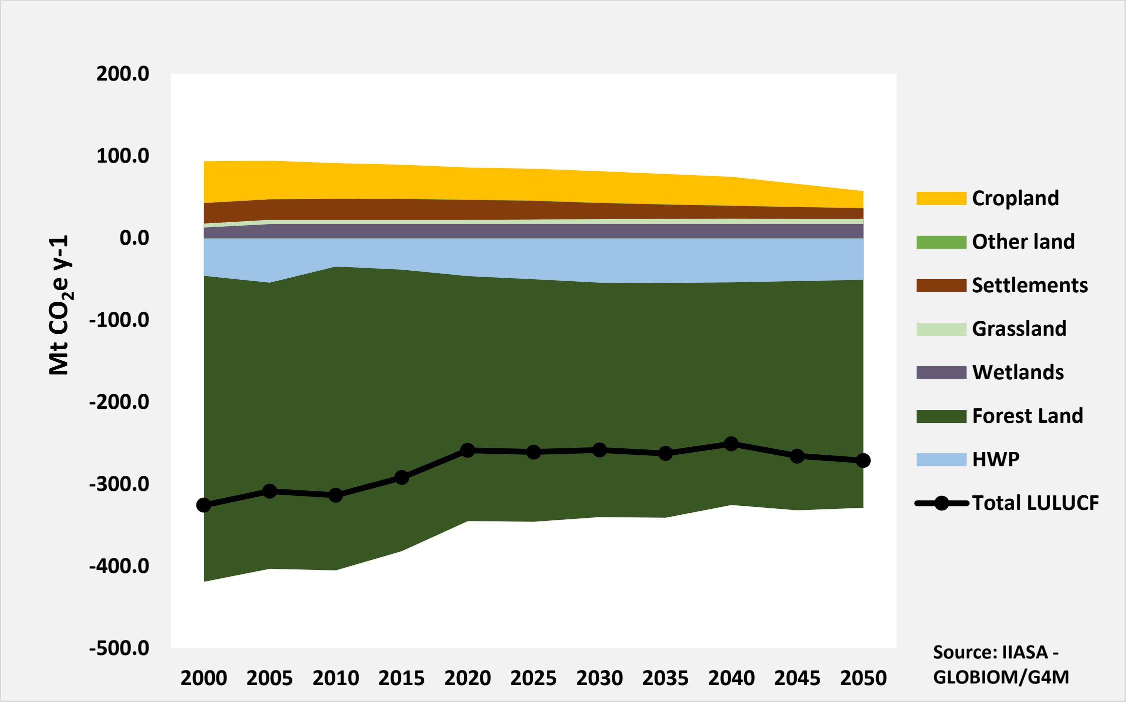
[106] http://unfccc.int

In the Reference Scenario, the LULUCF sink is expected to be maintained until 2050 even though it is projected to decline a bit stronger in the short-run from about -292 $MtCO_2$-eq in 2015, to -258 $MtCO_2$-eq in 2030, while in 2050 the sink is projected to be -271 $MtCO_2$-eq, which corresponds to a decrease of -12% by 2030 and -7% by 2050 compared to 2015 levels. This decline is the result of changes in different land use activities, of which changes in the forest sector are the most important. Figure 96 shows the projection of the total EU LULUCF sink in the Reference Scenario until 2050 and the contribution from different land use activities.

The carbon sink in managed forests is the main contributor to the LULUCF sink. The forest management sink is driven by the balance of forest harvest and forest increment rates (accumulation of carbon in forest biomass as a result of growth of the trees with the age). As forest harvest is projected to increase over time due to growing demand for wood for material uses (such as furniture or paper) or for energy production, the carbon sink (biomass, soil, and dead organic matter) in managed forests declines until 2050. Growing demand for woody biomass for material use as projected by GLOBIOM is mainly driven by population and income growth. Increasing demand for woody biomass for energy production is directly taken from PRIMES Biomass projections. The significant decline in the managed forests carbon sink is partially compensated by decreasing emissions from deforestation. Furthermore, carbon removals from newly planted forest are transferred from the afforestation category to the forest management category after 20 years (in consistency with most countries UNFCCC reporting), which also balances the decline in the long run. The afforestation sink stabilizes after 2025 and remains at around -45±2 $MtCO_2$-eq.

Increasing demand for biomass drives wood prices up which results in increased income of forest owners and reduces deforestation to maintain forest area. Consequently, emissions from deforestation continue to decline in line with historical trends.

Figure 96: EU LULUCF emissions/removals in $MtCO_2$-eq until 2050

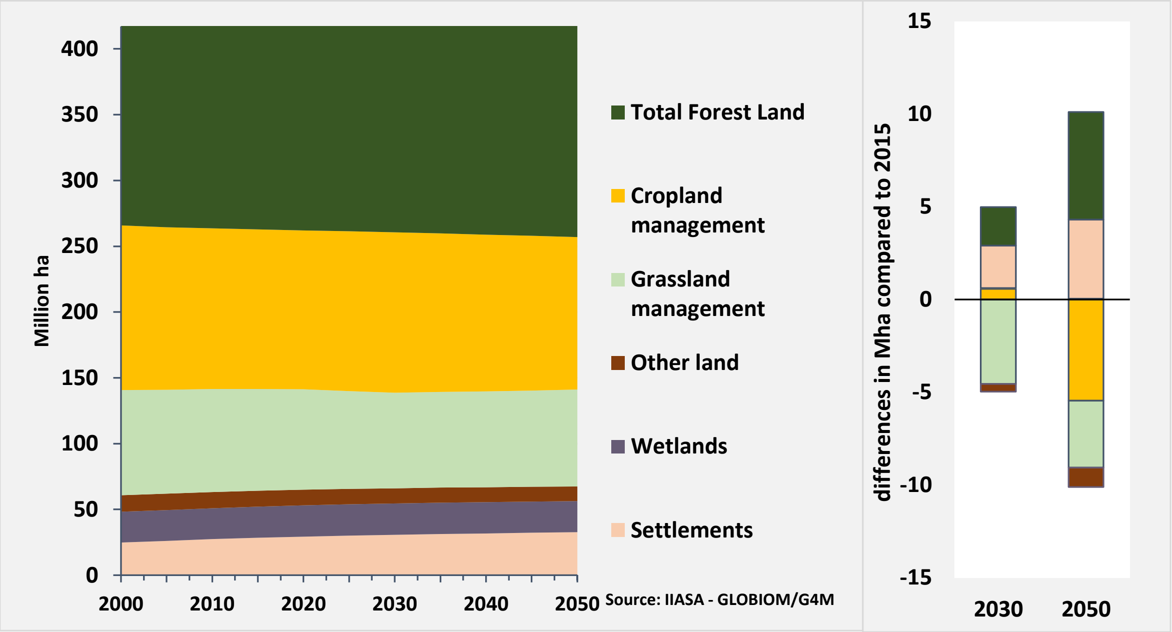


Source: IIASA - GLOBIOM/G4M

Activities in the agricultural sector have a smaller impact on the total LULUCF sink compared to the forest sector. Still, net carbon emissions from cropland are projected to decline by 6% by 2030 compared to 2015 as soils converge towards soil carbon equilibrium over time. In addition, perennial crops (miscanthus, switchgrass and short rotation coppice) that typically sequester additional carbon in soil and biomass contribute to decreasing cropland emissions. By 2050, 4.5 million ha (Mha) of perennial crops are being cultivated. Total grassland emissions (incl. non-CO_2) are expected to increase by 12% in 2030 and stabilizes at around 6-7 $MtCO_2$-eq thereafter.

Figure 97 shows the EU LULUCF sector land balance until 2050. Forest area includes afforestation as well as forest management area because the afforested area is reported as forest management area after 20 years and thus, keeping the two categories separated might be misleading. Over time, the total forest area expands by 1.3% in 2030 and 3.8% in 2050 compared to 2015 at the expense of cropland and grassland taken out of production. Cropland (-4.5%) and grassland (-4.7%) areas decrease slightly until 2050 due to afforestation and expansion of settlements. The area for perennial crops for renewable energy production is growing slowly until 2030 and only thereafter at a higher pace.

Figure 97: EU LULUCF sector land balance (in million ha) until 2050



The following sections provide a more detailed overview of the drivers, emission projections and overall trends in the different LULUCF sub-sectors.

Emissions from forest land

The current net forest sink (the sum of forest management, afforestation, deforestation, and harvested wood products) is projected to decrease from -382 $MtCO_2$-eq in 2015, to -340 $MtCO_2$-eq in 2030 and -329 $MtCO_2$-eq in 2050 which corresponds to a decline by 11% and 14% in 2030 and 2050, respectively. This is the result of different, partly, opposing trends. Increasing wood demand is an important driver which increases forest harvest and drives biomass prices up, but also a projected decline in the increment of standing forest due to forest ageing on the one hand, and the establishment of newly planted forest on the other hand impact the forest sink.

The carbon sink in managed forests declines from -343 $MtCO_2$-eq in 2015 to -286 $MtCO_2$-eq in 2030 and -278 $MtCO_2$-eq in 2050 as forest harvest removals increase steadily over time until 2040 and stabilize thereafter. At the same time, removals from afforestation are accounted for in the managed forest category after 20 years, which counterbalances the decline of the sink to a certain extent.

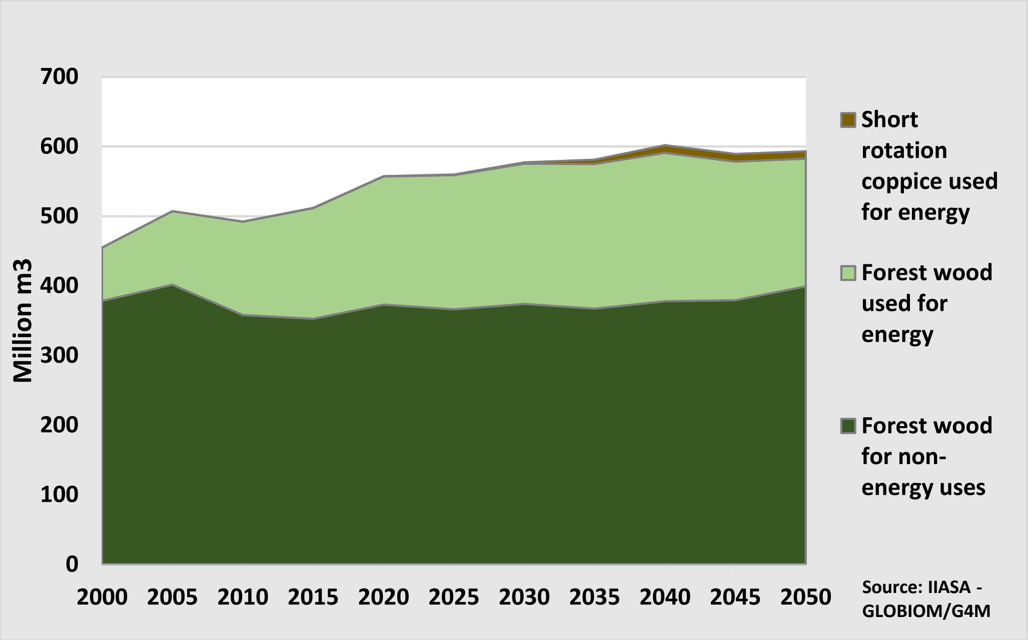
Total forest harvest in the EU is projected to rise from 512 million m^3 in 2015, to 575 million m^3 in 2030 and 583 million m^3 in 2050. Until 2030, additional forest harvest is mainly driven by increasing biomass demand for energy production while in the long run until 2050, the demand for biomass for energy production slightly decreases. The share of wood removed for energy production in the total forest harvest increases from 31% in 2015, to 35% in 2030 and declines again to 32% in 2050.

The area-specific increment of forests available for wood supply is slowly decreasing from 5.6 m^3/ha in 2015 to 5.4 m^3/ha in 2050, while the total increment of forests available for wood supply increases from 743 million m^3 in 2015 to 760 million m^3 in 2050. The reason for the declining area-specific forest increment is a change in age class structure towards a higher share of older forest stands that grow at lower rates. Despite this, the total increment is increasing due to the area expansion effect from afforestation activities.

By 2030, short rotation coppice provides 1.8 million m^3 of biomass for energy production, until 2050 it rises to 10 million m^3.

The carbon sink in harvested wood products (biomass for material use is processed to final products which store carbon and have a lifespan of several years) is increasing over time with a peak in 2030, as the growth of the material sector is overcompensating the historical harvested wood pool decay over time. After 2030 it is stabilizing at a slightly lower level. Consequently, the carbon sink of harvested wood products increases from -38 $MtCO_2$-eq in 2015 to -54 $MtCO_2$-eq in 2030 and is 51 $MtCO_2$-eq in 2050.

Figure 98: EU biomass harvest from forest (removals) and short rotation coppice (in million m3) until 2050

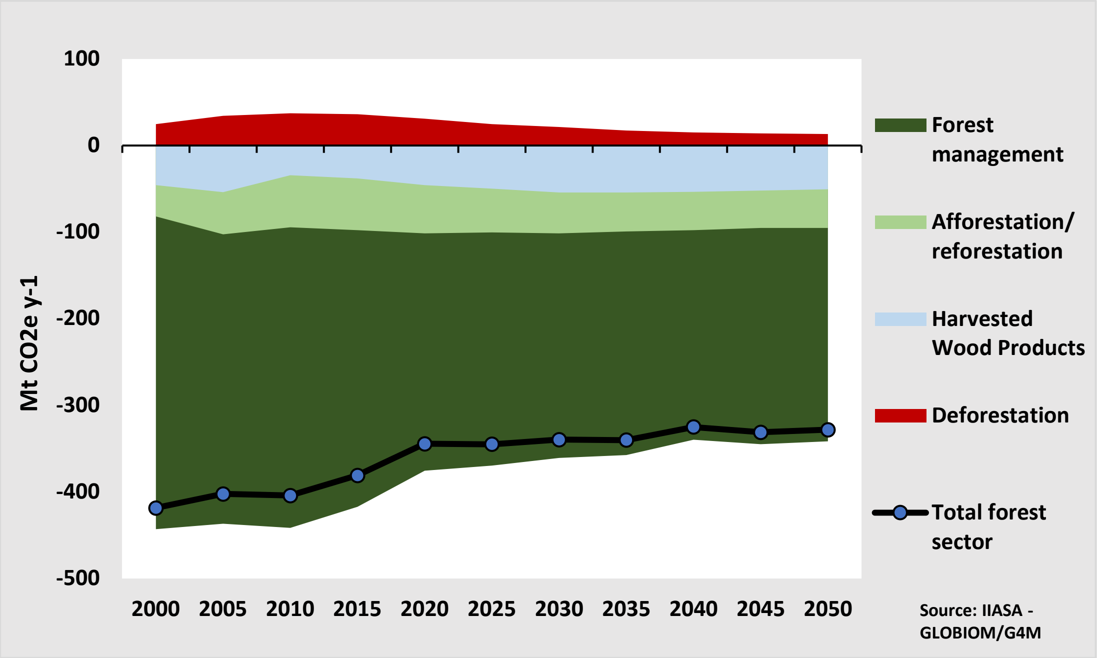


Source: IIASA - GLOBIOM/G4M

The carbon sink from afforested areas is declining until 2030 and stabilizing thereafter (after 20 years, afforested area is accounted for in the forest management category). The trend is also reflected in the area development, with 8.4 Mha afforested land reported in 2015, decreasing to 5.7 Mha in 2030 and stabilizing a bit above 5 Mha thereafter.

The total forest area is projected to increase from 154.6 Mha in 2015, to 157 Mha in 2030 and 160 Mha in 2050. With increasing age, the newly planted forests get more and more into a phase of high production and become gradually available for biomass supply. Towards 2050 these forests are therefore also taking harvest pressure from older forests and thus help to keep the sink up in managed existing forests.

Figure 99: Development of the EU emissions/removals in the forest sector in $MtCO_2$-eq until 2050



Emissions from deforestation continue to decrease from 36 $MtCO_2$-eq in 2015, to 21 $MtCO_2$-eq in 2030 and 13 $MtCO_2$-eq in 2050 as deforestation drops from 106.000 ha in 2015 to 46.000 ha in 2050. This development is consistent with historical trends and is driven by increasing biomass prices that incentivize forest owners to reduce deforestation and maintain forests. Figure 99 shows the development of the carbon sink in the forest sector for the different activities until 2050.

Emissions from cropland and grassland

Cropland is a net source of emissions in the EU at present. Over time, emissions are projected to decrease from 42 $MtCO_2$-eq in 2015, to 40 $MtCO_2$-eq in 2030 (6% decrease in comparison to 2015) and 21 $MtCO_2$-eq in 2050 (49% decrease). One of the main drivers for this decline is a saturation effect as soils emit less and less carbon when converging towards their equilibrium carbon stocks under a constant management regime. Disturbances of the equilibrium due to a change in management lead to a new equilibrium. The emissions or removals towards the equilibrium get smaller over time as the new management continues. This is especially true for more intense management changes such as the conversion of annual crops to perennial crop cultivation.

Another important driver is the projected establishment of perennial crops for renewable energy production which has a positive effect on the amount of carbon stored in the soil compared to conventional crops. The PRIMES biomass demand indicates that with growing demand the supply of these crops will grow and substitute partially forest biomass as they are relatively cost-efficient. The area covered by perennial crops sums up to 0.8 Mha by 2030 and 4.5 Mha by 2050. Emissions from cropland decline by 3 $MtCO_2$-eq from 2015 until 2030 and by 18 $MtCO_2$-eq from 2030 until 2050. Total cropland area is projected to remain constant until 2030 and decrease thereafter from 122 to 116 Mha in 2050.

Grasslands are a small net emission source at present in the EU (including non-CO_2 emissions from land use). Over time, emissions increase slightly from 5 $MtCO_2$-eq to 6 $MtCO_2$-eq in 2030, stabilizing thereafter. Total grassland area declines from 77 Mha in 2015 to 73 Mha in 2030 and stabilizes thereafter.

Emissions from wetlands, settlements, and other land

Emissions from wetlands are not modelled and kept constant at 2018 levels as reported in UNFCCC 2020 data[107]. Emissions from wetlands amount to 17 $MtCO_2$-eq. Settlement area is assumed to increase at a smaller pace over time following a logarithmic expansion trend based on historical UNFCCC data. Consequently, settlements emissions are projected to decrease from 25 $MtCO_2$-eq in 2015 to 20 $MtCO_2$-eq by 2030 and 13 $MtCO_2$-eq by 2050. Emissions from other land remain stable at around 0.3 $MtCO_2$-eq over time. In the EU, around 24 Mha are covered by wetlands, 12 Mha by other land and settlements are projected to increase from 28 Mha in 2015 to 31 Mha by 2030 and 33 Mha by 2050.

3.6. Total energy system and other mitigation costs

3.6.1. Investment expenditures

Investment expenditures reflect the amounts paid (and not annualised) for purchasing equipment or investing in energy efficiency improvements. In transport, investment expenditures concern the purchase of vehicles, rolling stock, vessels, aircraft, and recharging/refuelling infrastructure[108]. Investment in stationary energy uses concerns the purchase of equipment and investment in energy efficiency, e.g. heat recovery in industry or building renovation. Finally, investment also takes place in the supply side, to produce electricity or heat, and in networks.

Figure 100 and Figure 101 show the evolution over time of investment expenditures in the various components of the energy system.

While the investments in the transport sector expand steadily over the projection period, investment expenditures in the other sectors increase until 2030 and stabilise or even decline afterwards, in a context of no additional policies.

When it comes to buildings the projection shows that investment in equipment will be higher than investment in renovation, particularly until 2030. Yet the amounts for building renovation are also projected to be high in relation to past trends.

Investments in the power system peak in 2026-2030, which is followed by on the one hand a decline in the investments for production capacities and on the other hand a stabilisation of the investment needs in the electricity grid over the long term, which drives a progressively higher share of grid-related costs in total electricity price over time.

