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IMPACT ASSESSMENT

Accompanying the document

Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources (recast)

{COM(2016) 767 final}
{SWD(2016) 419 final}

Contents

ANNEX 4 - ANALYTICAL MODELS AND MODEL-BASED SCENARIOS USED IN PREPARING THE IMPACT ASSESSMENT

1. Description of analytical models used – PRIMES related suite of models

The model suite used for this impact assessment has a successful record of use in the Commission's energy and climate policy impact assessments – it is the same model suite as used for the 2020 climate and energy package as well as for the 2030 climate and energy policy framework. The models and their linkages are briefly described in the following subsections. Detailed model descriptions can be found on the DG CLIMA website[1]. Assumptions relevant for this impact assessment are described in section 2 on the EU Reference scenario and section 3 on policy scenarios.

The model suite covers:

- **The entire energy system** (energy demand, supply, prices and investments to the future) and all GHG emissions and removals:
- **Time horizon:** 1990 to 2050 (5-year time steps)
- **Geography:** individually all EU Member States, EU candidate countries and, where relevant Norway, Switzerland and Bosnia and Herzegovina
- **Impacts:** on energy, transport and industry (PRIMES and its satellite models on biomass and transport), agriculture (CAPRI), forestry and land use (GLOBIOM-G4M), atmospheric dispersion, health and ecosystems (acidification, eutrophication) (GAINS); macro-economy with multiple sectors, employment and social welfare (E3ME and GEM-E3).

The models are linked with each other in formally-defined ways to ensure consistency in the building of scenarios, as shown graphically in Figure 1. These inter-linkages are necessary to provide the core of the analysis, which are energy, transport and GHG emissions trends.

[1] http://ec.europa.eu/clima/policies/strategies/analysis/models/index_en.htm

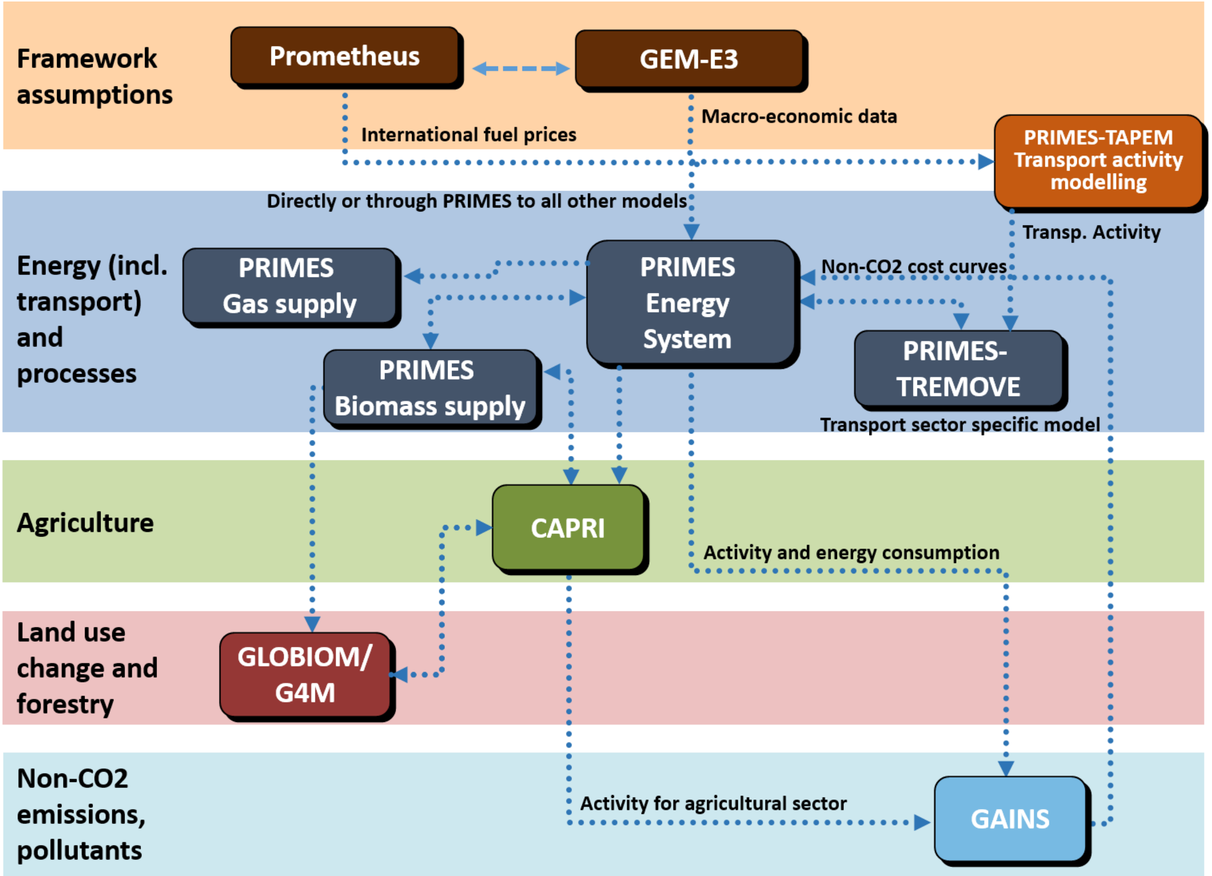

Figure 1: Inter-linkages between models
Source: EU Reference Scenario 2016 publication report