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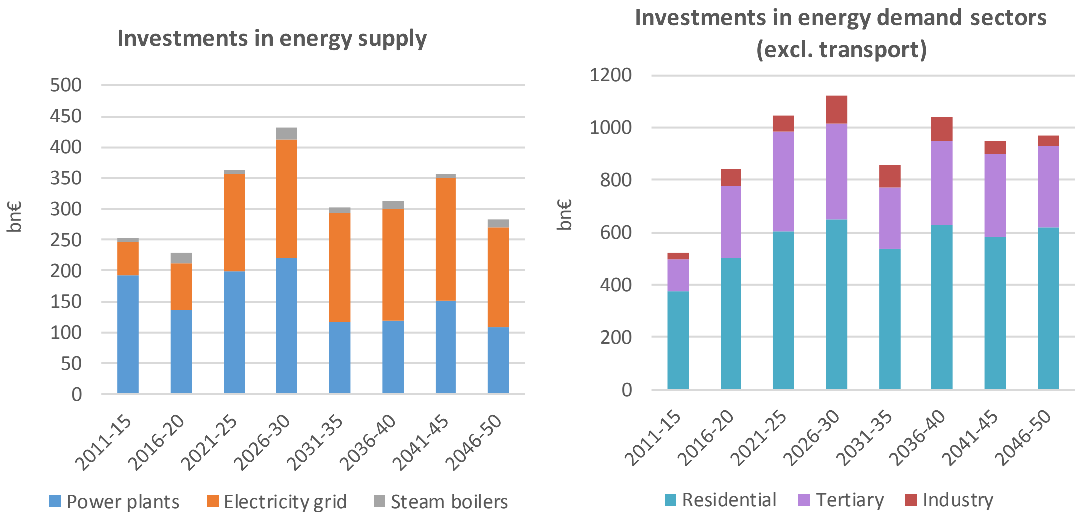
[107] http://unfccc.int

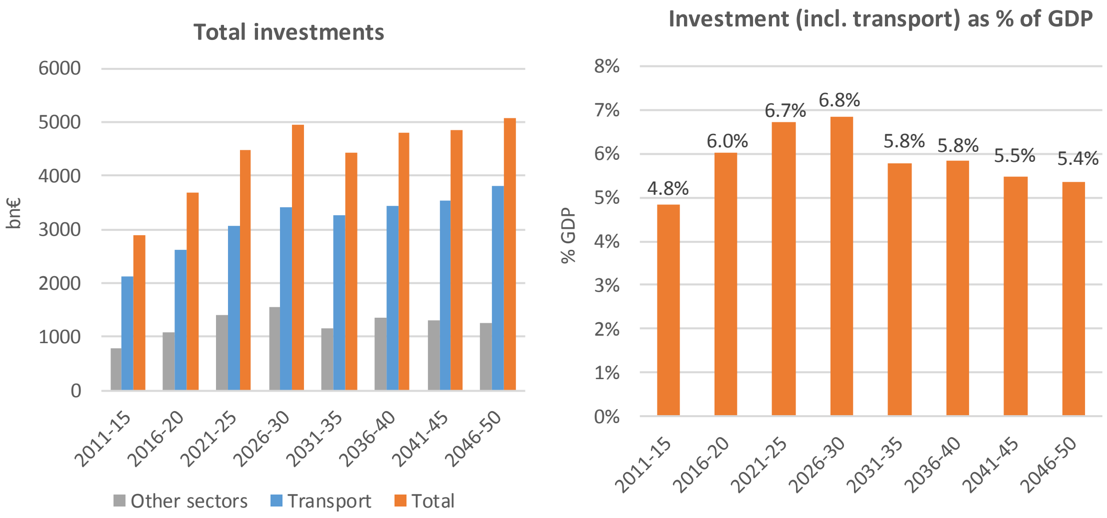
[108] Investment expenditures do not include expenditures for new road and rail network infrastructure.

Figure 100: Investment expenditures by energy sector (excluding transport)



Source: PRIMES model

Figure 101: Total investment expenditures (including transport)

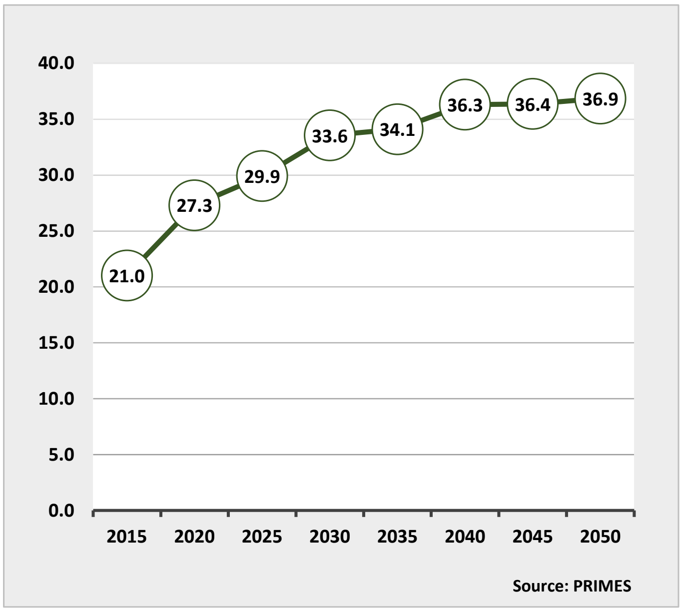


Source: PRIMES model

3.6.2. Energy system costs

The PRIMES model calculates energy system costs from an end-user perspective. Final consumers pay to purchase energy commodities – may that be electricity, district heating or distributed fuels. End-users also pay to purchase and maintain equipment used for energy and other purposes and also to improve energy efficiency conditions. In that sense, energy system costs are annual costs incurred for energy services of end-users including annualised capital costs, variable costs, and fuel costs. To annualise investment expenditures of end-users for reporting purposes only, PRIMES applies a 10% discount rate across all sectors and years.

Figure 102: Share of CAPEX by final consumers in total energy costs (%)

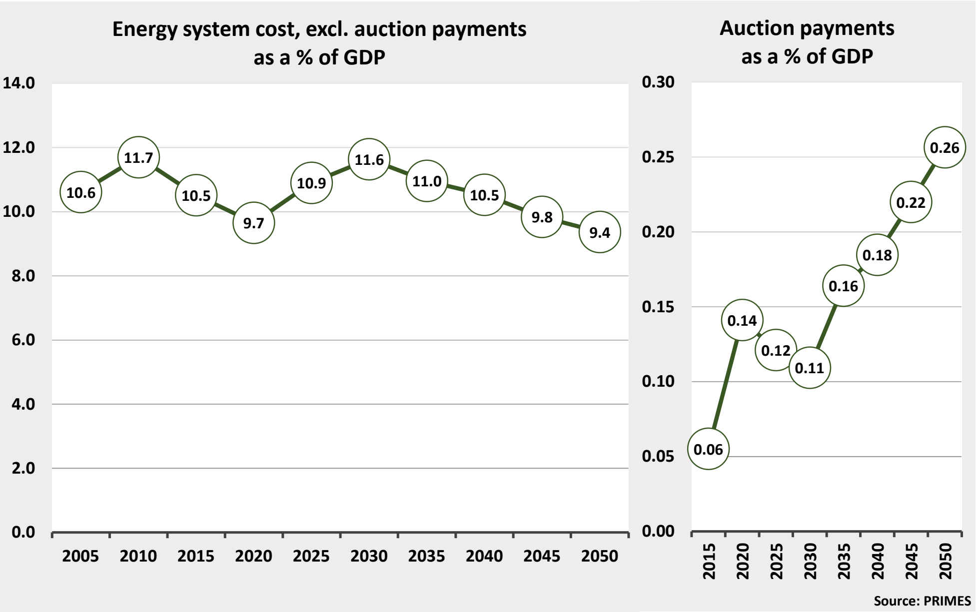


Source: PRIMES

Energy system costs as a percentage of GDP reflect the amount that the entire economy has to pay to purchase energy services (including for transport). This excludes auction payments, which are very small compared to total energy system costs and do not represent an actual economic cost but rather revenues recycled in the economy.

In 2015 energy system costs were 10.5% of GDP and are projected to reach 11.6% in 2030 and drop to 9.4% in 2050, which is associated with the absence of additional policies and falling technology costs. Looking at energy costs as a percentage of income in demand sectors, these grow towards 2030, more for expenditure related to transports than for expenditure related to buildings.

Figure 103: Evolution of energy system costs



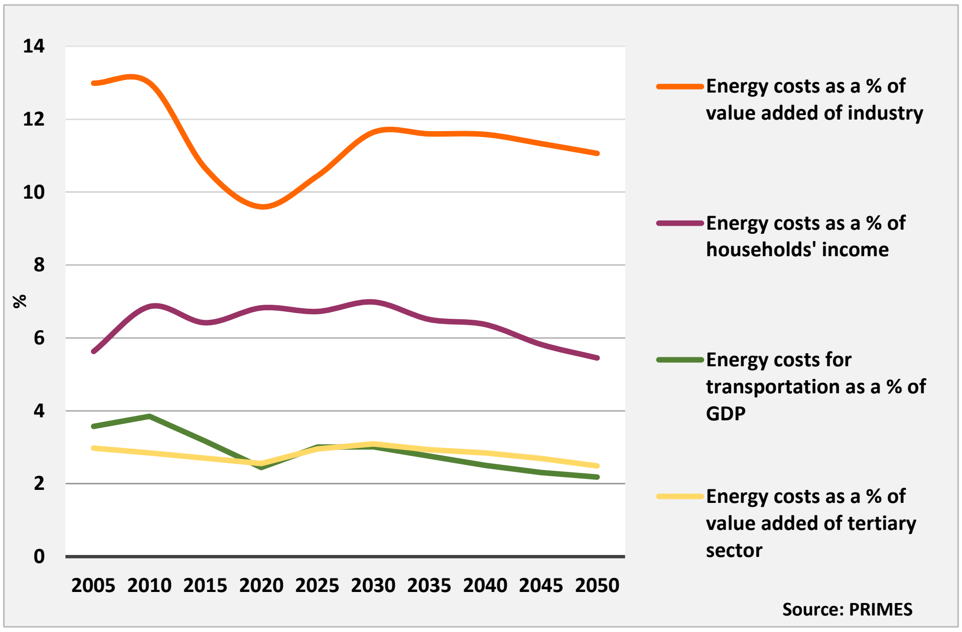
Source: PRIMES

Reflecting the increasing capital intensiveness of the energy system, the share of CAPEX (reflecting capital costs and direct efficiency investments incurred by individuals) in total system costs increases over time, reaching 33.6 % in 2030 and 36.9% in 2050 from 21% in 2015 (excluding ETS auction payments). CAPEX costs increase the most in the current decade due to the deployment of more efficient appliances and equipment, which have higher capital costs and lower fuel expenditures.

The remaining expenditures incurred by end-users can be grouped together as operational expenditures (OPEX). These include the payment for energy supply. The electrification of the residential and tertiary sectors over time makes electricity costs the main OPEX component for these sectors, as well as distributed heat steam costs. Conversely, the share of other fuel costs declines over time, despite increasing fuel prices.

For the industrial sector, fuel expenditures, including electricity, increase slightly throughout the projection period. Decreasing long term electricity prices to some extent compensate the increase in fossil fuel expenditures. Also, for this sector the share of CAPEX costs increases over time as more efficient investments in equipment occur.

Figure 104: Breakdown of energy costs (%)



Source: PRIMES

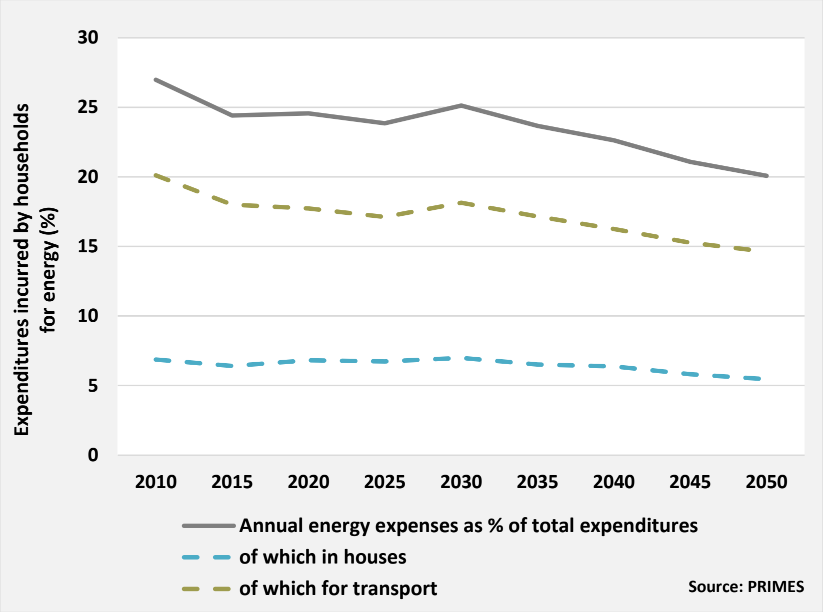
Note: OPEX and CAPEX are calculated at the level of final energy consumers. For example, payment for electricity consumption is OPEX from the perspective of the final consumer.

In the transport sector capital costs play an increasing role; investment in electric vehicles lead to higher investment expenditures until 2030. The projected uptake of electric vehicles in the Reference Scenario is not sufficient to bring down battery costs, which would lead to lower costs and possibly lower fuel expenditures.

3.6.3. Household expenditures

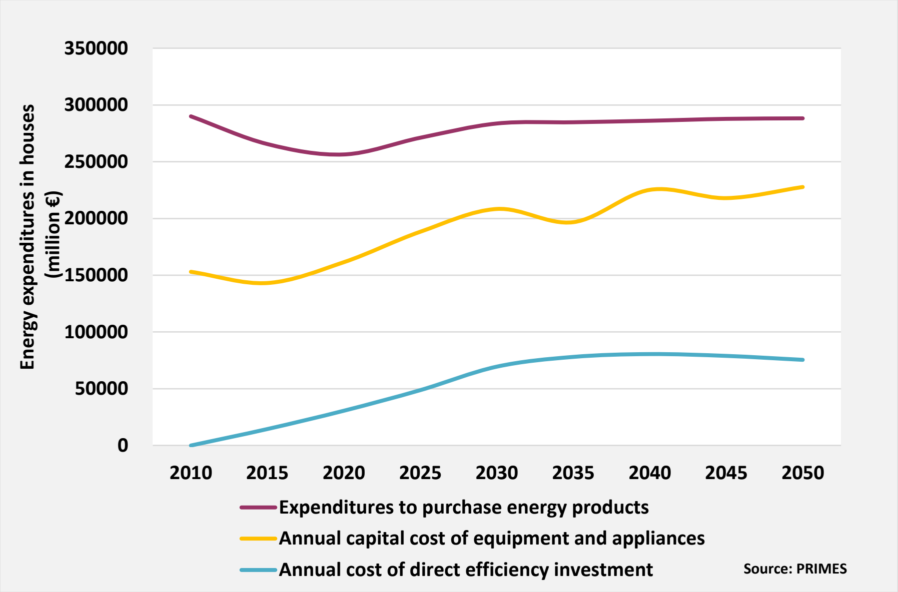
The share of annual expenditures for transport and energy services in total private consumption tends to remain stable or even decrease in the longer run (Figure 105).

Figure 105: Annual energy-related expenditures for households



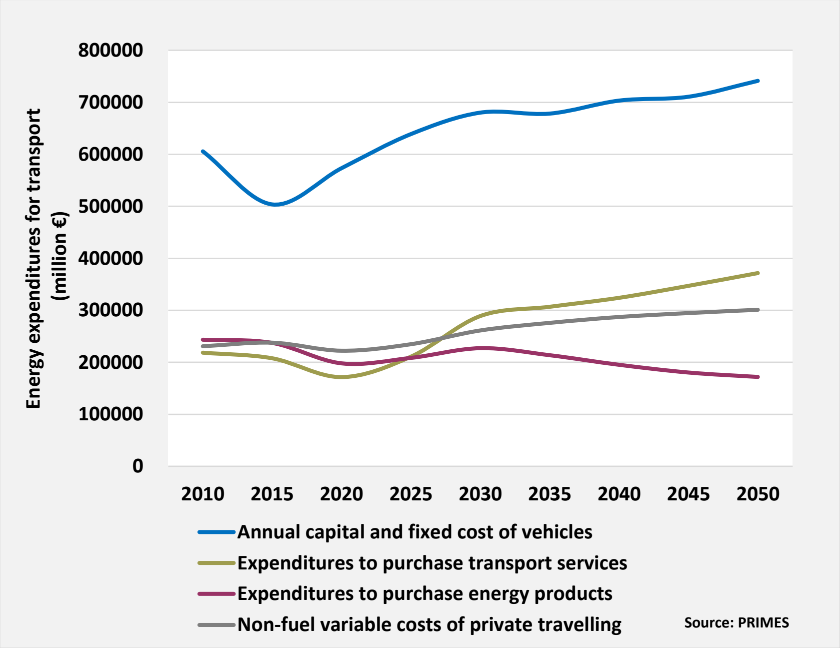
For households (Figure 106), CAPEX increases because of purchasing more expensive and efficient appliances and equipment i.e., a heat pump instead of a gas boiler, and because of investing directly in energy efficiency, i.e., in renovation. The purchase of fuels remain roughly stable compared to historical levels, as the product of reduced overall consumption (notably of fossil fuels) substituted by electricity, which displays relatively higher prices.

Figure 106: Energy expenditures in houses



In transport, expenditures to purchase transport services increase over time, due mainly to rising rail and aviation ticket prices, and the increase in the share of aviation activity. Furthermore, despite dropping battery costs for BEVs and some market uptake of PHEVs, the cost of purchasing electric vehicles remains high, driving up the capital and fixed costs of vehicles. However, expenditures to purchase fuels progressively decrease over time, due to the gradual shift towards low and zero-emission vehicles (Figure 107).

Figure 107: Energy expenditures for households in transport



4. Conclusion

The Reference Scenario 2020 is a projection of the evolution of the energy and transport systems and the associated GHG emissions in every Member State and in the EU as a whole until 2050 subject to the policy framework in place as of December 2019, including the NECPs. The projection is also subject to assumptions regarding the evolution of population, economic and industrial activity, world fuel prices, technology and market trends.

The assumed policy framework, including the NECPs, by design, have an implementation horizon until 2030. While there are no specific policy targets for the period after 2030, the assumed policy framework shows long-lasting impacts thanks to investment decisions and technological developments across the sectors. The EU ETS in particular is assumed to include provisions to the horizon of 2050 and so the ensuing carbon prices constitute a driver that influences investment and choices until 2050. Nonetheless, the long-term effects get progressively weaker over time and the transformation that happens until 2030 slows down afterwards, up to 2050.

The Reference Scenario is not a forecast and thus not a prediction of the most plausible evolution of the energy and transport systems. It is a projection or, in other words, a quantification of causal effects of policy and other assumptions on the energy and transport systems. The usefulness of the Reference Scenario projection is essentially in enabling comparisons to projections that mirror alternative policy frameworks and other assumptions.

Key findings:

The Reference Scenario projects significant changes in the EU energy and transport systems resulting from the EU and national policies adopted to the horizon of 2030. The projection confirms that the climate, energy and transport policy framework as of December 2019, if properly implemented, would lead to the achievement of most of the existing 2030 climate and energy targets.

The decoupling of GDP growth from energy demand growth is projected to intensify until 2030 driven by renewables and energy efficiency policies, and continue post-2030, owing to the lasting effects of these policies and certain technology trends.

GHG emissions are projected to decrease in the large majority of sectors, and particularly in power generation, despite the increase in gross electricity demand. This is due to rising EU ETS prices and renewable technologies reaching maturity. The Reference Scenario projections feature a large-scale integration of renewables in the power sector consistently with system reliability and affordability aims. Therefore, the projection also includes strong elements of sectoral coupling by growing electrification of heating and mobility combined with reducing the carbon footprint of electricity. This trend combined with energy efficiency gains and increasing direct uses of renewables allow to further reduce emissions also in final energy demand sectors.

Non-CO2 emissions follow different trends between sectors, with substantial decreases in waste and HFCs and small decreases in agriculture. LULUCF is currently a sink and is projected to remain at current levels in the Reference Scenario projection.

In the short to medium term the transformation of the energy system is substantial. GHG emissions reduce by 43.8% in 2030 compared to 1990 and overall renewables share reaches 33.2% in 2030. The overall renewable energy share thus slightly over-achieves the existing 2030 target, driven mainly by developments in the power sector, followed by transport, and heating and cooling.

Energy efficiency progresses, driven by the EU-level and national policies along the various energy and transport sectors, leads to a reduction in the respective final energy consumption by 2030. The Reference Scenario projection shows the achievement of the existing primary energy consumption efficiency target by 2030 but not of the final energy consumption target (29.6% reduction compared to 2007 Baseline is achieved, compared to a target of 32.5%).

The effects of COVID-19 pandemic, while striking in terms of energy consumption and emissions in 2020, are not projected to leave long-lasting impacts on the various energy and transport sectors and the behaviours of the related market actors/decision makers. Projections show a recovery of the activity of the sectors hit in 2020 by the pandemic, by 2025 or at the latest by 2030. The projection of the Reference Scenario 2020 does not consider very significant structural changes on the behaviours of the individual energy and transport decision-makers, as more empirical evidence would be required to do so. It indicates a rather stable structure of final energy use by sector over time.

The policies to achieve the EU level target for effort sharing sectors in 2030 are sufficient and a reduction of 30.7% in 2030 compared to 2005 is achieved in the ESR sectors.

Renewable energy deployment, energy efficiency improvements and nuclear production – envisaged to remain stable – prevent import dependency from increasing, which would otherwise occur due to the growth of the economy, the drop in lignite and coal use in the power and heat sectors, and the depletion of domestic oil and gas production. Incremental net imports relative to 2005 are negative for all fossils, including natural gas, despite its importance in the balancing of the increasing amount of renewables in the power sector. Nonetheless, oil continues to represent the largest share in total imports of energy.

The transformation of the energy system is projected to be capital-intensive. The power sector's shift away from fossil fuels and towards renewables does not entail significant increases in levelized costs of electricity but requires significant investment in transmission and distribution systems for connections, the completion of the internal market and the ensuing broadening of flexibility and balancing resources. The capital-related cost increases will have an upward effect on electricity prices and on energy system costs until 2030.

The market uptake of low and zero-emission vehicles that is already being recorded in the EU is projected to amplify by 2025 and, in particular, approaching 2030 and beyond. EU-wide policies such as CO2 emission targets on vehicle manufacturers and provisions on the alternative fuel refuelling and recharging infrastructure support their uptake. At the same time, national policies such as beneficial fiscal regimes and subsidies are projected to significantly trigger the demand for low and zero-emission vehicles. Further renewables uptake in transport and CO2 emission reduction is driven by the uptake of biofuels and biogas following explicit national policies in this regard. National policies on the uptake of biofuels and biogas are driven by EU legislation such as Renewable Energy Directive and Fuel Quality Directive. The transport system is also projected to increase its overall efficiency thanks to the higher use of rail and short sea shipping by 2030, driven by the TEN-T Regulation, supported by the Connecting Europe Facility and other EU level funding, and national policies.

In the buildings sector, the renovation of the buildings envelope along with the replacement of the heating and cooling equipment are driving energy consumption and emissions downwards. The energy efficiency measures presented in the NECPs, as well as in the national Long-Term Renovation Strategies, include financial support schemes, tax incentives and regulatory measures and focus mainly on the increase of the renovation rate of existing buildings and notably deep renovation measures that achieve high energy savings. The building renovation rates are projected to increase by 2030 with comparison to the recent past. Policies promoting the replacement of old fossils-fuelled equipment for space heating with new technologies, particularly with high-efficiency heat pumps are also included in many national plans, resulting in both energy efficiency and renewable energy uptake. Information campaigns to incentivise the uptake of new technologies as well as to influence consumer choice are also included in the policy framework and enable the transition of the buildings sector. The policy setup of the Reference Scenario regarding energy efficiency in the buildings sector is very ambitious and is projected to deliver high energy savings by 2030 but an up-scaling of the energy efficiency effort, across sectors, would still be required to meet the EU’s 2030 energy efficiency final energy consumption target.

In the medium to long term, in the absence of additional policies after 2030, GHG emissions are projected to reduce by 59.4% in 2050 compared to 1990, which falls below the target laid down in the European Climate Law. Likewise, renewables continue to develop especially in the power sector, albeit at a slower pace than before, thanks to technology progress, improved market conditions, the lasting effect of dedicated policies implemented in the decade 2021-2030 and the ETS price signal that increases after 2030.

Low-carbon electricity continues to enable energy efficiency and carbon emission reductions in heating and transport, albeit at a pace significantly lower than required for decarbonising these sectors. Electrification in selected transport market segments (e.g. cars and light commercial vehicles) is projected to continue developing in the post-2030 time horizon, as battery costs continue to progressively decrease and the vehicle fleet is renewed. The market share of biofuels and biogas is projected to remain relatively stable, as policies are not assumed to intensify compared to their 2030 ambition.

Industry is projected to shift towards high value-added and less energy-intensive products over time in an international competition context, with a significant part of the energy-intensive production to remain in the EU. Growing electrification and fuel switching are the main trends. Iron and steel, the energy-intensive branch of chemicals and non-metallic minerals move away from solids and oil; in non-ferrous metals and paper and pulp electrification is on the rise. Non-energy-intensive industries, which produce far more value-added compared to energy-intensive industries, undergo similar changes.

As a result, by 2050 net imports of fossil fuels (in absolute terms) decrease to almost a third of the projected peak in 2025.

System costs as percentage of GDP decrease after 2030, since technology improvement drives down the cost reductions. Electricity prices increase in the period to 2030, mainly due to the increase in grid-related costs. Beyond 2030 electricity prices stabilise: the fuel cost component remains stable, despite the increase in fuel prices, due to the dropping shares of combustion plants.

Annual energy-related household expenditures in residential (as percentage of total household expenditures) remain fairly stable by 2040, before declining afterwards. Even though the capital-related part of final consumer expenditures increases significantly throughout the projection period, fuel expenditures (including electricity) decrease as a share of total expenditures due to increased energy efficiency and fuel switching.

The European Climate Law and the need for a new policy framework

Overall the Reference Scenario projection shows a considerable development compared to past trends towards decarbonisation, in power generation as well as, to a lesser extent, in the demand side sectors.

Still, the EU-wide and national policies, assumed in the Reference Scenario and reflected in the projection as fully implemented until 2030, are not sufficient to achieve the new EU climate objectives enshrined in the European Climate Law. It falls short of the new 2030 emissions reduction objectives of 55%, notably by not spurring the necessary contributions stemming from the renewables and energy efficiency uptake. Even more so, over the longer run, the developments are insufficient to achieve the 2050 climate neutrality goal. The required new policy framework to bring the EU economy on this path are at the heart of the “Delivering the European Green Deal” (“Fit for 55”) policy package.

Annex I: Detailed EU policies included in the EU Reference Scenario 2020

Energy efficiency policies

Energy Efficiency		
1	Ecodesign Framework Directive	Directive 2009/125/EC
	Stand-by Regulation	Commission Regulation (EC) No 1275/2008 as amended by Commission Regulation (EU) No 801/2013
	Office/street lighting Regulation	Commission Regulation (EC) No 347/2010
	Lighting Products in the domestic and Tertiary Sectors Regulations	Commission Regulation (EU) 2019/2020 Commission Regulation (EC) No 244/2009 Commission Regulation (EC) No 245/2009 Commission Regulation (EU) No 1194/2012
	External power supplies Regulation	Commission Regulation (EU) 2019/1782
	TVs Regulation (+labelling) Regulation	Commission Regulation (EU) 2019/2021
	Electric motors Regulation	Commission Regulation (EC)No 640/2009
	Freezers/refrigerators Regulation	Commission Regulation (EU) 2015/1095 Commission Regulation (EU) 2019/2019 Commission Regulation (EU) 2019/2024
	Household washing machines Regulation	Commission Regulation (EU) 2019/2023
	Household dishwashers Regulations	Commission Regulation (EU) 2019/2022
	Air conditioners	Commission Regulation (EU) No 206/2012 Commission Regulation (EU) Regulation No 327/2011 Commission Regulation (EU) No 1253/2014 Commission Regulation (EU) 2016/2281
	Circulators Regulation	Commission Regulation (EC) No 641/2009 as amended by Commission Regulation (EU) No 622/2012 and Commission Regulation (EU) 2019/1781
	Water pumps	Commission Regulation (EU) No 547/2012
	Tumble driers	Commission Regulation (EU) No 932/2012
	Computers and servers	Commission Regulation (EU) No 617/2013 Commission Regulation (EU) 2019/424
	Vacuum cleaners	Commission Regulation (EU) No 666/2013
	Cooking appliances	Commission Regulation (EU) No 66/2014
	Power transformers	Commission Regulation (EU) No 548/2014

Energy Efficiency		
		Commission Regulation (EU) 2019/1783
	Heaters Regulation	Council Directive 92/42/EEC Commission Regulation (EU) No 813/2013 Commission Regulation (EU) No 814/2013 Commission Regulation (EU) 2015/1185 Commission Regulation (EU) 2015/1189 Commission Regulation (EU) 2016/2281
	Welding equipment	Commission Regulation (EU) 2019/1784
	Omnibus	Commission Regulation (EU) 2021/341
	Imaging equipment	Voluntary agreement – Report from the Commission to the European Parliament and the Council on the voluntary ecodesign scheme for imaging equipment COM/2013/023 final
	Game consoles	Voluntary agreement - Report from the Commission to the European Parliament and the Council on the voluntary ecodesign scheme for games consoles COM/2015/0178 final
2	Energy Labelling Directive and delegated Regulations covering:	Regulation (EU) 2017/1369 supplemented by Delegated Regulations and Commission Directives
	• lamps and luminaires,	Commission Delegated Regulation (EU) No 874/2012
	• air conditioners	Commission Delegated Regulation (EU) No 626/2011 Commission Delegated Regulation (EU) No 1254/2014
	• Electronic displays	Commission Delegated Regulation (EU) 2019/2013
	• household washing machines	Commission Delegated Regulation (EU) 2019/2014 Commission Delegated Regulation (EU) 2015/1094
	• household refrigerating appliances	Commission Delegated Regulation (EU) 2019/2016 Commission Delegated Regulation (EU) 2019/2018
	• household dishwashers	Commission Delegated Regulation (EU) 2019/2017
	• household electric tumble-driers	Commission Delegated Regulation (EU) No 392/2012
	• Labelling of tyres Regulations	

	Energy Efficiency	
	• Cooking appliances	Regulation (EU) 2020/740
	Omnibus	Commission Delegated Regulation (EU) 2015/1186 Commission Delegated Regulation (EU) No 811/2013 Commission Delegated Regulation (EU) No 812/2013 Commission Delegated Regulation (EU) 2015/1187 Commission Delegated Regulation (EU) No 65/2014 Commission Delegated Regulation (EU) 2021/340 of 17 December 2020 amending Delegated Regulations (EU) 2019/2013, (EU) 2019/2014, (EU) 2019/2015, (EU) 2019/2016, (EU) 2019/2017 and (EU) 2019/2018
3	Energy Performance of Buildings Directive	Directive 2010/31/EU as amended by Directive (EU) 2018/844
4	Energy Efficiency Directive	Directive 2012/27/EU as amended by Directive (EU) 2018/2002

Power generation and energy markets

	Power generation and energy markets	
1	Completion of the internal energy market (including provisions of the 3rd package).	Directive 2009/73/EC
	Since March 2011, the Gas and Electricity Directives of the 3rd package for an internal EU gas and electricity market are transposed into national law by Members States and the three Regulations:	Directive (EU) 2019/944
	- on conditions for access to the natural gas transmission networks	Regulation (EC) No 715/2009
	- on conditions for access to the network for cross-border exchange of electricity	Regulation (EU) 2019/943
	- on the establishment of the Agency for the Cooperation of Energy Regulators (ACER)	Regulation (EU) 2019/942
2	Energy Taxation Directive	Directive 2003/96/EC
3	Regulation on security of gas supply	Regulation (EU) 2017/1938
4	Regulation on market integrity and transparency (REMIT)	Regulation (EU) 1227/2011

Power generation and energy markets		
5	Nuclear Safety Directive	Council Directive 2009/71/Euratom
6	Nuclear Waste Management Directive	Council Directive 2011/70/Euratom
7	Basic safety standards Directive	Council Directive 2013/59/Euratom
8	Directive on the promotion of the use of energy from renewable sources	Directive 2009/28 EC as amended by Directive (EU) 2015/1513 Recast Directive (EU) 2018/2001 will only take place formally on 1 July 2021, when Directive 2009/28 EC is repealed.
9	Guidelines on State aid for environmental protection and energy 2014-20	2014/C 200/01

Climate policies

(Cross-sectorial) Climate policies		
1	EU ETS Directive	Directive 2003/87/EC as amended notably by Directive 2008/101/EC (aviation), Decision (EU) 2015/1814 (Market Stability Reserve), Regulation (EU) 2017/2392 (aviation "stop the clock" derogation) and Directive 2018/410 (revision for 2030 climate and energy framework)
2	Directive on the geological storage of CO_2	Directive 2009/31/EC
3	GHG Effort Sharing Regulation	Regulation (EU) 2018/842
4	F-gas Regulation	Regulation (EU) No 517/2014
5	EU framework for LULUCF	Regulation (EU) 2018/841, amending Regulation (EU) No 525/2013 and Decision No 529/2013/EU
6	Communication from the Commission Guidelines on certain State aid measures in the context of the system for greenhouse gas emission allowance trading post-2021.	2020/C 317/04

Transport policies

Transport related policies		
1	CO_2 emission performance standards for new passenger cars and for new light commercial vehicles	Regulation (EC) 2019/631

Transport related policies		
2	Improving testing procedures - real driving conditions ('Real Driving Emissions' – RDE) and improved laboratory test ('World Harmonised Light Vehicle Test Procedure' – WLTP)	Commission Regulation (EU) 2018/1832 Commission Regulation (EU) 2017/1151 Commission Regulation (EU) 2017/1154 Commission Regulation (EU) 2016/646 Commission Regulation (EU) 2016/427
3	CO_2 emission performance standards for new heavy-duty vehicles	Regulation (EU) 2019/1242
4	Regulation determining CO_2 emissions and fuel consumption of heavy-duty vehicles	Regulation (EU) 2017/2400
5	Regulation on the monitoring of CO_2 emissions from heavy-duty vehicles	Regulation (EU) 2018/956
6	Regulation EURO 5 and 6	Regulation (EC) No 715/2007, implemented by Commission Regulation (EU) 2017/1151
7	Directive on the promotion of the use of energy from renewable sources	Recast Directive (EU) 2018/2001 will only take place formally on 1 July 2021, when Directive 2009/28/EC is repealed.
8	Fuel Quality Directive	Directive 98/70/EC, as amended by Directive (EU) 2015/1513
9	Regulation Euro VI for heavy duty vehicles	Regulation (EC) No 595/2009, implemented by Commission Regulation (EU) 582/2011
10	Eurovignette Directive on road infrastructure charging	Directive 1999/62/EC, as amended by Directive 2011/76/EU
11	Directive on the Promotion of Clean and Energy Efficient Road Transport Vehicles (in public procurement)	Directive 2009/33/EC, as amended by Directive (EU) 2019/1161
12	Directive on the deployment of alternative fuels infrastructure	Directive 2014/94/EU
13	Directive on weights & dimensions	Directive 96/53/EC, as amended by Directive 2015/719/EU
14	End of Life Vehicles Directive	Directive 2000/53/EC, as amended by Directive (EU) 2018/849

Transport related policies		
15	Mobile Air Conditioning in motor vehicles Directive	Directive 2006/40/EC
16	Directive on the sound level of motor vehicles	Regulation (EU) No 540/2014 as amended by Regulation (EU) 2019/839
17	Roadworthiness Package	Directive 2014/45/EU, Directive 2014/46/EU, Directive 2014/47/EU
18	Road infrastructure safety management	Directive (EU) 2019/1936
19	General safety regulation	Regulation (EU) 2019/2144
20	Intelligent Transport Systems Directive	Directive 2010/40/EU
21	Regulation concerning type-approval requirements for the deployment of the eCall in-vehicle system	Regulation (EU) 2015/758
22	Fourth railway package	Directives (EU) 2016/798 on railway safety, Directive (EU) 2016/797 on railway interoperability and the Directive 2016/2370/EU regarding the opening of the market for domestic passenger transport services by rail and the governance of the railway infrastructure
23	Directive establishing a single European railway area (Recast)	Directive 2012/34/EU
24	European Rail Traffic Management System European deployment plan	Commission Implementing Regulation (EU) 2017/6
25	Regulation on electronic freight transport information	Regulation (EU) 2020/1056
26	Regulation on noise-related operating restrictions at Union airports	Regulation (EU) No 598/2014
27	Regulations governing the performance and charging schemes as well as the network functions of the Single European Sky	Commission Implementing Regulations (EU) No 390/2013, 391/2013 and 677/2011; later replaced by Regulations (EU) 2019/317 and 2019/123
28	Inland waterways and port services	Directive 2016/1629/EU on technical requirements for inland waterway vessels and the Regulation on non-road mobile machinery (NRMM) Regulation (EU) 2017/352 establishing a framework for the provision of port

Transport related policies		
		services
29	Provision of port services	Regulation (EU) 2017/352
30	European Maritime Single Window	Regulation (EU) 2019/1239
31	Directive on the sulphur content of marine fuels	Directive 2012/33/EU
32	Monitoring, reporting and verification of carbon dioxide emissions from maritime transport	Regulation (EU) 2015/757

Infrastructure, innovation, and RTD funding

Infrastructure, innovation and RTD and funding		
1	TEN-E guidelines	Regulation (EU) 347/2013
2	Regulation establishing the Connecting Europe Facility	Regulation (EU) 1316/2013
3	EEPR (European Energy Programme for Recovery) and NER 300 (New entrants reserve) CCS and innovative renewables funding programme	Regulation (EC) No 663/2009, ETS Directive 2009/29/EC Article 10a (8), further developed through Commission Decision 2010/670/EU and implementing decisions, e.g. EC(2014) 4493 and C(2015) 6882
4	Horizon 2020 support to energy research and innovation	Energy research under H2020: info available here: http://ec.europa.eu/programmes/horizon2020/en/area/energy
5	European Structural and Investment Funds[109]:	
	European Regional Development Fund (ERDF)	Regulation (EU) No 1303/2013
	European Social Fund (ESF)	Regulation (EU) No 1301/2013
	Cohesion Fund (CF)	Regulation (EU) No 1304/2013
	European Agricultural Fund for Rural Development (EAFRD)	Regulation (EU) No 1305/2013
	European Maritime & Fisheries Fund	Regulation (EU) No 508/2014

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[109] As of May 2021, a revision of the regulations of the European Structural and Investment Funds has been agreed and is planned for publication.

Infrastructure, innovation and RTD and funding		
	(EMFF)	
6	TEN-T guidelines	Regulation (EU) No 1315/2013 supported by the Connecting Europe Facility (Regulation (EU) No 1316/2013)

Environmental policies

Environment and other related policies		
1	General block exemption Regulation	Commission Regulation (EU) 2014/651, Commission Regulation (EU) 2017/1084
2	Landfill Directive	Directive 99/31/EC
3	EU Urban Wastewater Treatment Directive	Directive 91/271/EEC, Directive 98/15/EEC, Implementing Decision 2014/431/EU
4	Waste Management Framework Directive	Directive 2008/98/EC
5	Nitrate Directive	Directive 91/676/EEC
6	Common Agricultural Policy (CAP)	e.g. Council Regulations (EC) No 1290/2005, No 1698/2005, No 1234/2007, No. 73/2009, Regulations (EU) No 1305-1308/2013, Regulation (EU) 2020/2220
7	Industrial emissions (Recast of Integrated Pollution and Prevention Control Directive 2008/1/EC and Large Combustion Plant Directive 2001/80/EC)	Directive 2010/75/EU
8	Directive on national emissions' ceilings for certain pollutants	Directive 2001/81/EC, Directive (EU) 2016/2284
9	Water Framework Directive	Directive 2000/60/EC
10	Substances that deplete the ozone layer	Relevant EU legislation implementing the Montreal protocol, e.g. Regulation (EC) No 1005/2009 as amended by Commission Regulation (EU) 744/2010, Regulation (EU) No 517/2014, Council Decision (EU) 2017/1541

International policies

Other policies at international level		
1	International Maritime Organisation (IMO) International convention for the prevention of pollution from ships (MARPOL), Annex VI	2008 amendments - revised Annex VI (Prevention of Air Pollution from ships) Energy Efficiency Design Index (EEDI) and the Ship Energy

Other policies at international level		
		Efficiency Management Plan (SEEMP), IMO Resolution MEPC.203(62)
2	Voluntary agreement to reduce PFC (perfluorocarbons, potent GHG) emissions in the semiconductor industry	
3	International Civil Aviation Organisation (ICAO), Convention on International Civil Aviation, Annex 16, Volume II (Aircraft engine emissions) and Volume III (CO_2 emissions standard for aircraft)	

Implementation of non CO_2 policies

Sector	Gas	Policy	Regional coverage	Policy description and implementation in GAINS
Agriculture	CH_4	Feed-in tariffs or other subsidies to stimulate co-digestion of manure on farms	Italy, Netherlands, Latvia, Sweden, Cyprus, Austria, Croatia, Germany	Reflected via assumptions on uptake of farm-scale biogas technology consistent with information from EurObserv'ER (2020) on installed capacity. Future uptake follows trend in biogas production from anaerobic digestion as projected in the PRIMES model Reference scenario.
	CH_4 & N_2O	EU Common Agricultural Policy (CAP) and EU Nitrate Directive (EEC/676/1991) with revisions	EU-wide	Reflected in GAINS through input of CAPRI model data on trends in livestock numbers, milk yield and fertilizer use.
	CH_4	Ban on burning of crop residues	EU-wide	Assumed not fully enforced. GAINS uses information derived from satellite images (e.g., MODIS) as approximate estimates of the mass of crop burned on fields.
Waste & wastewater	CH_4	EU Landfill Directive (EC/31/1999) with amendment (EC/850/2018) and EU Waste and Packaging Directives (EC/851/2018,	EU-wide	Biodegradable waste diverted away from landfills (relative 1990 by -25% in 2006, -50% in 2009 and -65% in 2016). All landfill sites equipped with gas recovery by 2009. By 2035, countries must not landfill more than 10% of MSW generated. Member states that landfill more than 60% of

Sector	Gas	Policy	Regional coverage	Policy description and implementation in GAINS
		EC/852/2018)		MSW in 2013 are given a 5 years grace period but must not landfill more than 25% in 2035. GAINS Reference scenario assumes future targets will be met.
	CH_4	EU Waste Management Framework Directive (EC/98/2008)	EU-wide	The following hierarchy is to be respected in waste treatment: recycling and composting preferred to incineration/energy recovery, which in turn is preferred to landfill disposal. Considered in GAINS when simulating pathway for compliance with the Landfill Directive target.
	CH_4	Decree on waste landfill	Slovenia	Decree on landfill of waste beyond EU Landfill Directive. Includes partial ban on landfill of biodegradable waste.
	CH_4 & N_2O	Legislation to replace current composting with anaerobic digestion of food waste	Germany	In GAINS, the current composting of organic waste is phased-out linearly and replaced with anaerobic digestion between 2020 and 2050.
	CH_4	Ban on landfill of biodegradable waste.	Austria, Belgium, Denmark, Germany, Netherlands, Sweden	Complete ban on landfill of untreated biodegradable waste. Reflected in GAINS.
	CH_4	EU urban wastewater treatment directive (EEC/271/1991)	EU-wide	GAINS reflects an "appropriate treatment" of wastewater from urban households (all agglomerations > 2000 people) and food industry must be in place latest by end of 2005. This means discharge must ensure receiving waters meet relevant quality objectives.
Industry	N_2O, PFCs	EU ETS Directive (EC/29/2009): Primary aluminum	EU-wide	Industry needs to aquire tradable emission permits under the EU emission trading system (EU-ETS).