1.1. PRIMES

The PRIMES model is an EU energy system model which simulates energy consumption and the energy supply system. It is a partial equilibrium modelling system that simulates an energy market equilibrium in the European Union and each of its Member States. This includes consistent EU carbon price trajectories.

Decision making behaviour is forward looking and grounded in micro-economic theory. The model also represents in an explicit way energy demand, supply and emission abatement technologies, and includes technology vintages.

The core model is complemented by a set of sub-modules, of which the transport sector module and the biomass supply module are described below separately in more detail. Industrial non-energy related CO_2 emissions are covered by a sub-module so that total CO_2 emissions can be projected. The model proceeds in five year steps and is for the years 2000 to 2010 calibrated to Eurostat data.

The PRIMES model is suitable for analysing the impacts of different sets of climate, energy and transport policies on the energy system as a whole, notably on the fuel mix, CO_2 emissions, investment needs and energy purchases as well as overall system costs. It is also suitable for analysing the interaction of policies on combating climate change, promotion of energy efficiency and renewable energies. Through the formalised linkages with GAINS non-CO_2 emission results and cost curves, it also covers total GHG emissions and total ESD sector emissions. It provides details on the Member State level, showing differential impacts across Member States.

The PRIMES model represents energy efficiency by simulating different measures with different techniques. These modelling techniques will affect the context and conditions under which stylized agents per sector, make their decisions on energy consumption.

PRIMES has been used for the analysis underpinning the Commission's proposal on the EU 2020 targets (including energy efficiency), the Low Carbon Economy and Energy 2050 Roadmaps, the 2030 policy framework for climate and energy and the energy efficiency Impact Assessment in 2014.

PRIMES is a private model and has been developed and is maintained by E3MLab/ICCS of National Technical University of Athens[2] in the context of a series of research programmes co-financed by the European Commission.

The model has been successfully peer reviewed[3], most recently in 2011[4].

1 .2. PRIMES- TAPEM & PRIMES-*TREMOVE*

PRIMES-TAPEM, operated by ICCS/E3MLab is an econometric model for transport activity projections. It takes GEM-E3 projections (GDP, activity by sector, demographics and bilateral trade by product, and by country) as drivers, to produce transport activity projections to be fed into PRIMES-TREMOVE. The econometric exercise also includes fuel prices coming from PROMETHEUS, as well as transport network infrastructure (length of motorways and rail-ways), as drivers. The PRIMES-TAPEM model provides the transport activity projections for REF2016.

The PRIMES-TREMOVE Transport Model projects the evolution of demand for passengers and freight transport by transport mode and transport mean. It is essentially a dynamic system of multi-agent choices under several constraints, which are not necessarily binding simultaneously. The model consists of two main modules, the transport demand allocation module and the technology choice and equipment operation module. The two modules interact with each other and are solved simultaneously.

The projection includes details for a large number of transport means, technologies and fuels, including conventional and alternative types, and their penetration in various transport market segments. It also includes details about greenhouse gas and air pollution emissions, as well as impacts on external costs of congestion, noise and accidents.

PRIMES-TREMOVE has been used for the 2011 White Paper on Transport, Low Carbon Economy and Energy 2050 Roadmaps as well as the 2030 policy framework for climate and energy.[5]

The PRIMES-TREMOVE is a private model that has been developed and is maintained by E3MLab/ICCS of National Technical University of Athens [6], based on, but extending

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2 http://www.e3mlab.National Technical University of Athens.gr/e3mlab/.

3 http://ec.europa.eu/clima/policies/strategies/analysis/models/docs/primes_model_2013-2014_en.pdf.

4 https://ec.europa.eu/energy/sites/ener/files/documents/sec_2011_1569_2.pdf'.

5 The model can be run either as a stand-alone tool (*e.g.* for the 2011 White Paper on Transport) or fully integrated in the rest of the PRIMES energy systems model (*e.g.* for the Low Carbon Economy and Energy 2050 Roadmaps, and for the 2030 policy framework for climate and energy). When coupled with PRIMES, interaction with the energy sector is taken into account in an iterative way.

features of the open source TREMOVE model developed by the TREMOVE[7] modelling community. Part of the model (*e.g.* the utility nested tree) was built following the TREMOVE model.[8] Other parts, like the component on fuel consumption and emissions, follow the COPERT model.