Sector	Gas	Policy	Regional coverage	Policy description and implementation in GAINS
		production and production of nitric acid, adipic acid, glyoxal and glyoxylic acid.		
	PFCs	Voluntary agreement in semiconductor industry	EU-wide	Semiconductor producers to reduce PFC emissions by 2010 to a level at 10 percent of 1995 emissions. Accounted for in GAINS to the extent it is reflected in national emission inventories to the UNFCCC.
F-gases	HFCs, PFCs, SF_6	EU F-gas regulation (EC 517/2014)	EU-wide	Phase-down of F-gas sold on the market, banning of use in applications where alternatives to F-gases are readily available, and preventing emissions from existing use of F-gases through leakage control and end-of-life recovery.
	HFCs	EU MAC Directive (EC 40/2006)	EU-wide	Mobile air conditioners: replacing the use of high GWP HFCs with cooling agents GWP100 < 150 in all new vehicle models placed on the market.
	HFCs	EU Directive on end-of-life vehicles (EC 53/2000)	EU-wide	Scrapped mobile air conditioners: recovery and proper handling
	HFCs, PFCs, SF_6	National F-gas regulations more stringent than EU regulation	Austria ("HFKW-FKW-SF6-Verordnung"), Belgium (end-of-life regulation from 2005 for large-scale refrigeration), Denmark (deposit-refund scheme since 1992, tax since 2001 and ban on import, sale and use since 2002), Germany ("Chemikalien-Klimaschutzverordnung" specify maximum leakage rates), Netherlands ("STEK" since 1992), Sweden (envirionmental fees since 1998, specific regulation since 2007)	

Annex II: Background on macro-economic assumptions

Methodology

GEM-E3 is a large scale multi-sectoral CGE model that since the 1990s has been extensively used to assess the socio-economic implications of policies, mostly in the domains of energy and the environment. The development of GEM-E3 involved a series of modelling innovations that enabled 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 (the model represents 460 households distinguished by income group), unemployment in the labour market and endogenous formation of labour skills. The model has detailed sectoral and geographical coverage, with 67 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 specialized 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 2050 in increasing time steps: annual from 2015 to 2030 and then five-year period until 2050. The substitution elasticities of the model are not derived from the general literature but are estimated according to its dimensions and functional forms using the latest available datasets. The model is founded on rigorous and sound micro-economic theory allowing it to study in a consistent framework the inter-linkages of the economic sectors and to decompose the impacts of policies to their key driving factors. It is acknowledged that the model simulations are sensitive to a number of input parameters and modelling assumptions including capital costs of power producing technologies and associated learning rates, cost of capital and financing availability, easiness to substitute production factors, preferences over domestic and imported goods etc.

The Reference Scenario simulated with the GEM-E3 model provides numerical projections for the period 2020-2050 in 5-year time steps for each EU Member State and for the rest of the world, grouped in 18 countries/regions. 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.

The projection for world energy prices is provided by the POLES-JRC model. GEM-E3 and POLES-JRC make use of exactly the same GDP and population assumptions.

The dynamic calibration of the GEM-E3 macroeconomic projections is based on the assumption that countries follow a sustainable growth path, and so excessive current account deficits or surpluses are gradually reduced. This assumption is compatible with a zero-output gap, i.e. the efficient operation of the economy. Considering the differences between potential and actual GDP, the macroeconomic projection simulated with the GEM-E3 model assumes that the output gap closes in 2024 so actual and potential GDP growth rates are the same from 2024 onwards. This assumption is compatible with the 2021 Ageing Report prepared by the European Commission.

The model accounts for labour market imperfections since GEM-E3 computes involuntary unemployment through an empirical wage curve. In the long term it is assumed that the economy converges to full potential having no idle resources. The Reference Scenario design rests on the assumption that unemployment rate will decrease and converge in the long run with the natural rate of unemployment. This assumption is consistent with the 2021 Ageing Report labour market projections to which the GEM-E3 model is calibrated.

Public expenditures are dynamically adjusted in the model so that the public budget of each country is balanced in the long term and excess deficits or surpluses are reduced. Sectorial investment is derived partly endogenously, by comparing the sectorial rate of return on capital with the cost of replacing capital, and partly exogenously, with the introduction of sectorial growth expectations.

Data

The macroeconomic scenario makes use of several well-established datasets for EU and non-EU countries. The compiled database has been updated with the latest available data, i.e., first quarter of 2020. For EU countries the latest Eurostat statistics have been used including historical data covering the period from 1995 to 2020.

Data on the impact of COVID-19 pandemic on sectoral production are collected up to the 2nd quarter of 2020 and the impact on public financing, investments and lockdown in industry, tourism, transport, retail trade has been evaluated to have an estimate of the sectoral structure by each region for the end of 2020.

Depending on data availability the NACE 64, NACE 38 and NACE 10 datasets have been used. All past data are expressed in chain linked volumes of 2015. The methodology follows ESA2010 and NACE r2 (chained with NACE r1). In few cases normalization to the NACE 10 figures has been performed. This approach has been employed in cases where the total gross value added in current prices was not equal to the sectoral sum in NACE 64 and NACE 38. Structural Business Statistics (SBS) have also been used in order to disaggregate some sectors into subsectors. For instance, the Chemicals sector has been disaggregated into Fertilisers, Petrochemicals, Other Chemicals and Pharmaceuticals.

Sources of main exogenous projections

Projections for the aggregate GDP of EU countries in 2020 and until 2025/2030 have been based on the Spring 2020 Economic Forecast (DG ECFIN, European Commission). For the period after 2030, projections on Member State GDP growth are based on the 2021 Ageing Report.

Population projections for the EU make use of the European Population Projections, base year 2019 (EUROPOP 2019), for the period 2020 to 2050. The population projections used are compatible with GDP projections as the starting point of the 2021 Ageing Report projections is also the EUROPOP 2019 population projections for the period 2020-2050.

For non-EU countries, GDP growth for the period 2015-19 have been based on the IMF World Economic Outlook[110]. For the period 2020-2050, the GDP growth projections of the OECD Economic Outlook[111] have been used. Population projections for non-EU countries have been based on the United Nations 2019 revision of World Population Prospects[112].

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[110] "World Economic Outlook: A Long and Difficult Ascent", October 2020, International Monetary Fund

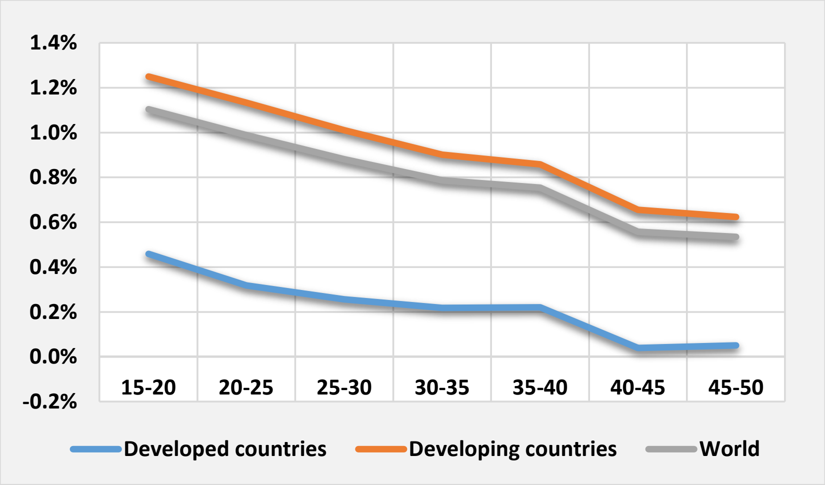
[111] "Long-term baseline projections, No. 103, OECD Economic Outlook: Statistics and Projections (database)", 2021, OECD

[112] "World Population Prospects 2019, Online Edition. Rev. 1", 2019, United Nations, Department of Economic and Social Affairs, Population Division

Global population projections

Population projections show world population to grow from 7.4 billion in 2015 to 9.7 billion in 2050. Population growth is driven mainly by developing countries and is projected to slow down over time. Also, projections show a shift in the ageing structure of the world population with a fall in the population aged 15-64.

Figure 108: Annual growth rate of population



Source: UN, Population Division

Global economic projections

Population ageing is the dominant demographic phenomenon of the 21st century with major implications for the global and EU economy. Demographic change comes in addition to a phasedown in global trade and productivity growth coupled with structural changes and a potentially lasting impact of the COVID-19 pandemic. In fact, the COVID-19 pandemic hit at a time when global GDP growth was recovering from the global financial crisis and is projected to cast a long shadow over the world's economies.

Following the deep recession of 2020, the global economy is expected to gain momentum gradually, as vaccines are deployed. After falling sharply, world GDP is projected to rise by 4.2% in 2021 and by around 4% in 2022. Recovery is expected to be uneven but significant still (OECD 2020[113]). The contribution of Europe and North America to global growth will remain smaller than their weight in the world economy. Growth in advanced economies recovers, still at a slow pace reflecting ageing population effects and the slowdown in investment, leading to low capital growth. The COVID-19 pandemic will continue to have a major shock on investment and human capital in emerging market and developing economies, setting back key development goals.

World GDP growth drops close to 2.5% in 2050 from close to 4% in 2025, mainly due to the deceleration of emerging economies (Brazil, Russia, India, Indonesia, China, and South Africa), which continue to account for the bulk of world economic growth. India and China take up a rising share of world output as the world's economic centre of gravity shifts toward Asia (OECD 2018[114]).

The transition of the Chinese economy from infrastructure and manufacturing to consumption and services is projected to continue to put pressure on commodity markets and impact GDP prospects in commodity exporters (i.e., Brazil, Canada, Australia,

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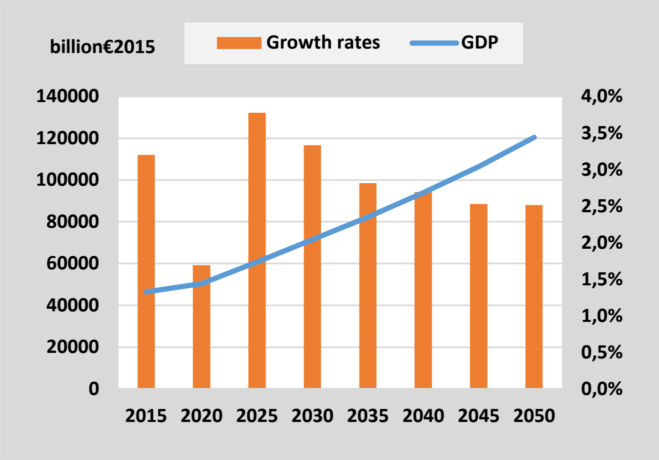
[113] "OECD Economic Outlook", OECD Publishing, 2020, Paris.

[114] "The Long View: Scenarios for the World Economy to 2060", OECD Economic Policy Papers, No. 22, OECD Publishing, 2018, Paris

Russia) but also on economies with strong trade links to China (like Japan, Korea and the South-East Asian economies).

Despite the growth and financial weaknesses, world GDP is projected to rise to 2050 as a response to supportive macroeconomic policy actions like stimulus measures in China, regional trade agreements, structural reforms, etc.

Figure 109: World GDP (excluding EU Member States)

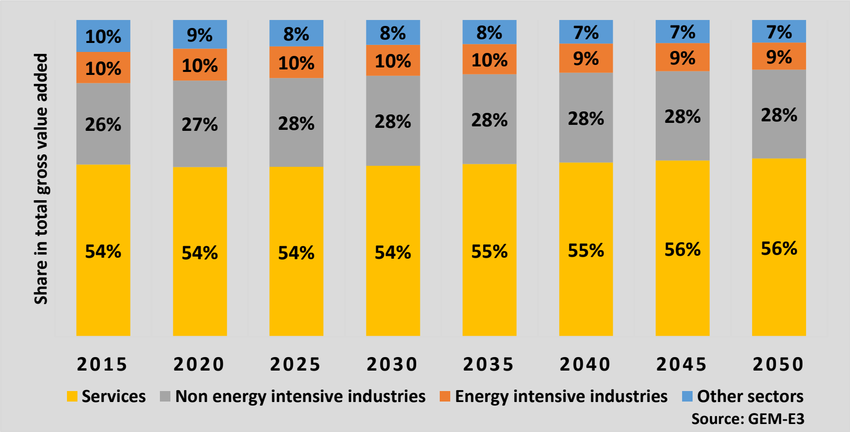


Source: IMF and OECD

Global sectorial projections

The macroeconomic projections show that at global level services account for 56% of total gross value added in 2050 from 54% in 2015. Services continue to play an important role in the economic activity of developed countries. Services also increase significantly in developing countries; these are assumed to converge in terms of economic structure with developed economies, where services account for a large share of the economic activity.

Figure 110: Structure of the world economic activity (excl. EU)



Note: "Other sectors" refers to agriculture and construction

Energy intensive industries and other sectors, including agriculture and construction, are projected to reduce their share in total economic activity at world level by 2050.

Annex III: Background on techno-economic assumptions

For the preparation of the Reference Scenario, techno-economic assumptions have been adjusted accordingly since 2016. The technologies subject to review have been divided in several categories. To ensure the assumptions are robust, a dedicated workshop took place in November 2019 with industry representatives, well placed to provide insights on techno-economic developments and future trends in each sector. Stakeholder input complemented the extensive literature review undertaken for the preparation of the assumption datasets used in the Reference Scenario.

All cost figures presented in the PRIMES and GAINS techno-economic assumptions are expressed in constant €2015, whereas GLOBIOM assumptions in constant €2010. This section presents background information on the techno-economic assumption data sets which are included in the EXCEL file "REF2020_Technology Assumptions" published along with this report.

Power and heat

Data on technologies and costs for power and steam/heat generation include, namely: "Overnight investment costs in a greenfield site", "Fixed Operation and Maintenance costs", "Variable non-fuel cost", "Electrical efficiency (net) in optimal load operation", "Self-consumption of electricity", "Technical lifetime" and average typical "Capacity Factors" for RES technologies.

A new representation of variable RES technologies and resources intensity classes (that differ per country) are used to capture the possible differentiation in the technologies used across different sites and better reflect the heterogeneity of resources in a region. Therefore, the values presented for capacity factors are average, shown for illustration purposes. The model further adjusts capacity factors per Member State based on observed performance of installed capacities.

Regarding fossil power generation, adjustments have been made to CCS power plants. Their current costs (for some technologies) have increased due to lack of project developments. Efficiency has also been revised downwards due to lack of technological improvements. For IGCC, costs have been reduced slightly based on comments from stakeholders, confirmed by literature.

On new technologies, the latest information for large-scale batteries available from the EIA NEMS reports[115] published in early 2020 have been included. CAES and flywheels have been amended using the HydroWIRES report[116]. Small scale batteries are amended based on the IRENA report.

For fuel cells, Solid Oxide Electrolysis Cells (SOEC) have been amended in accordance with the EIA NEMS reports.

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[115] https://www.eia.gov/outlooks/aeo/assumptions/pdf/electricity.pdf; https://www.eia.gov/analysis/studies/powerplants/capitalcost/pdf/capital_cost_AEO2020.pdf

[116] https://www.energy.gov/sites/prod/files/2019/07/f65/Storage%20Cost%20and%20Performance%20Characterization%20Report_Final.pdf

Transport

The techno-economic assumptions are split by transport equipment for various transport modes, by size (for cars, trucks, vessels) and by powertrain/fuel categories (i.e., thermal engine running on different fuels, plug-in hybrid, battery electric, hydrogen fuel cell, pantograph for trucks).

The categories are:

- **Small cars** (referring to A and B market segments)
- **Medium cars** (referring to C and D market segments)
- **Large cars** (referring to the rest of market segments)
- **Light Commercial vehicles** (**LCV**- referring to a medium-sized LCV)
- **Heavy Goods vehicles (HGV) of below 16 tons** gross-vehicle weight (also split into 3.5-7.5t and 7.5-16 t sizes)
- **Heavy Goods vehicles (HGV) of above 16 tons** gross-vehicle weight (also split into 16-32t and above 32 t sizes). The file presents assumptions for a 4x2 rigid regional 16-32t and 4x2 tractor long-haul >32t truck.
- **Buses** (for urban mobility) and **coaches** (for inter-urban mobility)
- **Aviation** (includes assumptions for a narrow-body aircraft)
- **Rail** (includes the cost of the entire train for passenger and freight)
- **Inland navigation** (includes inland waterways and national maritime)
- **International maritime** (includes selected sized of oil tankers, containers, dry bulk carriers and general cargo vessels)
- **Infrastructure** equipment related to the refuelling/recharging of alternative fuel vehicles. These costs are the costs for refuelling stations at distribution level: for hydrogen also the costs for compression and liquefaction are included for completeness. The investments are shown per kW-output. Fixed costs of refuelling technologies (operation and maintenance) are also presented per kW output.

The techno-economic assumptions are related to the evolution of the capital costs (vehicle prices excluding taxes) of the various transport technologies until 2050 in 10-year time steps (i.e., 2020, 2030, 2040, 2050). The assumptions are presented consistently across the different technologies:

Multiple **efficiency improvement levels** are available at different cost for transport vehicle technologies equipped with thermal engines, for each time period. The efficiency improvements are compared against a 2015 reference vehicle. For example, a small gasoline car in 2030 offering a 25% improvement in its specific energy consumption relative to 2015 is assumed to cost EUR 14,592 , while a small gasoline car offering 40% improvement in its specific energy consumption is assumed to cost EUR 16,114. The reference vehicle is a small gasoline car which is assumed to cost EUR 14,228 in 2015 with an average specific energy consumption of 5.5 lt/100 km. The same logic applies through the rest of the transport equipment categories (also for plug-in vehicle powertrains). In particular, for hydrogen fuel cell vehicles the presentation of the cost assumptions is also linked with the efficiency (expressed as kgH_2 per 100km); however, the costs of the hydrogen fuel cell vehicles are strongly dependent on the assumptions on the evolution of the hydrogen fuel cell costs.

For **battery electric vehicle technologies** (road, aviation, rail and waterborne) the capital cost of the equipment is linked with the available electric range offered by the equipment. Higher range requires higher battery capacity and leads to higher capital costs. For example, a medium size battery electric car with a range of 250 and 300 km is assumed to cost EUR 29,508 and EUR 31,847 in 2020, respectively. The costs of the electric vehicle technologies are assumed to decrease in the future as a result of the assumed reduction in the battery costs. For example, the medium size battery electric car with a range of 250 km is assumed to cost EUR 23,138 in 2030.

The assumptions on the technology costs for cars and LCVs draw on the work carried out by Ricardo and JRC[117]. The assumptions on the technology costs for trucks of above 16 tons are based on the work of JRC[118]. The assumptions on the evolution of the battery costs follow the *LOW* trajectory of the assumptions presented in the report of Ricardo[119]. The assumptions on the evolution of battery and hydrogen fuel cell costs have also been cross-checked to be in line with the most recent reports from IEA[120] [121], US DOE and JRC. The assumptions on the maritime sector are based on the work of the IMO GLOMEEP[122].

Industry

The assumptions include capital costs and efficiency for technologies used in the industrial sector. Efficiency is expressed as an index compared to 2015. Learning by doing is included. Increase in the efficiency rate implies a more efficient technology. As in the “Domestic” category, for every technology, the model considers seven (7) technology categories, ranging from an ordinary to an advanced and a future category.

Domestic appliances and equipment

Includes technologies for the buildings sector (residential and services). Data shown include ranges of purchasing costs (that refer to total acquisition costs) and efficiency by vintage (reference year of purchase), for several space and water heating technologies and appliances. For every item, the model considers a range of seven technology categories, ordered from an ordinary up to an advanced and a future category. The technical and economic characteristics of each technology category change over time as a result of learning by doing and economies of scale in industrial production. Not all technology categories are considered as fully mature from a user's perspective, but in general the users' acceptance of advanced technology categories increases over time. Policy assumptions may drive acceleration of learning-by-doing and users' acceptance in the context of a scenario. An advanced technology category is more efficient than an ordinary one and in general more expensive to purchase at a given point in time. However, depending on the learning potential of a technology, it is possible that an advanced technology becomes cheaper than ordinary technology in the long-term and still more efficient. For currently mature technologies this is generally unlikely to happen.

More specifically:

- The CHP efficiencies reported refer only to thermal efficiencies. The model considers the electrical production separately.
- Costs of space and water heating boilers have been modified to align with the studies for space heaters[123] and water heaters[124] published on October 2, 2019 for the revision of the Ecodesign Directive.[125] Costs are therefore in line with the latest

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[117] https://ec.europa.eu/clima/sites/clima/files/transport/vehicles/docs/ldv_co2_technologies_and_costs_to_2030_en.pdf
[118] https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/heavy-duty-vehicle-co2-emission-reduction-cost-curves-and-cost-assessment-enhancement-dione
[119] https://ec.europa.eu/clima/sites/clima/files/transport/vehicles/docs/ldv_post_2020_co2_en.pdf (Table 2.4)
[120] https://www.iea.org/publications/reports/globalevoutlook2019/
[121] https://www.g20karuizawa.go.jp/assets/pdf/The%20future%20of%20Hydrogen.pdf
[122] http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Air%20pollution/EE%20Appraisal%20Tool_Advanced.xlsm
[123] https://www.ecoboiler-review.eu/study.htm
[124] https://www.ecohotwater-review.eu/documents.htm
[125] Following Article 7 of Commission Delegated Regulation (EU) No 811/2013, Commission Delegated Regulation (EU) No 812/2013, Commission Regulation (EU) No 813/2013 and Commission Regulation (EU) No 814/2013 the regulations require review after 5 years of entering into force.

available studies and aligned with the minimum ecodesign requirements (today 75% GCV – future 86% GCV).

- The costs of the required chimney modifications for condensing boilers are included in the modelling, yet not under direct boiler costs.
- Costs and learning curves for solar thermal are included in the model and are comparable to those in literature (IEA-SHC “Solar Heat Worldwide” edition 2017 and 2018). Ultimate costs have been reduced by approximately 10% to reflect higher learning and lower bounds of possible prices.
- Information related to heat pumps is taken from the ETSAP Technology Brief on Heat Pumps published in January 2013. This source has not yet been updated. Hybrid heat pumps are included in the model as heat pumps with an additional small boiler (electric in most cases), where average temperatures require such an element. For geothermal heat pumps, values were double-checked with available information and the model is in line with estimates. The model makes the distinction between small-scale and large-scale geothermal heat pumps.

All relevant equipment has the option of using hydrogen. Since for the most part the consumer has no influence on the delivered fuel mix (and therefore the share of hydrogen in the fuel mix), the conversion of the equipment to hydrogen is considered as a mark-up in the fuel price. Social aspects for the adoption of hydrogen are considered in the model as perceived or hidden costs. Technologies that are not yet mature face more significant penetration challenges, which reduce over time as technology maturity increases.

Renovation

Renovation refers to average renovation costs by climate type and renovation deepness, as used in the PRIMES buildings module. Investment costs are the energy related expenditures needed to implement the indicated level of renovation of a building, excluding usual renovation expenditures needed for other purposes (structure, finishing materials, decoration etc.). The energy savings rate refers to a typical building as in the current stock of existing buildings, not savings in new constructions, which follow the buildings codes' insulation standards.

The data on renovation costs included in the EXCEL file “REF2020_Technology Assumptions“ are a summary of the data in the model which are more detailed and include several house types, house ages and geographical categories.

New fuels

Technologies for the production, transmission, and distribution of the so-called synthetic fuels (e-fuels) as well as storage technologies are presented. The following items are listed: “Investment costs”, “Fixed O&M costs”, “Heat rate” (ratio of energy input requirements over output), “Feedstock input requirements” (feedstock input required for the production of 1 unit of output from each technology).

Non-CO_2 greenhouse gas emissions abatement options

The GAINS model projects emissions of the non-CO_2 greenhouse gases by combining activity drivers with the emission intensity specific for a sector and technology set-up. This section lists, for each sector, key mitigation options to decrease emissions of non-CO_2 greenhouse gases for any given activity level through changes in the technology set-up. The implementation of different mitigation options as a result of current legislation in the different member states has been taken into account in the construction of the projected non-CO_2 greenhouse gas emissions in the EU Reference Scenario 2020.

Agriculture:

- Agricultural soils: Nitrification inhibitors (N_2O)
- Livestock manure: Farm-scale anaerobic digestion with biogas recovery (CH_4)
- Agricultural soils: Abandoning the use of organic soils (N_2O)
- Livestock enteric fermentation: Breeding through selection to enhance yield productivity and animal health, fertility and longevity, thereby minimizing kg CH_4/kg milk (CH_4)
- Livestock enteric fermentation: Feed additives and/or changed feed management practices (CH_4)
- Agricultural soils: Variable rate technology (N_2O)
- Agricultural soils: Precision farming (N_2O)
- Rice cultivation: Intermittent aeration, alternative hybrids and sulphate amendments (CH_4)
- Enforcement of existing ban on open burning of field residuals and other agriculture waste (CH_4)

Energy:

- Oil and gas production: Extended recovery of associated gas (CH_4)
- Gas distribution networks: Improved control through leak detection and repair programs (CH_4)
- Gas distribution networks: Replacement of grey cast iron networks (CH_4)
- Gas transmission pipelines: Set of measures including new controllers and replacement of wet with dry seals (CH_4)
- Abandoned coal mines: flooding (CH_4)
- Gas transmission pipelines: Pipeline upgrade through replacement (CH_4)
- Coal mining: Ventilation air methane oxidation (VAMOX) technology (CH_4)
- Oil and gas production: addressing unintended leakage through leak detection and repair programs (CH_4)
- Coal mining: pre-mining degasification (CH_4)
- Coal mining: combining VAMOX technology with improved mining ventilation (CH_4)
- Industry and power plant boilers: modification of fluidized bed combustion (N_2O)
- Oil refinery: reduced leakage (CH_4)
- Oil and gas production: monitoring and control of residual venting after max recovery of associated gas (CH_4)

Industry:

- Caprolactam production: Best available technology (N_2O)
- High and mid-voltage switches: leakage control, maintenance and recollection (SF6)
- Semiconductor industry: Switching from PFC to NF3 with post-destruction (PFC)
- Primary aluminium production: Move to advanced point-feed pre-bake technology (PFC)

- Primary aluminium production: New technology e.g., inert anode technology (PFC)

Air conditioning (AC) and refrigeration:

- Stationary AC: Alternative agent -hydrocarbons e.g., butane or propane (HFC)
- Commercial sector refrigeration: Alternative agent -HFC blends with GWP < 150 (HFC)
- Commercial sector refrigeration: CO_2-based technology (HFC)
- Industry sector refrigeration: Alternative agent -ammonia (HFC)
- Mobile AC: Alternative agent -HFO-1234yf (HFC)
- Stationary AC: Water chillers (HFC)
- Commercial sector refrigeration: Alternative agent -hydrocarbons e.g., butane or propane (HFC)
- Stationary AC: CO_2-based technology (HFC)
- Refrigerated transport: CO_2-based technology (HFC)
- Stationary AC: Alternative agent -HFO-1234yf (HFC)

Wastewater:

- Domestic wastewater: optimize process for low N_2O (N_2O)
- Food and other organic manufacturing industry: 2-stage treatment, anaerobic treatment with biogas recovery followed by aerobic (CH_4)
- Domestic wastewater: secondary/tertiary anaerobic treatment with biogas recovery (CH_4)

Solid waste:

- Municipal solid waste: source separation with maximum treatment, i.e., recycling, anaerobic digestion with biogas recovery and/or incineration with energy recovery (CH_4)
- Food manufacturing industry: Anaerobic digestion with biogas recovery (CH_4)
- Textile industry: incineration with energy recovery (CH_4)
- Wood industry: Maximum recycling for chip board production with the rest incinerated with energy recovery (CH_4)

Annex IV: Assumptions on fossil fuel prices projections

Approach

The EU Reference Scenario 2020 uses projections of international fossil fuel prices produced by the global model POLES-JRC[126] which are derived from work conducted for the Global Energy and Climate Outlook (GECO) JRC report[127]. The model's country-level energy system parameters are driven by income growth, cost-based competition between fuels and technologies with expected technological development and adjustment of market equilibrium and prices with lagged variables; energy and climate policies impact user costs directly or modify agent preference for different technology options (see POLES model documentation[128]). Oil Brent price, EU natural gas import, and EU coal import prices were all obtained from a REF2020 "Global Context" energy scenario where energy and climate policies adopted as of June 2019, as well as estimated impacts of the COVID-19 pandemic on macroeconomic parameters and sectoral activities, were included. The list of national energy and climate policies considered at global level can be found in the GECO 2019 report[129] (Reference scenario); the representation of the effects of the Covid-19 pandemic can be found in the GECO 2020 report[130] (Base_C19 scenario). In particular, EU energy and climate policies include the 2030 objective of reducing GHG emissions by at least 40% compared to 1990 levels[131]; no specific objective is considered for the EU beyond 2030[132].

In the modelling, fossil fuel prices are primarily the result of supply and demand equilibrium on global (oil) or regional (gas, coal) markets. They constitute an important marker at the macroeconomic level, as well as for the future of the energy system: any transition process away from fossil fuels will have to compare the economics of alternative pathways. In the modelling of the supply side, the production costs of different types of resources across the globe, including new capacity additions and constraints, are added to transportation costs, defining the cost of supplying primary energy to the various regional markets. In this respect, unconventional oil and gas resources, the development of new supply routes, as well as geopolitical parameters such as the OPEC's swing supplier strategy, will play a crucial role in equilibrating markets.

On the demand side, the consumption of fossil fuels depends on a variety of factors, including technological and behavioural, but also policy-related, notably in a context of enhanced climate policies. End-user prices and equipment costs are key drivers of energy demand patterns, and the rapid evolution of costs for key alternatives to fossil fuels (wind and solar power generation, electric vehicles) will impact the future evolution of the energy mix and of the energy prices.

The COVID-19 pandemic brought significant changes to the global economy and mobility patterns. First, the historic decline in energy demand due to sanitary measures caused a major drop in prices. The extent to which the ongoing rebound would return to (or even

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[126] https://ec.europa.eu/jrc/en/poles

[127] https://ec.europa.eu/jrc/en/geco

[128] 2018 documentation: Després, J., Keramidas, K., Schmitz, A., Kitous, A., Schade, B., Diaz Vazquez, A., Mima, S., Russ, H. and Wiesenthal, T., POLES-JRC model documentation, EUR 29454 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-97300-0 (online), doi:10.2760/814959 (online), JRC113757

[129] Global Energy and Climate Outlook 2019: Electrification for the low-carbon transition, EUR 30053 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-15065-7 (online),978-92-76-15066-4 (print), doi:10.2760/350805 (online),10.2760/58255 (print), JRC119619

[130] Global Energy and Climate Outlook 2020: A New Normal Beyond Covid-19, EUR 30558 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-28417-8 (online), doi:10.2760/608429 (online), JRC123203

[131] The modelling of the EU with the POLES-JRC model in the "Global context" scenario is calibrated on the Baseline scenario of the EU LTS (see "In-depth analysis in support of the Commission Communication COM(2018) 773"), including the EU policy framework as of end of 2018 and notably the 2030 targets on climate (at least 40% reductions), renewable energy (32%) and energy efficiency (32.5%).

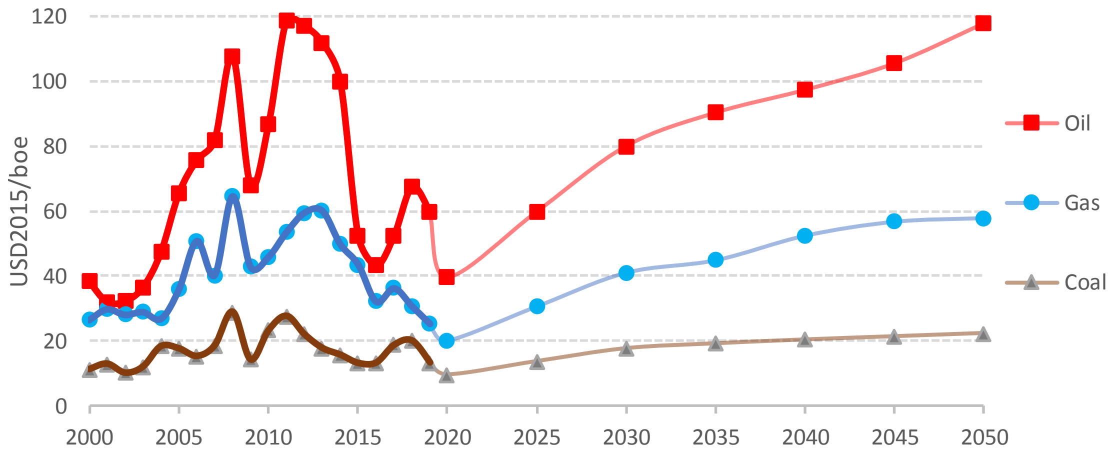
[132] With the exception of the EU ETS, which is maintained beyond 2030 with a linear reduction factor of the cap of 2.2%/year.

exceed) pre-crisis levels within a couple of years is still an open question. These short-term dynamics will depend on the degree to which some changes that took place during the pandemic will be perpetuated[133]. For the REF2020 "Global Context" scenario, assumptions were made on economic recovery[134], and in particular on a gradual recovery of sectoral transport activity to pre-pandemic levels. Finally, an important driver of future price is the behaviour of key global fossil fuel suppliers (notably from OPEC) in this context.

Price projections

Figure 111 provides the international fuel prices trajectories considered for the Reference Scenario 2020.

Figure 111: International fossil fuel prices in the EU Reference Scenario 2020



Note: oil prices refer to Brent, gas and coal prices refer to the average imports to the European market.
Source: historical (bold): Eurostat, PLATTS; 2020: estimates with data as of August 2020

Oil

For decades, oil demand has known a sustained growth, in line with macroeconomic indicators. The future, however, might go along a different path as new technologies contribute to cutting oil demand in key sectors develop. The recent economic context has brought even more uncertainty into this picture. After a 2019 year around 60 $/bbl, the Brent marker plummeted to around 20 $/bbl while demand significantly shrank to less than 75 Mb/d in April 2020, compared to an average of ~100 Mb/d before the crisis stroke. Prices returned to pre-crisis levels early in 2021. The recovery in prices was eased by a series of factors, including important supply cuts by the OPEC, and a gradual recovery of demand due to a progressive ease of lockdown measures. The short-term price evolution therefore depends a lot on assumptions made to define a "new normal" for the oil market and beyond. The transitory price decrease during the pandemic is also resulting in decreased investment in exploration and in the development of new reserves, and in the reorganization of the upstream sector in the form of a series of mergers and acquisitions. In the projection of international oil price for the EU Reference Scenario 2020, these factors combine into a pronounced increase of the price by the mid-2020s.

In the longer run, supply and demand equilibrium in a context of increasingly expensive resources will be the key driver setting the oil price.

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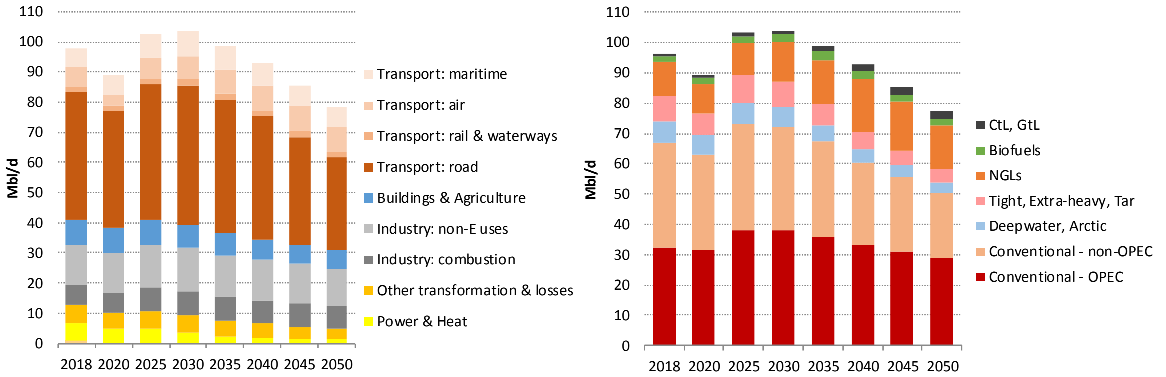
[133] IEA Oil report 2021: https://www.iea.org/reports/oil-2021

[134] Macroeconomic assumptions were derived from World Bank (2000-2019), IMF WEO (2020-2024), OECD long-term baseline projections (2027 and beyond) with an interpolation of GDP/capita for the 2024-2027 period, for non-EU countries; the 2021 Ageing Report was used for EU countries. Population was derived from JRC-IIASA 2018 for non-EU countries and Europop 2020 for EU countries.

Figure 112: World liquids demand by sector (left) and supply by type (right) in the REF2020 “Global Context” scenario

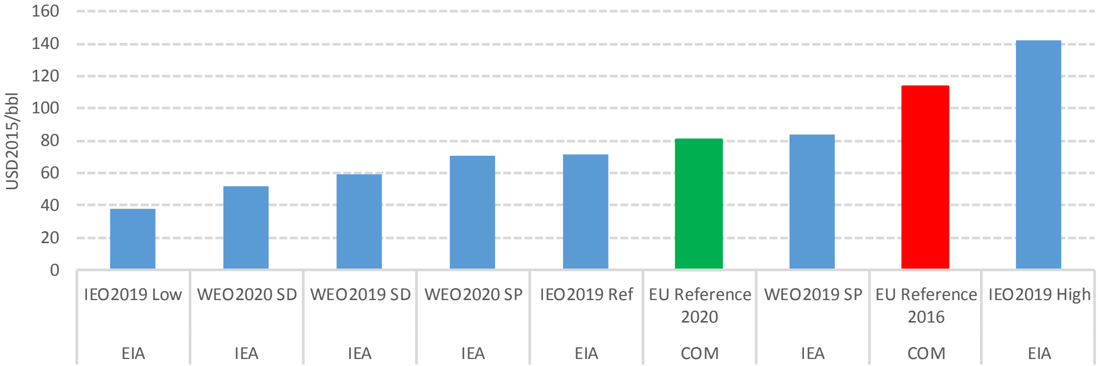


Source: 2018: BP Statistical Review, Enerdata, IEA, national statistics; projections: POLES-JRC model

After total consumption of liquids recovers to pre-pandemic levels by 2025, it is maintained until 2030, with a similar structure. Beyond 2030, an important shift occurs as the main driver for liquids demand, road transport, erodes at an average growth rate of -2.0% p.a., due to increasing efficiency standards in road vehicles and the emergence of electrification in certain key market segments. This is the main cause for the cut of more than 20 Mbl/d of crude oil supply between 2030 and 2050, 15 of which are due to road transport. Therefore, both industry uses (energy and non-energy) and international bunkers see their relative contributions in liquids demand rising. Alternative liquids supply (liquids from coal, gas and biomass) remain limited contributing 4% of total liquids demand globally in 2030 (up from 3% in 2019). Sales of electricity-powered vehicles (battery-electric, plug-in hybrids as well as hydrogen fuel cell vehicles) grow to make up one fifth of global annual sales in cars and light duty vehicles in 2030.

In parallel, the supply-side experiences important reductions in conventional oil supply from non-OPEC regions and non-conventional resources[135].

Figure 113: Comparison of oil price projections in 2030



Gas

Natural gas uses are dominated by different sectors than oil, namely power generation and heat production (including for industry and space heating); its economics and pricing principles depend essentially on the price of competitors (e.g. oil), or of the output it is used for (e.g. electricity). If the standard for gas import pricing has long been the oil-indexation of long-term contracts, the more recent emergence of gas hubs made prices more reactive, hence capable of reflecting current market conditions. Over the past few years, the global gas market growth was sustained by an increase in demand for power generation, driven by

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[135] Deepwater, arctic, tight, extra-heavy and tar sands.

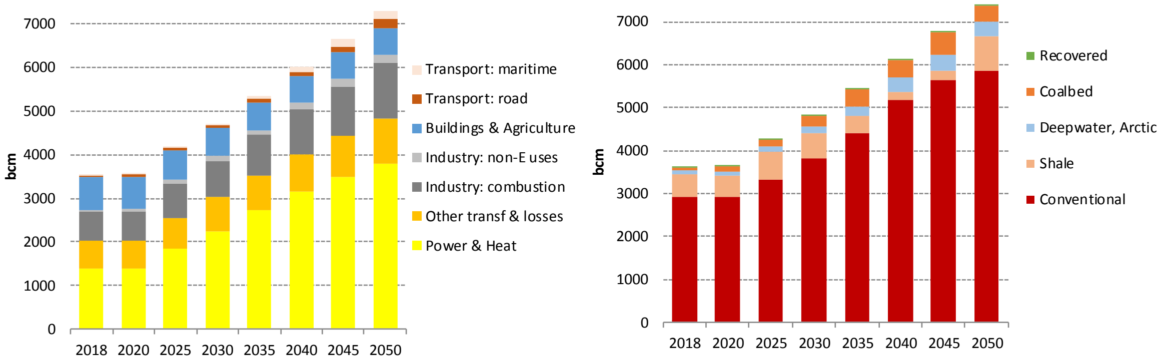
low gas prices, with the US providing an important part of the incremental supply. A dynamic LNG market took in most of the additional trade needs[136].