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

1.3. PRIMES Biomass Supply

The biomass system model is linked with the PRIMES energy system model for Europe and can be either solved as a satellite model through a closed-loop process or as a stand-alone model.

It is an economic supply model that computes the optimal use of biomass/waste resources and investment in secondary and final transformation, so as to meet a given demand of final biomass/waste energy products, projected to the future by the rest of the PRIMES model. The biomass supply model determines the consumer prices of the final biomass/waste products used for energy purposes and also the consumption of other energy products in the production, transportation and processing of the biomass/waste products. The model also reflects the sustainability criteria currently in place and can be used for reflecting policies facilitating the use of renewable energy sources. After cross check of input data and draft results, results of the biomass supply model are used to ensure consistency between PRIMES, CAPRI and GLOBIOM bioenergy modelling.

The PRIMES biomass supply model is private and has been developed and is maintained by E3MLab/ICCS of National Technical University of Athens[9].

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6 http://www.e3mlab.National Technical University of Athens.gr/e3mlab/

7 http://www.tmleuven.be/methode/tremove/home.htm

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

9 http://www.e3mlab.National Technical University of Athens.gr/e3mlab/

1.4. GAINS

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

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

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

The GAINS model is accessible for expert users through a model interface[10] and has been developed and is maintained by the International Institute of Applied Systems Analysis[11]. The underlying algorithms are described in publicly available literature. The source code is not disclosed. GAINS and its predecessor RAINS have been peer reviewed multiple times, in 2004, 2009 and 2011.

1.5. GLOBIOM-G4M

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

GLOBIOM covers 28 (or 50) world regions. The disaggregation of the EU into individual countries has been performed only recently.

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

10 http://gains.iiasa.ac.at/models/

11 http://www.iiasa.ac.at/

The GLOBIOM-G4M is a private model and has been developed and is maintained by the International Institute of Applied Systems Analysis[12].

1.6. Prometheus

PROMETHEUS is a fully stochastic world energy model used for assessing uncertainties and risks associated with the main energy aggregates including uncertainties associated with economic growth and resource endowment as well as the impact of policy actions. The model projects endogenously the world energy prices, supply, demand and emissions for ten world regions.

World fossil fuel price trajectories are used as import price assumptions for EU Reference scenario and for policy scenario modelling.

The Prometheus model is private and has been developed and is maintained by E3MLab/ICCS of National Technical University of Athens[13]

1.7. CAPRI

CAPRI is an open source economic partial equilibrium model developed by European Commission research funds. Operational since more than a decade, it supports decision making related to the Common Agricultural Policy and Environmental policy related to agriculture based on sound scientific quantitative analysis.

CAPRI is only viable due to its pan-European network of researchers which based on an open source approach tender together for projects, develop and maintain the model, apply it for policy impact assessment, write scientific publications and consult clients based on its results. It has been the basis of numerous peer reviewed publications.

The model has been used to provide consistent agricultural activity projections for the EU Reference scenario 2016s. It is also used in the LULUCF impact assessment. The CAPRI model is an open source model which has been developed and is maintained by Eurocare GmbH[14], JRC, and other partners of the CAPRI network.

2. The EU Reference Scenario 2016 – approach and main results

2.1. Scenario design, consultation process and quality assurance

Scenario design and consultation process

Building an EU Reference scenario is a regular exercise by the Commission. It is coordinated by DGs ENER, CLIMA and MOVE in association with the JRC, and the involvement of other services via a specific inter-service group.

REF2016 2016 (REF2016) has been developed building on a modelling framework including as core models PRIMES (PRIMES-TREMOVE for transport), GAINS and GLOBIOM-G4M and as supporting models GEM-E3, PROMETHEUS, PRIMES Biomass supply and CAPRI (see prior section for details).

12 http://www.iiasa.ac.at/
13 http://www.e3mlab.National Technical University of Athens.gr/e3mlab/
14 http://www.eurocare-bonn.de/

For the REF2016, the model was calibrated on energy data up to year 2013 from Eurostat and other sources, and for agriculture and non-CO_2 emission data up to the year 2015.

Member States were consulted throughout the development process through a specific Reference scenario expert group which met three times during the development of REF2016. Member States provided information about adopted national policies via a specific questionnaire, key assumptions have been discussed and in each modelling step, draft Member State specific results were sent for consultation. Comments of Member States were addressed to the extent possible, keeping in mind the need for overall comparability and consistency of the results.

Quality of modelling results was assured by using state of the art modelling tools, detailed checks of assumptions and results by the coordinating Commission services as well as by the country specific comments by Member States.

REF2016 projects EU and Member States energy, transport and GHG emission-related developments up to 2050, given current global and EU market trends and adopted EU and Member States' energy, transport, climate and related relevant policies.

"Adopted policies" refer to those that have been cast in legislation in the EU or in MS (with a cut-off date end of 2014[15]). Therefore the binding 2020 targets are assumed to be reached in the projection. This concerns GHG emission reduction targets (both for the EU ETS as well as ESD sectors) as well as renewables targets, including renewables in transport.