The COVID-19 pandemic affected the European gas market in different ways. At the most critical moment of the crisis, European gas demand fell by 10% (Q2 2020), compared to the same period in the previous year. Industry but also power generation, due to the abundance of renewables compared to electricity needs in the same period, were the most affected sectors. At the same time, prices dropped by more than 50% on a year-over-year basis.

The gas price projection of the EU Reference Scenario 2020 is in line with the recent fundamentals. By the mid-2020s, the average EU import price progressively recovers its historical level.

World natural gas production is projected to increase, with conventional gas still making up the bulk of supply. Alternative natural gas supply types, such as shale, deepwater and coalbed, are projected to contribute a limited share of global supply (21% combined in 2030, up from 19% in 2019). Natural gas supplied by LNG grows to 18% of the global market in 2030 (up from 10% in 2019).

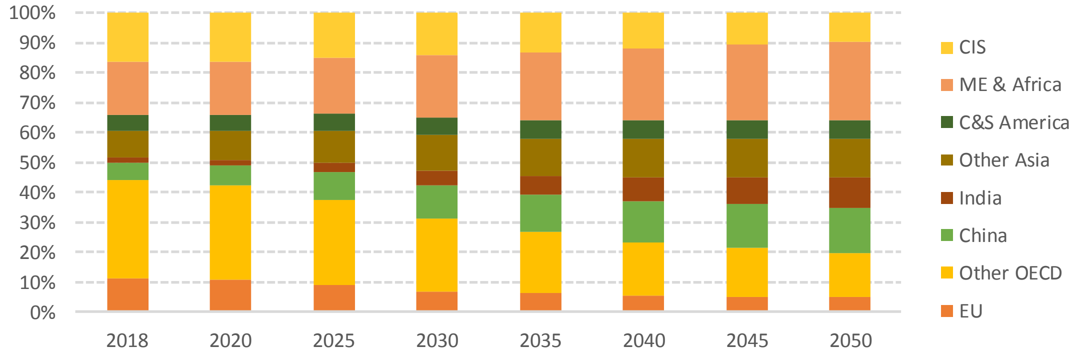
Figure 114: World natural gas demand by sector (left) and supply by type (right) in the REF2020 "Global Context" scenario



Source: 2018: BP Statistical Review, Enerdata, IEA, national statistics; projections: POLES-JRC model

The size of the EU gas market is small compared to the global market. In 2018, EU gas demand amounted to 12% of the global demand; it shrinks to less than 5% throughout the projection period. Other OECD regions would also represent a lower share of the market, which would be balanced by Asian countries, especially China and India.

Figure 115: Natural gas demand shares by region in the REF2020 "Global Context" scenario



Source: 2018: BP Statistical Review, Enerdata, IEA, national statistics; projections: POLES-JRC model

Coal

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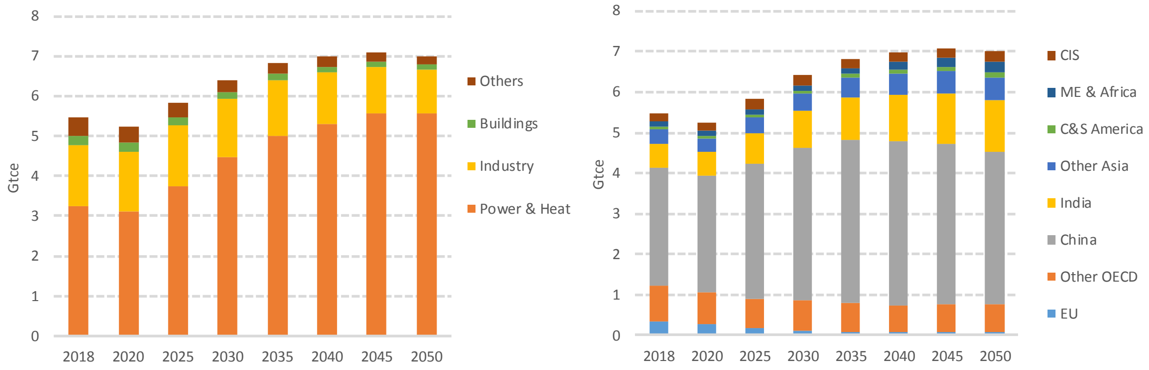
[136] IEA Gas report 2020: https://www.iea.org/reports/gas-2020

While coal demand had grown in 2017 and 2018, the market faced a shrinkage for 2 years in a row, due to a fierce competition with gas for power generation in 2019 and, in addition, due to the COVID-19 outbreak in 2020. As a result, international trade took a serious hit, with a reduction of global coal exports of 11% in 2020 compared to 2019, mostly from thermal coal. Supply adjusted consequently from the different basins, mainly from the US, Colombia, Indonesia and Australia. After an upsurge in 2016-2018, international coal prices withstood at 70-100 USD/t in 2019, compared to 100-300 at the end of 2016. EU import prices for thermal coal have followed a downward path since 2018, and fell below 60 USD/t FOB in the second half of 2020.

The main uncertainties surrounding the global coal market in the forthcoming years relate to the strategies of China and India – two countries whose economy heavily rely on coal, and their ability to secure access to cheap coal through national industrial and commercial plans[137].

At the sectoral level, global coal demand growth is sustained by coal use for power generation, increasing by 80% between 2020 (3.1 Gtce) and 2050 (5.6 Gtce) in the “Global Context” scenario of REF2020. Industrial demand, the second largest consuming sector, decreases by 28% from 1.5 to 1.1 Gtce, in the same period. Nearly all the growth in global coal demand is indeed driven by Asian economies, China and India in particular, while demand in the EU and OECD economies is projected to decrease. This results in slightly growing prices for internationally traded coal, with prices slowly recovering to their 2018 (high) level in the late 2030s.

Figure 116: World coal demand by sector (left) and region (right) in the REF2020 “Global Context” scenario



Source: 2018: Enerdata, IEA, national statistics; projections: POLES-JRC model

Price indexes

Overall, the price projections present a gradual evolution of current market dynamics. On an energy-equivalence basis, gas progressively gains an advantage compared to oil and progressively closes its competitiveness gap to coal. The gas/oil price ratio is stable around 0.50 from 2020 onwards. The gas/coal price ratio reaches a value of 2.3 in 2030, back to the 2010-2019 average, after a drop at 1.5 in 2018.

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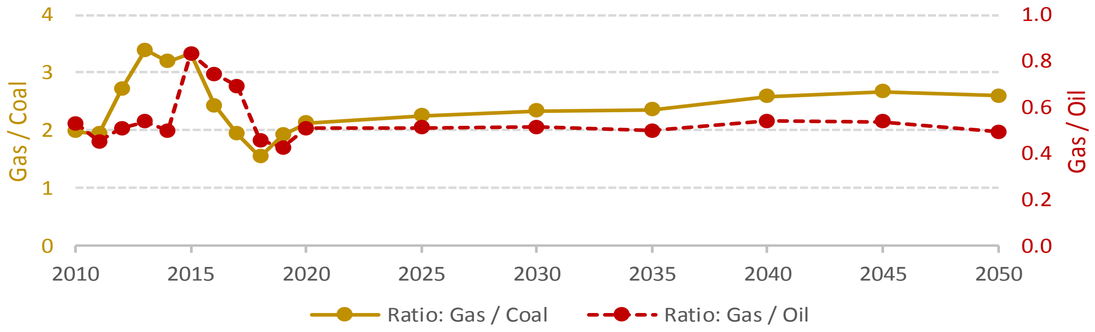
[137] IEA Coal report 2020: https://www.iea.org/reports/coal-2020

Figure 117: Price indexes for average EU import prices for gas/coal (left axis) and gas/oil (right axis)



Annex V: Note on discount rates used in PRIMES

Discount rates from a modelling approach

The PRIMES model explicitly considers the time dimension and performs dynamic projections. Actors are simulated to take decisions in which they consider the time dimension of money flows. Following microeconomic theory, they are also assumed to have preferences[138] about the time dimension of revenues and costs, in the sense that they have to discount an amount defined at future time to make it equivalent to an amount available at present time. For example, the costs of energy efficiency or a renewable energy generation investment incur in the first year, while monetary savings or revenues accumulate over the lifetime of the investment. To do cost-effectiveness comparisons, one has to aggregate the stream of money over time as a present value, which inevitably uses a discount rate.

The PRIMES model mimics decentralised decisions of the actors so that each actor can apply its individual discount factor, in contrast with other models which formulate central planning optimisation and assume that the central planner applies a uniform discount factor on behalf of all actors.

The central planning approach can be characterised as normative, whereas the descriptive approaches, as PRIMES follows, use market-based discount factors differing by agent.

PRIMES follows a descriptive approach because it aims at assessing policy impacts as close as possible to reality in order to avoid under- or over- estimation of the costs and difficulties of transformation towards meeting targets and transition objectives (i.e. transition towards a low carbon economy). As it is known, the transitions are capital intensive (e.g. energy efficiency investment, renewables and other clean energy technologies, electric vehicles, and infrastructure). The model simulates individual decision making as appropriate by type of investment. The decision reflects a private perspective, subject to uncertainties, risk taking behaviours and limited access to funding. Some of the investments (e.g. infrastructure, public transport) are taken by entities which are state-owned or subject to regulation by the state. Also for these cases, PRIMES uses discounted present values mimicking the practices followed by these entities.

Other models may have different aims, as for example to evaluate what should be the “optimum” system from a social perspective. To do this they use a social discount rate, which is much lower than private discount rates, for all present value calculations. Obviously a social discount rate renders capital intensive decisions more attractive than a calculation using private discount rates. Therefore, the approach based on social discount rates finds transitions less costly and easier than approaches using private discount rates. Even in a no policy scenario the social discount rate approach would project a lot of energy efficiency and renewable energy investments that a private discount rate approach would find uneconomic without incentives. The social discount rate approach suggests that if the investments were undertaken they would entail negative costs for the society. If not undertaken in reality, then the only explanation would point to barriers and imperfections which influence the assessment of the decision-maker. Generally, the social discount rate approach tends to underestimate the intensity of policies which may enable the transition. For the same reasons, this approach can be misleading for policy making aiming at promoting clean technology diffusion.

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[138] In economics, time preference is the relative valuation placed on a good at an earlier date compared with its valuation at a later date. In mathematical terms, the decision maker uses a discount factor, say d (a rate measured as a percentage), so as to be indifferent when to choose between a present amount F and a future amount $F \cdot (1+d)^{-t}$ available with certainty time t. The time preference has nothing to do with inflation and is subjective. In addition to pure time preference, a discount factor also reflects risk and opportunity costs. Future earnings are obviously more risky compared to those available at present with certainty. The amounts that are presently equivalent to uncertain future earnings depend on risk aversion or risk prone behaviour, which is also subjective.

The approach followed by PRIMES (and other models, e.g. NEMS in the US DOE/EIA) using private discount rates postulates that fundamentally private discount rates differ from social ones, and only the former can realistically mimic individual decision making. The discount rates reflect opportunity costs of funding capital intensive investment and these costs differ fundamentally between private entities/persons and the state. Access to capital, risk behaviours, finite horizon for individuals versus overlapping generation prospect for the state and others are among the causes of this difference. In addition, risk premium factors expressing barriers, imperfections and other failures are part of the private discount rates and push them upwards.

State-owned entities also include risk premiums in real-world. Hence a model such as PRIMES uses higher discount rates than social ones also for these entities.

Modelling behaviours should not be confused with cost-benefit assessments of public policy. For example, consider a cost-benefit analysis of a policy which uses public money to subsidise energy efficiency investments of individuals. If the policy maker wants to assess whether it is worth funding energy efficiency compared to other destinations of subsidies, the cost-benefit analyses correctly has to use a social discount rate. This is because public funds are at stake and the beneficiary is the society as a whole. The same logic applies to cost-benefit analysis[139] of a public infrastructure investment, a regional development plan, etc.

But if the policy maker wants to assess whether the amount of subsidies is sufficient to incite the targeted amount of energy savings, then the analysis has to use private discount rates to estimate the individual behaviours in the undertaking of energy efficiency investment. Using a social discount rate for this purpose would obviously be misleading.

The same holds for assessing costs of regulatory policies via scenario analysis. The investment decision and cost figures of each scenario projection must be generated using simulation of individual behaviours, which as explained has to use private discount rates. Assessing transition scenarios which have different distributions over time of investments and benefits requires in addition calculating present values, in which it is appropriate to use a social discount rate for discounting costs and benefits occurring in the future.

The approach of PRIMES never leads to negative costs of clean energy investments just because the private discount rates account for the imperfections. Hence, to enable transitions which do not happen in a business-as-usual scenario, policies have to apply to offset the effect of the imperfections or to remove the imperfections, when possible, as a minimum step towards enabling transitions.

Capital-budgeting decisions are simulated by the PRIMES model in all sectors, both in demand and supply of energy. The simulation mimics the appraisal undertaken by a decision-maker of whether purchasing of equipment or investing in energy savings or infrastructure is worth the funding.

The decision involves comparison among alternative options, e.g. technologies, which have different proportions of upfront costs and variable operating expenditures (including fuel costs). As the cost structure, in terms of CAPEX and OPEX, differ across the various options, the decision maker has to do arbitration over time. Therefore, the decision maker’s time preferences (their discount factor) influences their choices. The time preference is inherently subjective and the decision maker appraises whether the upfront spending is worth the funding, compared to other options of using the funds, while taking into account uncertainty surrounding the investment options and the scarcity of funding.

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[139] Sartori, Davide; Catalano, Gelsomina; Genco, Mario; Pancotti, Chiara; Sirtori, Emanuela; Vignetti, Silvia; Del Bo, Chiara (2015). “Guide to Cost-Benefit Analysis of Investment Projects. Economic appraisal tool for Cohesion Policy 2014-2020.” European Commission (EC), DG REGIO. Luxembourg Publication Office.

Therefore the value of the discount factor is influenced by many factors, such as the interest rates prevailing in capital markets, the degree of access to such markets for fund raising, and mostly by the value that the actor associates to own funding resources, such as equity capital or savings of individuals.

Therefore private discount factors can be defined as reflecting opportunity costs of raising funds by the actor on a private basis. Obviously, the opportunity costs of raising funds differ by sector and by type of actor, being very different by income class. They also vary with the degree of risk associated to the decision options. In contrast, social discount rates[140] are defined as opportunity costs of raising funds by the state or the society; in this sense social discount rates are defined following a different perspective than private ones.

In addition, the value of discount factors may be influenced by policies when for example actors use high discount rates due to market distortions and non-market barriers. Many examples of policies influencing discount rates can be conceived in sectors such as energy efficiency, renewables and even nuclear or CCS investment.

The state may apply support schemes to mitigate risks and reduce the individual discount rates, such as feed-in-tariffs (FIT), contracts for differences (CfD), power purchase agreements (PPA), sovereign guarantees on investment, reduced taxation, subsidies on interest rates, and generally innovative financing mechanisms. Policies may also transfer risk hedging from individuals to institutions, the latter being able to manage risk collectively and thus more efficiently; examples are the energy service companies (ESCO), the policies obliging utilities to save energy at the premises of their customers, the loans by development banks, etc. All these policies are modelled in PRIMES as reductions of individual discount factors.

Summary of the modelling of capital budgeting decisions in PRIMES

An investment choice always involve upfront costs and variable-operating expenditures or revenues which take place over time (e.g. annually). The decision is based on a comparison of different investment options.

The PRIMES model uses different capital budgeting methods in the various sub-models. Examples are presented below.

In the standard version of the power sector model, the choice of power capacity expansion investment options is based on comparison of equivalent annuity costs (EAC). This is included in an inter-temporal minimization of costs which guide investment choices within stylised generator portfolios. In the model version which represents market imperfections version (not used in the Reference scenario context), expected Net Present Value of investment (NPV), which include risk aversion factors, is calculated for each capacity expansion option so as either to invest by selecting among the options or to decide not to invest at all.

In the sub-model which calculates investment based on feed-in tariffs or on contracts for differences (CfDs) the model uses a method based on Internal Rate of Return (IRR) calculation by type of investment project from which it derives the probability of investment implementation. Instead of assuming a single threshold value for acceptable IRR, the model uses a frequency distribution of threshold values depending on the IRRs in order to capture heterogeneity of actors and different investment circumstances.

In the sub-models which calculate tariffs for using infrastructure subject to regulation as a natural monopoly (power grids, gas network, recharging infrastructure for vehicles, etc.), PRIMES follows the NPV method and uses the regulated rate of return as discount factor.

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[140] If social discount rates are used in simulations of private investment decisions, the modeller implicitly assumes that the economy has no funding scarcity and perfect capital markets allow unlimited liquidity.

In the sub-models which include investment options for energy savings (e.g. insulation of buildings, control systems in industry, etc.) PRIMES calculates equivalent annuity costs of the energy saving investment and compares annual capital costs to economised annual expenditures due to lower energy consumption. The model calculates a payback period which is considered in relation to a frequency distribution of threshold values reflecting heterogeneity of consumers and installations.

In the demand sub-models which include technology choice by type of equipment or vehicle, the formulations calculate equivalent annuity costs for each option and also formulate a frequency distribution of technology choices based on relative EACs so as to reflect heterogeneity of consumers.

Methodology for defining values of discount rates

The model follows different approaches by sector:

A. **Decisions by firms generally follow the approach of the weighted average cost of capital (WACC) to define discount rates.**

The WACC expresses the unit cost of capital for a firm depending on the source of funding, with each type of source using a different interest/discount rate. The main distinction is between equity capital (E) and borrowed capital (D). The former is valued at a subjective discount rate r_e and the latter at a market-based lending rate r_d. A simple WACC formula is as follows:

$$WACC = \frac{E}{E+D} r_e + \frac{D}{E+D} r_d$$

To determine the discount rate on equity the model follows the methodology of the capital asset pricing method (CAPM) which is:

$$R_e = R_f + \beta \cdot (R_m - R_f) \Leftrightarrow \beta = \frac{R_e - R_f}{R_m - R_f}$$

In the above formula, R_f is the risk-free interest rate, R_m is the benchmark or specific market rate of return on capital (expressing the usual practice of the sector) and β is a subjective ratio expressing risk premium of equity relative to risk free options over the usual risk premium of the sector expressed by the difference of the market specific rate and the risk-free rate. Obviously $\beta > 1$ indicates a risk averse behaviour which implies high WACC values compared to risk prone behaviours using $\beta < 1$. Technology- or project-specific risk premium values can also be reflected by using a value of β higher than one.

An alternative formulation for estimating the unit capital cost of equity (COE) is to decompose R_e as follows:

$$COE = R_e = R_f + ERP + SP + IRP + CSRP$$

In the above R_f is the risk-free rate, ERP the equity risk premium, SP the size risk premium, IRP the industry risk premium and CSRP the company-specific risk premium.

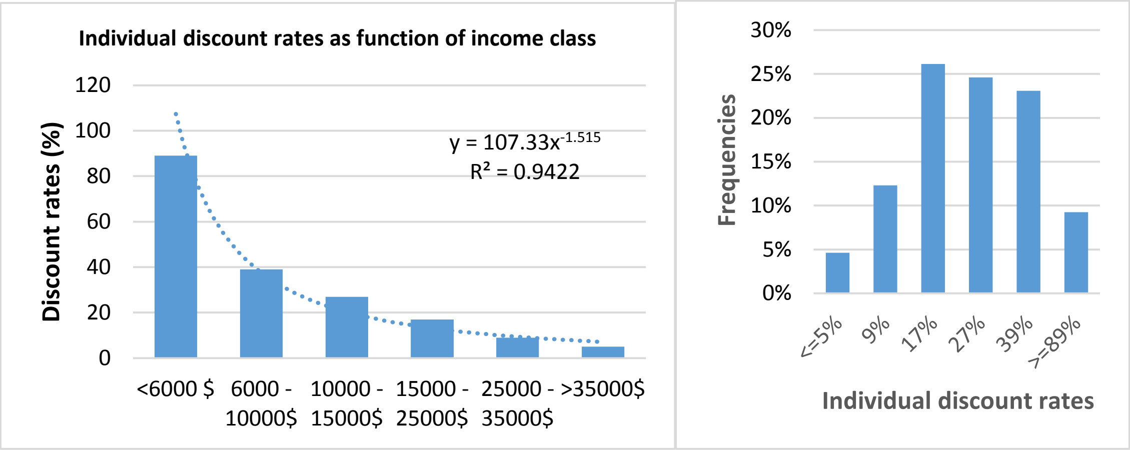
Surveys of equity costs for various firms indicate that the values used in practice differ by country and over time reflecting country-specific and risks specific to economic context. The equity costs depend on the sectorial and general economic context rather than on the conditions of drawing funds from the banking system. The lending conditions influence the capitalization ratio. The surveys of WACC (cost of capital) over firms generally confirm that capital intensive sectors generally use lower capital cost rates than labour-intensive sectors. The capital cost rates are higher in small scale businesses compared to large scale ones and they are higher in technologically emerging sectors or applications. The capital cost rates are lower for firms holding dominant positions in markets or when they are state-owned or supported by the state (e.g. utilities, public transport), compared to firms operating in market competition conditions. Based on these considerations, the PRIMES model applies different WACC rates by business sector, by type of technology (mature versus emerging), by scale level (e.g. industrial or decentralised versus utility scale) and for regulated companies. In the PRIMES model, the cost of capital rates apply for energy-related investment in the industrial and services sectors. Therefore, additional considerations specific to energy consumption are necessary to determine cost of capital rates for these sectors in the PRIMES model. For other sectors represented in PRIMES, such as energy supply, power generation, grids, transport sectors, the cost of capital rates refer to the entire investment of the sector.

B. Decisions by individuals using a subjective discount rate to annualize investment (upfront) costs following the equivalent annuity cost method.

Literature collected as part of PRIMES modelling research has shown numerous statistical surveys which estimate the subjective discount rate that individuals implicitly use when making a choice between equipment varieties having different upfront costs and different variable operating costs.

A pioneering research[141], back in the '70s, has used a large sample of data based on surveys of purchasing of air-conditioning systems by individuals; the sample included a variety of air conditioning types with different purchasing costs and different energy efficiency rates. Using the sample, the author econometrically estimated the median value of the discount rate that implicitly individuals use to make their choices. He founds a median value between 24 and 26% for the discount rate and points out to the fact that this value substantially exceeds values used in engineering calculations to determine the so called life-cycle costs for evaluating the trade-off between energy efficiency and higher initial capital costs.

Figure 118: Illustration of dependence of individual discount rates on income



The low rates used in engineering calculations suffer from two shortcomings: from a positive standpoint they are too low to forecast accurately consumer behaviour and thus can be misleading for policy making purposes, while from a normative standpoint they are too low to suggest how individuals should make their choice of equipment. The lower bound of the individual discount rate (within the confidence interval based on the sample population) was found equal to 15%, which is also much higher than values used in engineering calculations. The author compares the estimated values to the interest rate of 18% applied on credit cards at that time and finds logical that individuals value cash scarcity (opportunity costs of raising funding from a private perspective) at a rate above the rate prevailing in the credit market.

From a public policy perspective, one may see the difference between the individual and the social discount rates as a non-price market barrier, a sort of market imperfection. Therefore,

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[141] Jerry A. Hausman, "Individual discount rates and the purchase and utilization of energy-using durables", The Bell Journal of Economics (Vol. 10, No 1, spring issue), 1979.

in circumstances with strong barriers, policies based on efficiency standards and labelling are better placed to incite energy-efficient choice of appliances than pure price-based policies, precisely because of offsetting factors causing high individual discount rates.

The results of econometric estimations published in the literature suggest that the implicit discount rate is inversely strongly correlated with income and can be as low as 3.6% (i.e. close to market interest rates) for high income classes. But it can well be a two digit number (i.e. much above market interest rates) for low and medium-to-low income classes.

Economic theory suggests that discount rates should decrease as income rises, even with perfect capital markets, since the marginal income tax rate rises with income and the gains from using efficient appliances are untaxed.

A histogram of individual discount rates depending on income level is shown in Figure 118. The median value of the discount rates is 24% and the income elasticity is -1.5, which indicate a remarkably high increase of the discount rate for low income percentiles.

The differentiation of discount rates has been confirmed by numerous studies and publications surveying purchasing behaviours for a large variety of equipment types. To illustrate these findings, many authors proposed terms such as “energy efficiency gap” or “energy efficiency paradox” to describe the implications of using high individual discount rates rather than engineering-oriented or social ones.

Kenneth Train[142], as well as Sanstad, Blumstein and Stoft[143] summarised the findings of many surveys of the ‘80s and ‘90s of consumer behaviour for a large number of equipment. All surveys confirmed the strong inverse correlation of individual discount rates and income. The estimations confirmed the large variation of individual discount rates mainly as inverse function of income per household:

- 14% - 56% for heating equipment
- 5%-90% for cooling equipment
- 5%-30% for automobiles
- 4%-88% for insulation of houses
- 15%-45% for double glazing and other similar measures in buildings
- 15%-62% for cooking and water heating equipment
- 4%-51% for boilers (difference with heating equipment, see first bullet)
- 35%-100% for refrigerators and
- 20%-40% for small black appliances.

A statistical estimation[144] for the implicit discount rates used in vehicle choices, specifically for energy savings, shows a median value, estimated for a US sample, of 21% (with standard deviation 6.5 percentage points). The median value differentiates by income class, the maximum difference being 4 percentage points. There is significant uncertainty regarding the discount factor for car choices. The same author proposes discount factors between 16% and 18% for car choices when using a different econometric estimation methodology.

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[142] Kenneth Train, “Discount rates in consumers’ energy-related decisions: a review of the literature”, Energy, Vol. 10, No 12, pp. 1243-1253, 1985

[143] Sanstad, Blumstein and Stoft, “How high are option values in energy-efficiency investment?” Energy Policy, Vol. 23, Mo 9, pp. 739-743, 1995

[144] Daziano Ricardo (2015) “Inference on mode preferences, vehicle purchases, and the energy paradox using a Bayesian structural choice model”, Transportation Research Part B Methodological. June, Vol. 76, pp. 1-26

Various surveys[145] also revealed that beside income, which is the main explanatory factor of variance of discount rates, the range is also influenced by the age of the persons and the ownership of the property.

A similar approach is based on the concept of hurdle rates which express the minimum rate of return on a project or investment required by the decision maker to compensate for risk associated to future gains. Several econometric studies based on surveys provided evidence that hurdle rates effectively used by individuals and small firms to make investment decisions on energy efficiency are set at levels much above interest rates considered by large firms for equity capital in the context of capital asset pricing methods.

A survey carried out by Ameli and Brandt (2014)[146] for the OECD followed by a literature survey[147] confirms that “behavioural” discount rates explain the underinvestment in clean energy technologies and that the probability of investing in an energy efficiency project significantly decreases for low income classes (estimated from a large sample[146]). This finding supports the idea that one of the main factors explaining the high behavioural discount factors is the perception of opportunity costs of raising funding, which obviously differ by income class.

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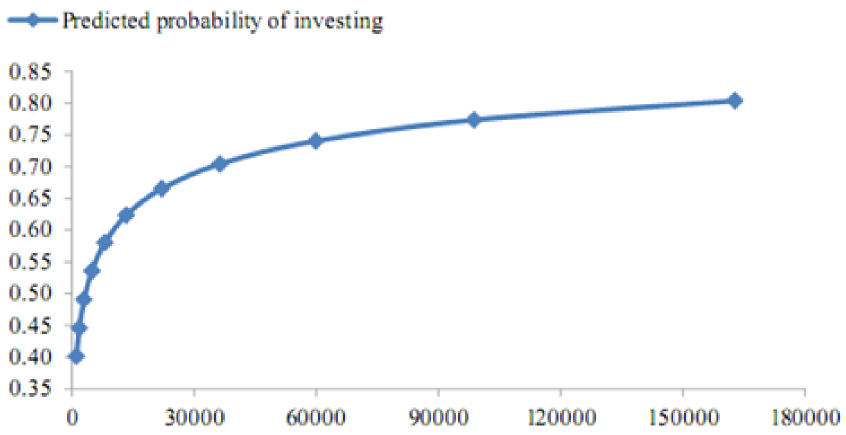
[145] The following references include data from surveys and econometric estimations of individual discount rates:

- Dale, Larry and K. Sydny Fujita (2008) “An Analysis of the Price Elasticity of Demand for Household Appliances”, Energy Analysis Department, Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory, University of California ,Berkeley, CA 94720, February 2008.
- Dubin, Jeffrey A. (1992) “Market Barriers to Conservation: Are Implicit Discount Rates Too High?”, No 802, Working Papers from California Institute of Technology, Division of the Humanities and Social Science.
- Ekins Paul, Fabian Kesicki and Andrew Z.P. Smith (2011). “Marginal Abatement Cost Curves: A call for caution”. A report from the UCL energy Institute to Greenpeace, UK
- Gately, Dermot (1980) “Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables: Comment” The Bell Journal of Economics 11(1), spring: 499-523
- Harrison, Glenn W., Morten I. Lau, Melonie B. Williams (2002) “Estimating Individual Discount Rates in Denmark: A Field Experiment”, The American Economic Review, Vol. 92, No. 5 (Dec., 2002), pp. 1606-1617.
- Hausman, J.A. and Joskow, P.L. (1982) “Evaluating the costs and benefits of appliance efficiency standards”, American Economic Review 72: 220-225.
- Hausman, Jerry A. (1979) “Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables”, The Bell Journal of Economics, Vol. 10, No. 1 (Spring, 1979), pp. 33-54.
- Houston Douglas A. (1983),”Implicit discount rates and the purchase of untried, energy-saving durable goods”, Journal of Consumer Research, Vol. 10, September 1983.
- Hughes, P. J., and J. A. Shonder (1998) “The Evaluation of a 4000-Home Geothermal Heat Pump Retrofit at Fort Polk”, Louisiana: Final Report. Oak Ridge, TN: Oak Ridge National Laboratory. ORNL/CON-460. March.
- Khawaja, Muhannad, Thomas Potiowsky, and H. Gil Peach (1990) “Cost-Effectiveness of Conservation Programs: The Hood River Experiment”, Contemporary Policy Issues, Vol. VIII, July 1990.
- Meier, Alan, and J. Whittier (1983) “Consumer Discount rates Implied by Purchases of Energy-Efficient Refrigerators” Energy. Vol. 8, no. 12, pp. 957-962.
- Pollitt, Hector; Barker, Anthony; Barton, Jennifer; Pirgmaier, Elke; Polzin, Christine; Lutter, Stephan et al. (2010): “A Scoping Study on the Macroeconomic View of Sustainability”. Final report for the European Commission, DG Environment. Edited by Sustainable Europe Research Institute (SERI), Cambridge Econometrics (CE). Cambridge.
- Train, Kenneth (1985) "Discount Rates in Consumers' Energy-Related Decisions: A Review of the Literature", Energy. vol. 10, no. 12. pp. 1243-12.

[146] Ameli, Nadia; Brandt, Nicola (2014) “Determinants of Households’ Investment in Energy Efficiency and Renewable: Evidence from the OECD Survey on Household Environmental Behavior and Attitudes”, OECD, Working Paper 1165

[147] Ameli, Nadia; Brandt, Nicola (2015) “What Impedes Households’ Investment in Energy Efficiency and Renewable Energy?”, OECD, Working Paper 1222

Figure 119: Probability of investing in energy efficiency as a function of income (x axis) - illustration



This is further confirmed by a more general purpose statistical analysis (Harrison et al., 2002)[148], which finds a strong negative correlation of individual discount rates and personal income. The income dimension is found to provide the highest correlation with discount rates than any other explanatory factor, such gender, age, education, etc. Another statistical survey (Newell, 2015)[149] also finds strong inverse correlation of individual discount rates and income.

An extensive literature surveyed (Mundaca et al., 2010)[150] shows that households use high implicit discount rates (50 or even 200%) also because of imperfections, such as lack of information, uncertainties lack of sufficient funding, agency costs, transaction and hidden costs. The literature (Ameli et al., 2015)[147] proposes to associate the imperfections or barriers with specificities of energy-efficient investments. Longer payback periods and greater risks and uncertainties imply higher subjective discount rates. According to the reviewed literature, the typology of possible causes can be summarised as follows:

- lack of information about cost and benefits of efficiency improvements
- lack of knowledge about how to use available information
- uncertainties about the technical performance of investments
- lack of sufficient capital to purchase more expensive but efficient products (or capital market imperfections)
- income level and consequently savings resources; high transaction costs for obtaining reliable information
- hidden costs, for example related to comfort, side payments and possibly temporary relocation,
- risk averse attitudes associated with possible financial failure of the investment
- ownership status versus user status.

This justifies the practice of several economic models, including PRIMES, which mimic the effects of policy instruments, mainly campaigns and labelling programs, by using lowered discount rates when these policies are implemented.

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[148] Harrison, Glenn W., Morten I. Lau, Melonie B. Williams (2002) “Estimating Individual Discount Rates in Denmark: A Field Experiment”, The American Economic Review, Vol. 92, No. 5 (Dec., 2002), pp. 1606-1617

[149] Newell, Richard G. and Juha Siikamaki (2015). “Individual Time Preferences and Energy Efficiency”. NBER Working Paper No 20969

[150] Mundaca Luis, Lena Neiz, Ernst Worell and Michael McNeil (2010) “Evaluating energy efficiency policies with energy-economy models”, Ernest Orlando Lawrence Berkeley National Laboratory

Modern behavioural economics propose models which deviate from classical microeconomics (e.g. bounded rationality model[151], loss aversion model[152]) which are asserted to explain the persistence of high hurdle rates (equivalently discount rates) in choices for energy-efficiency investments, with initial investments being given asymmetrically greater weight than future savings.

But, despite the different explanatory approaches there is no doubt in the literature about the persistence of high hurdle and discount rates at levels much above engineering and social rates. Until today, there has been no statistical survey finding low hurdle or discount rates for individuals making selection of energy efficient investment or equipment.

It is useful to clarify that several surveys of public policies funding energy efficiency find that in practice regulators and authorities use much lower discount rates, than the subjective ones[153,154,155]. The difference is that in these cases the discount rates are used to calculate whether or not is it worth to allocate public money as a support to an energy efficiency project (example house refurbishment). This is reasonable from a public perspective, because as appropriate discount rates close to social rates must be used for spending public money, to reflect opportunity costs of drawing funds by the public. This is a different aim than in the modelling which has the objective of simulating individual behaviours, in order to identify the size of incentives (such as prices or taxes) for increasing energy efficiency. To perform this simulation accurately, the model has to reflect the opportunity costs of drawing funds from a private perspective, which implies using subjective discount rates higher than social ones. This is also the conclusion of Harrison (2010)[156] which on behalf of the Australian government suggests a method for cost benefit analyses.

All these arguments advocate in favour of maintaining high values of discount and hurdle rates for individuals in the PRIMES modelling. The use of low discount rates, based on lending rates or social discount rates, has been criticized in the surveyed literature, which points out that transaction and hidden costs exist in reality, as for example for retrofit investments being illiquid and risky in most cases. An ECOFYS survey report[157] mentions that “The default subjective discount rates used in PRIMES for mimicking decision behaviour lie within the huge range of what literature provides”.

A quite similar approach is followed by the NEMS model in the US DOE/EIA as recommended by Sanstad and McMahon (2008)[158]. The approach of NEMS is also evaluated by Mundaca and Neij (2010)[159] confirming the relevance of using high implicit discount rates for modelling households’ decisions.

C. Discount factors used to evaluate tariffs of using infrastructure regulated as a natural monopoly.

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[151] Bounded rationality is the idea in decision-making, rationality of individuals is limited by the information they have, the cognitive limitations of their minds and the finite time they have to make a decision. According to this theory, the decision maker is a satisfier, seeking a satisfactory solution rather than the optimal one. Nested decision making models, in which the first level nests refer to seemingly non-economic choices (e.g. colour, convenience, and modernity) imply biased selection of lower level nests, which involve economic considerations and thus the selection can deviate from economic optimality.

[152] In economics and decision theory, loss aversion refers to people's tendency to strongly prefer avoiding losses to acquiring gains. Most studies suggest that losses are twice as powerful, psychologically, as gains. This point of view can be represented also by classical microeconomic theory by assuming strong risk aversion.

[153] Geller, Howard; Attali, Sophie (2005). “The Experience with Energy Efficiency Policies and Programs in IEA Countries. Learning from the Critics.” IEA Information Paper. IEA.

[154] Lazar, Jim; Colburn, Ken (2013) “Recognizing the Full Value of Energy Efficiency”. Regulatory Assistance Project Publications

[155] Woolf, T., Steinhurst, W., Malone, E., and Takahashi, K. (2012). “Energy Efficiency Cost-Effectiveness Screening”. The Regulatory Assistance Project publications.

[156] Harrison Mark (2010), “Valuing the Future: the social discount rate in cost-benefit analysis”, Commonwealth of Australia, The Productivity Commission, ISBN 978-1-74037-313-5

[157] Hermelink Andreas and David de Jager (2015) “Evaluating our future: the crucial role of discount rates in European Commission energy system modelling”, ECOFYS, final report for Project no BUIDE16021 commissioned by ECEEE.

[158] “Aspects of Consumers’ and Firms’ Energy Decision-Making: A Review and Recommendations for the National Energy Modelling System (NEMS)”, Lawrence Berkeley National Laboratory, April, 2008

[159] Mundaca, L., & Neij, L. (2010). A Meta-Analysis of Bottom-Up Ex-Ante Energy Efficiency Policy Evaluation Studies. In International Energy Program Evaluation Conferences International Energy Program Evaluation.

The model[160] uses discount rates based on surveys of actually applied regulated rates of return by state and regulatory agencies in various countries and for different types of infrastructure. The surveys indicate that the regulated rates of return on assets of natural monopolies are set significantly above social discount rates and are based on the WACC method. The main difference from private practices is that the state agencies or regulators do not accept high risk premium factors on equity capital, in contrast to private practices. This is justified on the basis that the natural monopoly business has by definition lower risks compared to business subject to competition.

Values of discount rates used in the model

Discount rates for investment decisions in power generation

To determine discount rate values reflecting reality one has to start from a risk-free (or low risk) discount rate. According to business surveys, the common practice in industry is to take a value of 4%-5%.

Business surveys indicate that equity risk premium (which is added on top of risk free discount rate) is usually defined at 6-9% plus a country- or project-specific risk which can vary between -1% up to 6%. Assuming a capitalization structure consisting of 65% borrowed funds at 5.5% interest rate and 35% equity capital valued at 9% cost of equity rate (large, capital intensive business), the minimum level of WACC would be:

$$\begin{aligned}&WACC\\&= 65\% \cdot 5.5\%\ (debt)\\&+ 35\% \cdot (4\% + 2.5\% + 2.5\% + 2\%)\ (equity)\\&= 7.5\%\end{aligned}$$

Where 4% is the risk-free rate, 2.5% the equity risk premium, 2.5% the industry risk premium and 2% the company-specific risk premium.

The minimum WACC is used in the model as a proxy of the rate of return a regulator would agree to award to regulated natural monopoly infrastructures. This value corresponds to common practice of regulators in Europe and in the USA (it is verified that in practice regulated rates of return on capital vary between 7% and 8%). In the model it applies to infrastructure for calculating tariffs of service.

Large energy utilities operating in competitive markets would add 1-2 percentage points as a company-specific risk premium and small or medium size companies would add 1-3 percentage points as a size-related risk premium. Therefore, the WACC ranges between 8% and 12% for power sector generation and trade companies operating in competitive markets. Adding country- or project- specific risk premiums would make the WACC vary between 8 and at least 18%. Relevant surveys can be seen in AFP (2011)[161] and Fernandez et al. (2011)[162], among others.

The basic discount rate in competitive power, gas, coal and gas markets used in the model is 8.5% based on the WACC calculation shown below:

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[160] The tariffs of using infrastructure are calculated using the following formula:

$$P = \frac{RAB + \sum_{t=1}^{T} \frac{C_t}{(1+d \pm r)^t}}{\sum_{t=1}^{T} \frac{D_t}{(1+d \pm r)^t}}$$

RAB is the regulated asset basis (roughly the cumulative cost of investment), C_t are the annual operating variable and fixed costs, D_t denotes the expected future use of the infrastructure (measured as a volume indicator), T is the time horizon, d is the regulated discount rate expressing the allowed rate of return on capital and r expresses either a discount on return on capital (if it is deduced) targeted by the regulator or a bonus (when it is added) used as an incentive for technology or coverage improvement.

[161] AFP (2011), “Current Trends in Estimating and Applying the Cost of Capital”, Report of Survey Results, Association for Financial Professionals, www.AFPonline.org

[162] Fernandez Pablo, Javier Aguirreamalloa and Luis Corres (2011), “Market risk premium used in 56 countries in 2011 : A survey with 6,014 answers», IESE Business School, University of Navarra

$$
\begin{aligned}
&WACC \\
&= 65\% \cdot 5.5\%\ (debt) \\
&+ 35\% \cdot (4\% + 3.5\% + 3.5\% + 3\%)\ (equity) \\
&= 8.5\%
\end{aligned}
$$

Where 4% is the risk-free rate, 3.5% the equity risk premium, 3.5% the industry risk premium and 3% the company-specific risk premium. The cost of equity rate is assumed 14% for companies exposed to competition and 11% for companies protected as regulated monopolies.

Table 12: Discount rates in energy supply sectors

Assumptions for EU Reference Scenario 2020	Discount rates
Regulated monopolies and grids	7.5%
Companies in competitive energy supply markets	8.5%
RES investment under feed-in-tariff	7.5%
Investment under contract for differences	7.5%
RES investment under feed-in premium, RES obligation, quota systems with certificates	8.5%
RES investment in competitive markets	8.5%
Risk premium specific to immature or less accepted technologies	1%-3%
Risk premium specific to investment surrounded by high regulatory or political uncertainty	None
Country-specific risk premiums	None

Power purchase agreements (PPA) has been applied since many years as a way of supporting generation investment. Other forms of PPA are the feed-in-tariff systems applied to support investment in renewables and the Contracts for Differences which can be concluded between private entities or with the state. The feature of these support schemes guaranteeing stream of revenues for the investor implies lowering risk premium factors. They also ease collecting funding and thus borrowing interest rates are also lower than without revenue guarantee. Therefore power projects supported by feed-in tariffs or CfD are considered in the model less risky than investment in competitive markets and the starting level of the WACC is 7.5%.