However, policies which are not yet legally implemented, *e.g.* those necessary to implement the 2030 energy and climate framework, are not part of REF2016[16]. On this basis, REF2016 can help identify areas where the current policy framework falls short of reaching the EU's climate and energy objectives[17]. Notably, REF2016 shows that current policy and market conditions will deliver neither the 2030 targets nor the long-term 2050 80-95% GHG emission reduction objective.

REF2016 provides projections, not forecasts. Unlike forecasts, projections do not make predictions about what the future will be. They rather indicate what would happen if the assumptions which underpin the projection actually occur. Still, the scenario allows for a consistent approach in the assessment of energy and climate trends across the EU and its Member States.

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15 In addition, amendments to two Directives only adopted in the beginning of 2015 were also considered. This concerns notably the ILUC amendment to the RES Directive and the Market Stability Reserve Decision amending the ETS Directive.

16 For the period after 2020, policies are included that are part of the EU *acquis*, as well as important investments that are part of Member States' national energy plans. For instance, ETS with the Market Stability Reserve is included in REF16, but not the Commission's proposal for a change in the linear reduction factor post-2020. New near-zero energy buildings after 2020 - as defined in the Energy Performance of Buildings Directive - continue to be built, as well as energy labelling continues. Member States also gave input on planned energy investments, particularly in nuclear energy.

17 Each new update of REF2016 models the projected impact of policy adopted up to the relevant cut-off date. Therefore, differences between two consecutive Reference scenarios, *e.g.* between the one from 2013 and REF2016, can be explained by the implications of policies adopted in the meantime as well as by changed economic and technological trends.

The report "EU Energy, Transport and GHG Emissions Trends to 2050 - Reference Scenario 2016" describes the inputs and results in detail. This section summarises the main messages derived from it, especially those relevant for the Energy Union framework.

Main assumptions

The projections are based on a set of assumptions, including on population growth, macroeconomic and oil price developments, technology improvements, and policies.

Macroeconomic assumptions

In REF2016, the population projections draw on the European Population Projections (EUROPOP 2013) by Eurostat. The key drivers for demographic change are: higher life expectancy, convergence in the fertility rates across Member States in the long term, and inward migration. The EU28 population is expected to grow by 0.2% per year during 2010-2030 (0.1% for 2010-2050), to 516 million in 2030 (522 million by 2050). Elderly people, aged 65 or more, would account for 24% of the total population by 2030 (28% by 2050) as opposed to 18% today.

GDP projections mirror the joint work of DG ECFIN and the Economic Policy Committee, presented in the 2015 Ageing Report[18]. The average EU GDP growth rate is projected to remain relatively low at 1.2% per year for 2010-2020, down from 1.9% per year during 1995-2010. In the medium to long term, higher expected growth rates (1.4% per year for 2020-2030 and 1.5% per year for 2030-2050) are taking account of the catching up potential of countries with relatively low GDP per capita, assuming convergence to a total factor productivity growth rate of 1% in the long run.

Sectorial activity projections are derived in a consistent way from these macroeconomic assumptions, using the macro-economic modelling tool GEM-E3 as well as econometric estimates for global demand for energy intensive industries.

Fossil fuel price assumptions

Oil prices have fallen by more than 60% since mid-2014, to an average of around 40 $/barrel for Brent crude oil in the first four months of 2016. The collapse of oil prices has been driven by low demand and sustained oversupply, due in particular to tight oil from North America and to the decision of the Organization of Petroleum Exporting Countries (OPEC) countries not to cut their output to rebalance the market. REF2016 considers a gradual adjustment process with reduced investments in upstream productive capacities by non-OPEC countries. Quota discipline is assumed to gradually improve among OPEC members. Thus, oil price is projected to reach 87 $/barrel in 2020 (in year 2013-prices). Beyond 2020, as a result of persistent demand growth in non-OECD countries driven by economic growth and the increasing number of passenger cars, oil price would rise to 113 $/barrel by 2030 and 130 $/barrel by 2050. This price trend resulting from PROMETHEUS modelling is in line with other reference sources such as the 2015 IEA World Energy Outlook.

No specific sensitivities were prepared with respect to oil and gas price developments. Still, it can be recalled that lower fossil fuel price assumptions tend to increase energy consumption and CO_2 emissions not covered by the ETS. The magnitude of the change would depend on the price elasticities and on the share of taxation, like excise duties, in

[18] European Commission/ DG-ECFIN (2015) "The 2015 Ageing Report Economic and budgetary projections for the 28 EU Member States (2013-2060)", European Economy 3/2015

consumer prices. For instance, for transport, the changes would be limited (depending on the magnitude of the change in the oil price) due to the high share of excise duties in the consumer prices but they are still expected to lead to some higher energy consumption and CO_2 emissions. They also tend to lead to lower overall energy system costs, as the increase in consumption is more than compensated by lower prices. Conversely, costs for emission mitigation could slightly increase. Different fossil price assumptions are unlikely to lead to significantly different impacts across Member States.