A WACC applied to an investment project where upfront investment expenditures is recovered by a stream of annual revenues (as in the case of RES support schemes) can be also seen as the hurdle rate, i.e. the minimum IRR rendering investment financially feasible. The hurdle rate reflects the perspective of the investor and obviously includes risk premium factors as the WACC does.

Country-specific risk premium are considered in business practices to reflect regulatory uncertainty, revenue risks or monetary uncertainties, which are specific by country. It is reported that for countries experiencing deficits in renewables accounts and having practiced retrospective changes in FIT contracts, the country risk premium can be 5-6% (as add-on) and so minimum IRR becomes in these cases close to 15%. By nature country-specific risks are short-term views of uncertainties and are less practised for long-term planning of investment.

Other renewable support schemes may involve higher uncertainty about future stream of revenues. Feed-in-premium schemes depend on price volatility in wholesale markets and therefore 1-3 percentage points of risk premium are added following common practice. Similarly, renewable policies applying RES obligations on load serving entities or the quota systems with certificates imply higher risk premium, than feed-in-tariffs, as investors' revenues will depend on procurement conditions depending on private entities (the load serving entities) or on volatile certificate prices. We consider adding 1-3 percentage points as risk premium.

Compared to an IRR of 7.5% assumed for RES investment covered by guaranteed stream revenues, the model assumes an IRR of 8.5% for RES investment supported by feed-in-premium, RES obligations or quota systems with certificates. Similarly, the model applies an IRR of 8.5% for RES investment without financial support.

Investments in power projects covered by contracts for differences (e.g. Hinckley nuclear project in the UK and investment in renewables also based on CfD) theoretically enjoy similar certainty as RES projects under feed-in tariffs. Auctioning to determine the level of feed-in-tariffs or of CfD do not alter the guarantee of revenues that enjoy feed-in-tariffs and CfD in which the price level is defined administratively.

Project-specific risk premium is a common practice for immature renewables and for projects subject to uncertain social acceptance (or surrounded by high political or regulatory uncertainty). The hurdle rate of investment in yet immature RES is increased by 1-3 percentage points above the rates used for mature RES. Of course, the addition applies as long the immaturity persists.

Although practiced in reality, the model does not assume additional risk premium for project surrounded by high regulatory or political uncertainty, such as nuclear or CCS.

The model does not apply country-specific risk premiums. This is justified on the basis that the aim of the modelling is to project long term market trends and thus it ignores short term financial instabilities that would suggest country risk premiums in the EU different from zero.

Table 12 summarises the discount rate values used in business in the energy supply sectors of PRIMES for the Reference Scenario.

Discount rates for energy-related investment decisions by non-energy firms

The WACC for industry and services is used only for energy-related investment in these sectors, and not for general productive investment, which is out of the scope of the PRIMES model.

For energy-related investment of energy-intensive industries the model applies the minimum level of WACC, equal to 7.5%.

The reason is that energy costs are a very significant component in energy intensive industries and therefore these industries pay attention to select the most cost-efficient investments. For this reason the model does not apply risk premium factors related to market competition.

For other industries, which are not energy-intensive, the model applies a WACC of 9%, which is equal to the rate assumed for all purpose investment in these sectors. The non-differentiation of WACC rates by type of investment in these sectors is justified by the fact that energy costs represent a small share in total costs.

In the services sector energy costs are also a small fraction of total costs and therefore a WACC for all purposes investment applies. Energy-related investment decisions compare advanced efficient solutions, which have high upfront costs, to conventional ones. The former however are usually less known to the decision maker, who applies a risk premium because they perceives uncertainty concerning technical performance. To capture this, the model uses a default value of WACC equal to 11% for energy-related investment.

Table 13: Discount rates of firms in energy demand sectors

Assumptions for EU Reference Scenario 2020	Discount rates
Energy intensive industries	7.5%
Non energy intensive industries	9%
Services sectors	11%
Public transport (conventional rail, public road)	7.5%
Public transport (advanced technologies, e.g., high speed rail)	8.5%
Business transport sectors (aviation, heavy goods vehicles, LCVs, maritime)	9.5%
Country risks	None

For the business activities of the transport sector, the model applies the minimum WACC rate of 7.5% to the cases of regulated business, such as public road transport and conventional rail, which is dominated at large extent by state-owned enterprises. For more advanced transport technologies in public transport, such as high speed rail, the models uses a higher value of WACC, namely 8.5%, to reflect risk premium of investment in such technologies. The WACC values are used to calculate ticket prices in the public transport sectors and for investment decisions in vehicles or rolling stock.

For the private business activities in transport, such as trucks, LCVs, aviation and maritime, the model uses a WACC value of 9.5% which is within the range uses for industrial and services sectors. These WACC values are used in investment decisions for new vehicles, aircrafts and vessels. For the choice of private cars and motorcycles, the model applies the discount rates of decisions by individuals, which are discusses in the next section.

Table 13 summarises the discount rate values used in business sectors of energy demand sectors of PRIMES for the Reference Scenario.

Discount rates for investment decisions by households

The choice of discount rate values employed for investment decisions by households is based on the literature reporting empirical statistical findings of surveys which calculate implicit discount rates used for energy efficient equipment choice and investment. When the implicit discount rates are specified by income class or other classification of consumers, a weighted average discount rate has been calculated.

Table 14: Definition of discount rates of individuals in energy demand sectors

Assumptions for EU Reference Scenario 2020	Discount rates	Modified discount rates due to EE policies[163]
Passenger cars and powered two wheelers	11%	
Households for renovation of houses and for heating equipment	14.75%	12%
Households for choice of appliances	13.5%	9.5%
By income class (for the decision on renovation and the choice of equipment)		
Low	14.1%	
Low-Mid	13.6%	
Mid	13.2%	
Mid-High	12.8%	

Based on the literature, the discount rate values differ by type of decision and type of equipment. For instance, surveys have found lower implicit discount rate values for choice of cars than for housing equipment. Surveys have also identified that for heating systems and for thermal integrity expenditures specifically for new-built houses (i.e. choices undertaken when building the house) the individual discount rates are much lower than in similar choices when renovating existing houses. The reason is that it is more uncertain to undertake refurbishment investment than incorporating efficient technologies in new houses taking also into account that the efficiency choices for new houses will last longer than for existing houses. For this reason the model applies lower discount rates (than the default values shown in the first column of) for new buildings concerning thermal integrity and heating systems.

It is assumed that the default discount rates values are influenced downwards by policies, which focus on barriers and imperfections considered among the causes explaining the

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[163] It is assumed that standard discount rate values are pushed downwards by policies addressing the barriers which caused the high discount rate values in the first place.

initially high discount rate values. Such policies are included in the Reference Scenario; examples are the energy labelling and certain measures included in Energy Efficiency Directive and the promotion of energy service companies. They increase awareness of individuals about the benefits of advanced efficient solutions. They also support involvement of large companies such as utilities or energy service companies to leveraging individual choices, thus helping individuals perceiving lower financial and technical risks in the undertaking of efficiency investment. Table 14 indicates in separate columns the discount rates used as default values and the discount rates used when representing the effects of policies targeting removal of barriers obstructing rational energy efficiency choices.

“Discount rate” for costs reporting

Once having ran the model for a scenario, which means after simulating behaviours and market clearing which are using the discount rates shown in the previous section, the PRIMES model calculates total energy system costs for reporting purposes. In other words, the modelling framework includes two distinct stages: a) a first stage models decision-making behaviour of agents, hence investment and technology choices; b) a second stage calculates total costs for the entire energy system in order to support comparisons across scenarios.

This section discusses how the calculations are defined in the second stage and what discount rates to use in this context. In an energy system there are demanders and suppliers of energy. For energy system analysis and in order to assess the cost impacts from a macroeconomic perspective, the crucial element is the amount that end use sectors (households and firms, in services and industry, transport and agriculture) are required to pay in order to get the energy services they need. Energy services are defined by how energy is used, for example, if the energy supports heating, cooling, entertainment, mobility and transportation, industrial production, i.e., uses that enable utility and activity for final energy consumers. Energy services are delivered by using energy commodities purchased by end-consumers, which depend on energy efficiency at the consumption level. The end-users undertake investment for purchasing equipment (e.g. boilers, vehicles, etc.), for insulating buildings and for installing energy saving systems.

The accounting of capital costs for end-users (CAPEX) is based on the part of investment expenditure for equipment purchasing that corresponds to energy purposes; for example, the additional cost of a highly efficient vehicle (on top of cost of a conventional vehicle) incurred for energy purposes. In addition, the final energy consumers incur annual variable and fixed costs which include the purchasing of energy commodities from energy supplying and trading sectors, the maintenance costs of equipment and other annual costs (e.g. assurance costs, vehicle taxes, etc.). These annual costs are operating expenditures (OPEX). Energy supply and trading sectors fully recover their total costs (CAPEX and OPEX) from revenues paid by end-consumers. Therefore the total energy system cost only includes the CAPEX and OPEX incurred by end-consumers, with their OPEX already incorporating the CAPEX and OPEX costs incurred by the supply and trading sectors.

The PRIMES model determines the prices of supply and trading sectors in a manner that fully recovers total supply costs using the WACC that represents the real unit cost of capital experienced by a firm operating in energy supply sectors. The PRIMES report aggregates CAPEX and OPEX of end-consumers to show a single total cost figure with annual periodicity. To do this, also the CAPEX figures related to investments by final energy demand consumers need to be annualised following the equivalent annuity cost method which involves use of a discount factor over the lifespan of the investment. The annualised equivalent cost expresses the cost incurred for the end-consumer for owning an asset until the end of its lifetime. As such it expresses the gradual accumulation of resources to be able to replace the asset as the present value of the annuity payments for capital is by definition equal to the investment (upfront) expenditure.

The choice of discount rate for the CAPEX cost reporting by final energy demand consumers should reflect the perspective of the private investor faced with real world investment constraints.

One approach could be to base the cost reporting of the CAPEX by final energy demand consumers on true payments for capital costs. This implies that the CAPEX has to be annualised using lending rates for the part of capital borrowed from banks and equity rates for the rest. It has the drawback that it does not reflect the fact that there are also opportunity costs associated with higher debt rates (i.e. risk averseness as well as reduced incentives to make other investments). In addition, detailed information would need to be collected to identify the borrowing rates faced by different end-users. Furthermore, equity rates are subjective and therefore assumptions must be made about their values. Finally, policies may enable reduction of equity discount rates and if this differs by scenario, comparability of costs is lost across scenarios. In conclusion, comparability across the scenarios is of key importance and implies that the discount rates used in the cost accounting must not vary between scenarios.

It is important also to keep in mind that borrowing costs have experienced important variations in the past. While they are currently historically low, their evolution over the time horizon of the Reference Scenario (up to 2050) is impossible to anticipate. In addition, comparison of system costs across projected periods would be very difficult if using a rate that would be evolving over time.

Considering the various elements listed above, the Reference scenario accounts the costs associated with CAPEX for all investments, including for final energy demand consumers, over the projected period (2020-2050), using a rate that is more in line with the WACC traditionally used for the supply and industry sector. Hence, as simplification and in a long time horizon perspective, a flat and constant over time discount rate of 10% is used for annualising CAPEX of end-consumers in the cost reporting of the Reference Scenario.

Glossary

Aviation: The EU Reference Scenario 2020 distinguishes aviation into intra-EU and extra-EU aviation. Intra-EU aviation covers flights within and between Member States and extra-EU covers flights between Member States and countries outside the EU.

Biofuels: Biofuels include bioethanol, biodiesel, biokerosene and bio-heavy.

Blast furnace: A tall, cylindrical smelting furnace for reducing iron ore to pig iron; the blast of air blown through solid fuel increases the combustion rate. In the new reporting of Eurostat energy balances, blast furnaces are included in the Energy Branch sector and not in the final energy demand of the Iron and Steel sector, implying that this consumption is no longer part of final energy demand.

Carbon capture and storage (CCS): Carbon capture and geological storage is a technique for trapping carbon dioxide emitted from large point sources, compressing it, and transporting it to a suitable storage site where it is injected into the ground.

Carbon intensity: The amount of CO_2 emitted per unit of energy consumed or produced (t of CO_2/tons of oil equivalent (toe) or MWh).

CO_2 Emissions to GDP: The amount of CO_2 emitted per unit of GDP (carbon intensity of GDP – tons of CO_2/million Euro).

Cogeneration thermal plant: A system using a common energy source to produce both electricity and steam for other uses, resulting in increased fuel efficiency (see also: CHP).

Combined Cycle Gas Turbine plant (CCGT): A technology which combines gas turbines and steam turbines, connected to one or more electrical generators at the same plant. The gas turbine (usually fuelled by natural gas or oil) produces mechanical power, which drives the generator, and heat in the form of hot exhaust gases. These gases are fed to a boiler, where steam is raised at pressure to drive a conventional steam turbine, which is also connected to an electrical generator. This has the effect of producing additional electricity from the same fuel com-pared to an open cycle turbine.

Combined Heat and Power (CHP): This means cogeneration of useful heat and power (electricity) in a single process. In contrast to conventional power plants that convert only a limited part of the primary energy into electricity with the remaining energy being discharged as waste heat, CHP makes use of a greater proportion of this energy for e.g., industrial processes, district heating, and space heating. CHP therefore improves energy efficiency (see also: cogeneration thermal plant).

Efficiency for thermal electricity production: A measure of the efficiency of fuel conversion into electricity and useful heat. It is calculated as heat and electricity output divided by the calorific value of input fuel.

Efficiency indicator in freight transport (activity related): Energy efficiency in freight transport is calculated based on the energy use per ton-km. Given some methodological inconsistencies between transport and energy statistics, in some cases absolute numbers (especially at the level of individual Member States) might be misleading. For that reason, the numbers given are only illustrative of the trends in certain cases.

Efficiency indicator in passenger transport (activity related): Energy efficiency in passenger transport is calculated based the energy used per passenger-km travelled. The inconsistencies between transport and energy statistics also apply to passenger transport (see also: Efficiency indicator in freight transport).

Effort Sharing Regulation (ESR): The Effort Sharing Regulation specifies that sectors of the economy not covered by the EU ETS (buildings, transport except aviation and international shipping, agriculture, non-ETS industry, agriculture except LULUCF, and waste) must reduce emissions by 30% by 2030 compared to 2005 and establishes binding annual greenhouse gas emission targets for each Member State for the period

2021–2030 based on the principles of fairness, cost-effectiveness and environmental integrity.

Electric arc furnace: An electric arc furnace is a furnace that heats charged material by means of an electric arc.

Energy branch consumption: Energy consumed in refineries, electricity, and steam generation and in other transformation processes.

Energy intensity: energy consumption/GDP or another indicator for economic activity.

Energy intensive industries: Iron and steel, non-ferrous metals, chemicals, non-metallic minerals, and paper and pulp industries.

Energy Service Company (ESCO): A company that implements a broad range of energy efficiency projects.

EU Emissions Trading System (EU ETS): The EU ETS works on a “cap and trade” principle and covers: *carbon dioxide (*CO_2*)* from electricity and heat generation, energy-intensive industrial sectors including oil refineries, steel works, and production of iron, aluminium, metals, cement, lime, glass, ceramics, pulp, paper, cardboard, acids and bulk organic chemicals, commercial aviation within the European Economic Area; *nitrous oxide (*N_2O*)* from production of nitric, adipic and glyoxylic acids and glyoxal; *perfluorocarbons (PFCs)* from production of aluminium.

Feed-in tariff: The price per unit (of electricity) that an eligible renewable electricity produced receives according to cost-based calculations for the specific resource used.

Feed-in-premium: A pre-established premium on the market price of energy given to an eligible renewable electricity producer. The payment of this premium is guaranteed for a certain time and is linked to the economic life of the relevant RES project.

Final energy demand: Energy consumed in transport (excluding international shipping and aviation), industrial, household, services, and agriculture sectors; the latter two sectors are sometimes aggregated and named "tertiary". It excludes deliveries to the energy transformation sector (e.g., power plants) and to the energy branch. It includes electricity consumption in the above-mentioned final demand sectors. In some cases, final energy consumption is also reported including international aviation. This is specifically mentioned in the report, where the case.

Freight transport activity: Covers goods transport by road, rail, inland waterways and national maritime, unless specified otherwise in the report. Road transport activity is defined according to the territoriality principle, in line with the available statistics from Eurostat.

Fuel cells: A fuel cell is an electrochemical energy conversion device that converts hydrogen and oxygen into electricity and heat with the help of catalysts. The fuel cell provides a direct current voltage that can be used to power various electrical devices including motors.

Fuel input to power generation: Fuel use in power plants and CHP plants.

Gas: Includes natural gas, blast furnace gas, coke-oven gas, and gasworks gas.

Generation capacity: The maximum rated output of a generator, prime mover, or other electric power production equipment under specific conditions designated by the manufacturer.

Geothermal plant: A plant in which the prime mover is a steam turbine, which is driven either by steam produced from naturally hot water or by natural steam that derives its energy from heat in rocks or fluids beneath the surface of the earth. The energy is extracted by drilling and/or pumping.

Greenhouse Gas (GHG): a group of gases contributing to global warming and climate change. The Kyoto Protocol, an environmental agreement adopted by many of the parties to the United Nations Framework Convention on Climate Change (UNFCCC) in 1997 to curb global warming, nowadays covers seven greenhouse gases: the non-fluorinated gases which include: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O); the fluorinated gases: hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3).

Gross Inland Consumption: Quantity of energy consumed within the borders of a country. It is calculated as primary production (plus) recovered products (plus) imports (plus)/(minus) stock changes (minus) exports (minus) bunkers (i.e., quantities supplied to international sea-shipping).

Gross Inland Consumption/GDP: Energy intensity indicator calculated as the ratio of total energy consumption to GDP (toe/million Euro).

Hydro power plant: A plant that produces energy from moving water. In this report, hydro excludes pumped storage plants that generate electricity during peak load periods by using water previously pumped into an elevated storage reservoir during off-peak periods when excess generating capacity is available. Energy losses in pumping are accounted for separately.

Indirect land use change (ILUC): Where land destined for food and feed markets is diverted to biofuel production, the need to produce food and feedstock will have to be satisfied either through the intensification of current production or by transforming non-agricultural to agricultural land elsewhere. The latter constitutes indirect land-use change and can lead to significant greenhouse gas emissions when the converted land is of high carbon stock.

International maritime: International maritime refers to the transport activity between EU Member States and between the EU and the rest of the world.

Import dependency: Demonstrates the extent to which a country relies on imports to meet its energy needs.

Land Use, Land Use Change and Forestry (LULUCF): The LULUCF sector covers GHG emissions into the atmosphere and removal of carbon from the atmosphere resulting from the use of soils, trees, plants, biomass, and timber.

New fuels: synthetic fuels/e-fuels such as e-methane and more complex hydrocarbons; hydrogen produced from increasingly carbon-free electricity; and the accompanying infrastructure, namely networks and refuelling stations for the distribution, storage, and conversion of the new fuels.

Non-fossil fuels: Nuclear and renewable energy sources.

Non-energy uses: The use of petrochemicals and other energy carriers for purposes other than energy production, such as chemical feedstocks, lubricants, and asphalt for road construction.

Nuclear power plant: A plant in which a nuclear fission chain reaction can be initiated, controlled, and sustained at a specific rate for production of energy.

Oil: Includes crude oil, feedstocks, refinery gas, liquefied petroleum gas, kerosene, gasoline, diesel oil, fuel oil, naphtha, and other petroleum products.

Peak devices: Gas turbines, internal combustion engines and other small-scale thermal power plants which are usually used to supply electricity in peak hours.

Passenger transport activity: Passenger transport activity, unless specified otherwise in the report, covers road transport (buses and coaches, passenger cars, powered 2-wheelers (excluding e-bikes and pedelecs), rail transport, intra-EU aviation, inland waterways and national maritime. Tram and metro activity is provided together with rail.

Primary production: Total indigenous production.

Renewable energy sources (RES): Energy resources which are naturally replenishing but flow limited. These are virtually inexhaustible but limited in the amount of energy that is available per unit of time. Renewable energy resources include biomass, waste energy, hydro, wind, geothermal, solar, wave and tidal energy.

Solar power plant: A plant producing energy with the use of radiant energy from the sun; includes solar thermal and photovoltaic (direct conversion of solar energy into electricity) plants.

Solids: Include both primary products (hard coal and lignite) and derived fuels (patent fuels, coke, tar, pitch and benzol).

Thermal power plants: Type of electricity-generating plant in which the source of energy for the prime mover is heat (nuclear power plants are excluded).

Wind power plant: Typically, a group of wind turbines supplying electricity directly to a consumer or interconnected to a common transmission or distribution system. Offshore wind includes wind turbines located at sea (coastal wind turbines are usually included in onshore wind).

Useful energy services: Useful energy services refer to the provision of the desirable amounts of energy to cover sufficiently the need for heating, cooling, and electricity.

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