Technoeconomic assumptions

In terms of technological developments, input assumptions are based on a wide range of sources[19], with estimates on technological costs across main types of energy equipment, from power generation to heating systems and appliances. In addition, it should be recalled that the PRIMES model (and other models where relevant) take into account technological progress.

In terms of technological developments relevant to the transport sector, battery costs for electric vehicles and plug-in hybrids are assumed to go down to 320-360 $/kWh by 2030 and 270-295 $/kWh by 2050; further improvements in the efficiency of both spark ignition gasoline and compression ignition diesel are assumed to take place. In addition, the market share of internal combustion engine (ICE) electric hybrids is expected to increase due to their lower fuel consumption compared to conventional ICE vehicles.[20]

For the techno-economic assumptions in the projection of non-CO_2 GHG emissions, see the detailed technical documentation[21]. In general, technological progress in this domain is strongly linked to regulation; hence Reference scenario assumptions are conservative.

Technology assumptions are based on extensive literature review and have been peer-reviewed by the Commission services, notably the Joint Research Centre of the European Commission.

Specific policy assumptions

Following the above described policy modelling approach, the key policies included in the REF2016 are[22]:

- The EU Emissions Trading System (Directive 2003/87/EC and its amendments) is fully reflected in the modelling, including the linear reduction factor of 1.74% for stationary installations and the recently adopted Market Stability Reserve.[23]

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19 Those include, among others, the European Commission Joint Research Centre, notably for power generation costs or identification of Best Available Technologies, or MURE, ICARUS or ODYSSEE for the demand sectors.

20 REF2016, by design, assumes the continuation of the current trends and policies without the implementation of additional measures. Hence, due to the absence of further policies, car manufacturers and industry are not expected to devote additional effort in marketing advanced vehicle technologies. The relatively low production of advanced vehicles, in REF2016, is not expected to yield economies of scale which could potentially imply high reduction in battery costs as suggested by other sources. Such assumptions change in a decarbonisation policy scenario context.

21 Höglund-Isaksson, L., W. Winiwarter, P. Purohit, A. Gomez-Sanabria (2016): Non-CO2 greenhouse gas emissions in the EU-28 from 2005 to 2050: GAINS 2016 Reference scenario, International Institute for Applied Systems Analysis (IIASA)

22 For a comprehensive discussion see REF2016 report

23 Decision EU/2015/1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading scheme and amending Directive 2003/87/EC

- The Effort Sharing Decision (406/2009/EC) is assumed to be implemented, *i.e.* ESD GHG emission reductions at EU level in 2020 need to reach at least -10% compared to 2005 levels. It turned out that no specific policy incentives in addition to adopted EU and national policies were needed to achieve the EU level target. National ESD targets need not be achieved domestically given the existing flexibilities (*e.g.* transfers between Member States).

- The Energy Efficiency Directive (EED) and the Energy Performance of Buildings Directive (EPBD) are reflected, including Member States' specific obligations as regards energy savings obligation and buildings codes.

- Ecodesign and Energy Labelling Directives and Regulations are also reflected.

- CO_2 standards for cars and vans regulations (Regulation (EC) No 443/2009, amended by Regulation EU No 333/2014 and Regulation (EU) No 510/2011, amended by Regulation EU 253/2014); CO_2 standards for cars are assumed to be 95gCO_2/km as of 2021 and for vans 147gCO_2/km in line with current legislation. Standards are assumed constant after 2020/2021.

- The Renewable Energy Directive (Directive 2009/28/EC) and Fuel Quality Directive (Directive 2009/30/EC) including ILUC amendment (Directive (EU) 2015/1513): achievement of the legally binding renewables target for 2020 (including 10% renewables in transport target) for each MS, taking into account the use of flexibility mechanisms when relevant as well as of the cap on the amount of food or feed based biofuels (7%). Member States' specific renewable energy policies for the heating and cooling sector are also reflected where relevant.

- Directive on the deployment of alternative fuels infrastructure (Directive 2009/30/EC).

- The Waste Management Framework Directive (Directive 2008/98/EC) and in particular the Landfill Directive (Directive 1999/31/EC) which contribute to a significant reduction of emissions from waste.

- The revised F-gas Regulation (Regulation 517/2014) strengthens existing measures and introduces a number of far-reaching changes, notably limiting the total amount of the most important F-gases that can be sold in the EU from 2015 onwards and phasing them down in steps to one-fifth of 2014 sales in 2030, and banning the use of F-gases in many new types of equipment where less harmful alternatives are widely available.

- The impacts of the Reforms of the Common Agricultural Policy are taken into account, *e.g.* the milk quota abolition.

- Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP) for maritime transport.[24]

- Relevant national policies, for instance on the promotion of renewable energy, on fuel and vehicle taxation or national building codes, are taken into account.

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 framework includes two distinct stages: a) a first stage models decision-making behaviour of agents,

[24] IMO Resolution MEPC.203(62)

hence investment and technology choices; b) a second stage calculates total costs for the entire energy system in order to support comparisons across scenarios.

In the first stage, agents take decisions considering the time dimension of money flows. Private discount factors can be defined as reflecting opportunity costs of raising funds by the actor on a private basis. The opportunity costs of an investment decision also vary with the degree of market distortions and non-market barriers as well as with the degree of risk associated with the decision options. The opportunity costs differ hence by sector and by type of agent.

The aim is to assess policy impacts as close as possible to reality and to avoid under- or over- estimation of the costs, and thus the difficulties, of transformation required to meet targets and transition objectives (*i.e.* transition towards a low carbon economy). Therefore, in line with the impact assessment guidelines the modelling is based on private discount rates[25].

For determining the values of discount rates to be applied, the model follows different approaches by sector. Decisions by firms are based on the weighted average cost of capital (WACC) to determine the discount rates. REF2016 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 companies subject to regulation by the state. WACC rates vary between 7.5% and 11%.

Decisions by individuals are modelled based on a subjective discount rate, annualizing investment costs following the equivalent annuity cost method. Literature surveys[26] find high implicit discount rates for households, because of various factors, such as lack of information, uncertainties, different income levels, lack of sufficient funding, agency costs, transaction and hidden costs. By varying the discount rates applied in the model, it is therefore possible to reflect, for instance, the effects of energy efficiency policy instruments, mainly ESCOs, campaigns and labelling programs, by lowering the discount rates when these policies are implemented. Therefore, the EU Reference scenario uses discount rates for individuals reflecting both existing barriers for investment decisions (which have an upward effect on discount rates) and the impact of existing energy efficiency policies, such as energy-labelling, energy performance certificates for buildings, or the promotion of energy service companies (ESCOs), which are reflected by lower discount rates compared to default values. As such, discount rates for investment decisions used in REF2016 are comprised between 9.5% and 12% depending on the consumer good subject that is purchased.

As said above, in a second stage the model analyses the resulting energy system costs. Here, the crucial element is the amount of money that energy consuming agents (households and firms, grouped into the sectors services and industry, transport and agriculture) are required to pay in order to get the energy services they need. Energy services are provided by using energy commodities purchased by end-consumers, which depend on energy efficiency at the consumption level. The PRIMES report aggregates

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[25] This is different from the perspective of a social planner who optimises the whole system from a societal perspective. In such a perspective social discount rates could play a role for determining normative inter-temporal choices.

[26] For instance: Mundaca Luis, Lena Neiz, Ernst Worell and Michael McNeil (2010) "*Evaluating energy efficiency policies with energy*-economy *models*", Ernest Orlando Lawrence Berkeley National Laboratory

capital or investment expenditures (CAPEX) and purchasing costs for fuels and other energy commodities or operational expenditures (OPEX) of end-consumers to show a single total cost figure. OPEX for end-users already incorporates through pricing of energy commodities the CAPEX and OPEX costs incurred by the energy supply and trading sectors (calculated using the above mentioned WACC rates for those sectors). For making costs comparable, the CAPEX figures related to investments by final energy demand consumers also need to be annualised, and a flat discount rate of 10% is used for this purpose, a lower rate than in the past that is more in line with the WACC used for the supply sector. The cost accounting approach adopted in the EU Reference scenario maintains comparability of costs across different scenarios, which is key.

2.2. Summary of main results

Figure 2 below presents the projected evolution of EU Gross Inland Energy Consumption. After the 2005 peak, energy consumption is projected to steadily decline until 2040, where it stabilises. Oil still represents the largest share in the energy mix, mostly because of transport demand. Solid fuels see a significant reduction in their share of the energy mix, while the biggest increase is for renewable energy. Natural gas and nuclear energy keep relatively stable shares in the energy mix.

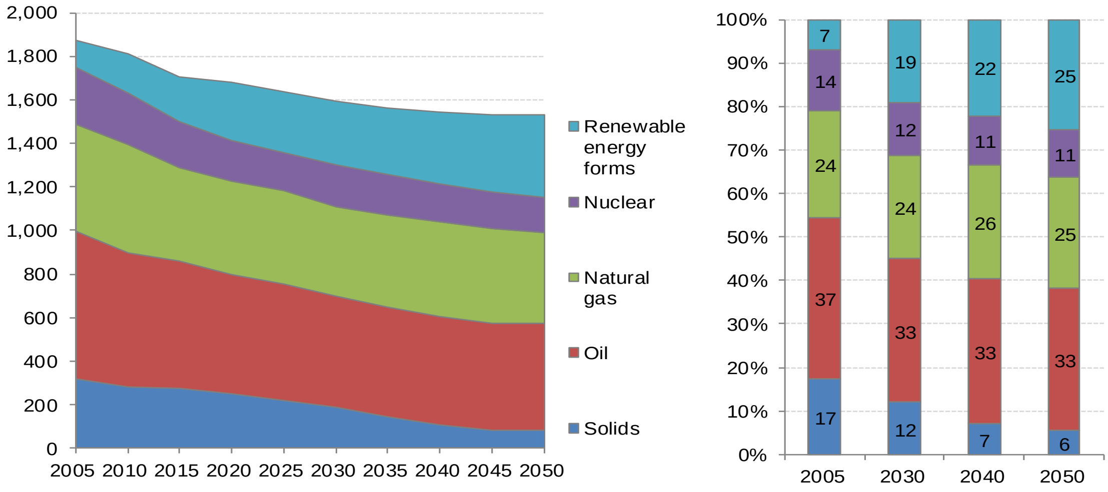

Figure 2: EU28 Gross Inland Consumption (Mtoe, left; shares (%), right)
Source: PRIMES

Energy security

EU energy production (Figure 3) is projected to continue to decrease from around 760 Mtoe in 2015 to around 660 Mtoe in 2050. The projected strong decline in EU domestic production for all fossil fuels (coal, oil and gas) coupled with a limited decline in nuclear energy production is partly compensated by an increase in domestic production of renewables. Biomass and biowaste will continue to dominate the fuel mix of EU domestic renewable production, although the share of solar and wind in the renewable mix will gradually increase from around 17% in 2015 to 36% in 2050.

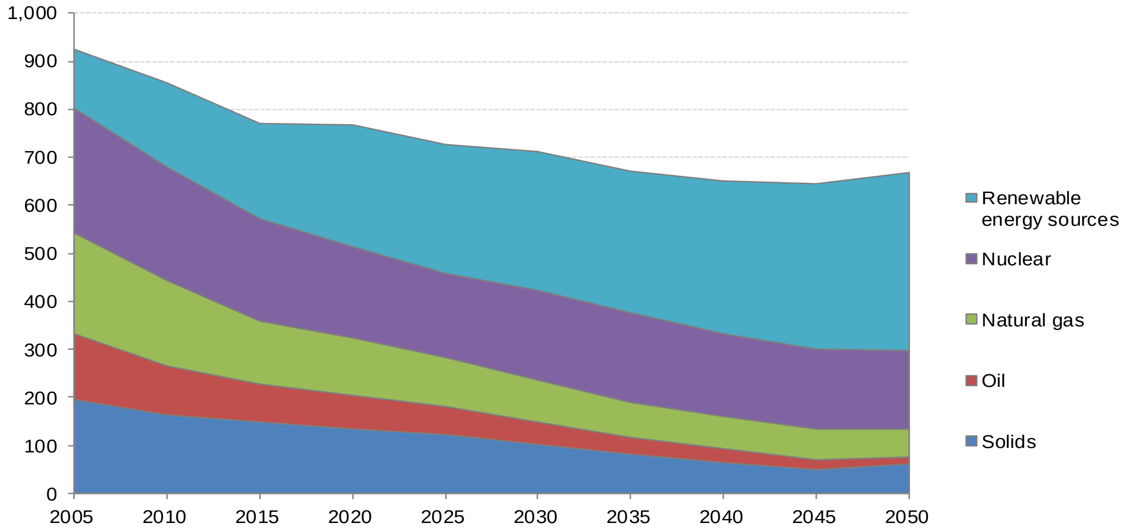

Figure 3: EU28 Energy Production (Mtoe)
Source: PRIMES

EU's import dependency shows a slowly increasing trend over the projected period, from 53% in 2010 to 58% in 2050. Again renewables deployment, energy efficiency improvements and nuclear production (which remains stable) counteracts the strong projected decrease in EU's fossil-fuel production.

Solid imports as well as crude oil and (refinery) feedstock decline throughout the projection period, while oil products imports slightly increase. Natural gas imports increase slightly in the long term reaching approximately 370 bcm[27] net imports in 2050. Biomass remains mostly supplied domestically, although the combination of increased bioenergy demand and limited potential for additional EU domestic supply leads to some increases in biomass imports post-2020 (from 11% of biomass demand in 2020 to about 15% in 2030 and beyond).

Up to 2020, the consumption of gas[28] is expected to remain stable (at around 430bcm in gross inland terms). Net import dependency of natural gas registers an increase as domestic gas production continues its downward trend. Post 2020, a slight decrease in gross inland consumption of gas (412 bcm in 2030) is projected, as well as further reductions in indigenous production of gas. Net import dependency of natural gas registers an increase as domestic gas production continues its downward trend. The imported volumes of gas are projected to increase between 2015 and 2040 and then to stabilise in the long term, 15% above the 2010 net import level (from 309 bcm in 2010 to 369 bcm in 2050).

[27] The conversion rate of 1 Mtoe = 1.11 bcm was used for natural gas, based on the BP conversion calculator.

[28] The imported volumes of gas are projected to increase between 2015 and 2040 and then to stabilise in the long term, 15% above the 2010 net import level (from 309 bcm to 369 bcm - Figure 3).

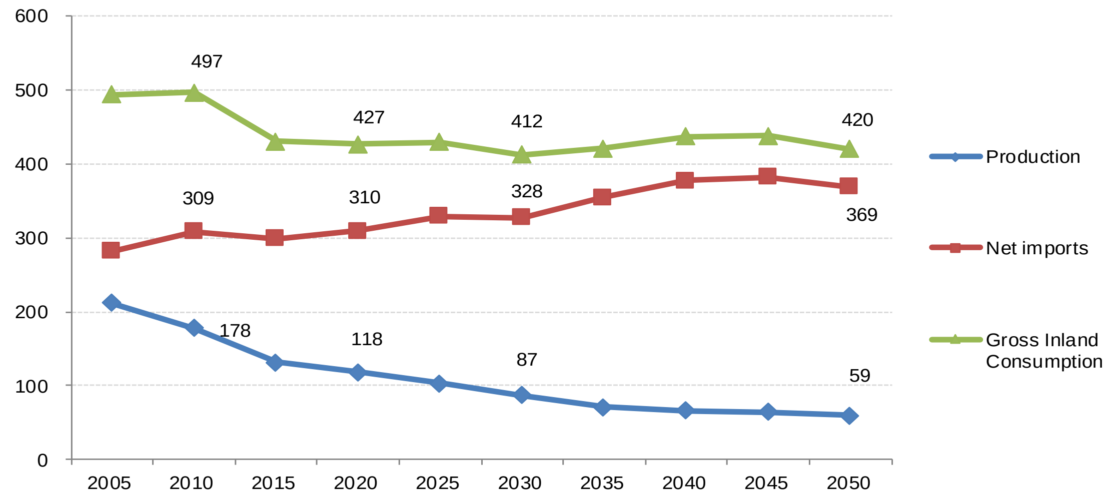

Figure 4: Gas - production, net imports and demand (volumes expressed in bcm)
Source: PRIMES

Internal energy market and investments

The EU power generation mix changes considerably over the projected period in favour of renewables (Figure 5). Before 2020, this occurs to the detriment of gas, as strong renewables policy to meet 2020 targets, very low coal prices compared to gas prices, and low CO_2 prices do not help to replace coal. After 2020, the change is characterised by further renewables deployment, but also a larger coal to gas shift, driven mainly in anticipation of increasing CO_2 prices.

Gas therefore maintains its presence in the power generation mix in 2030 (at slightly higher levels in the long term compared to 2015). The share of solids/coal in power generation significantly declines, but not before 2020, to 15% in 2030.

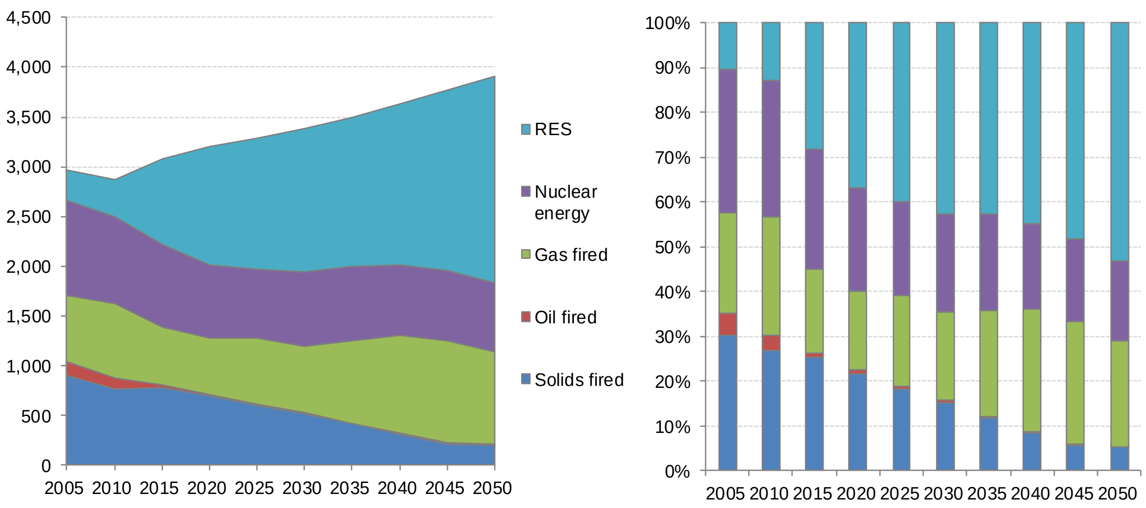

Figure 5: EU power generation (net) by fuel (Mtoe – left, shares – right)
Source: PRIMES

Variable renewables (solar and wind) reach around 19% of total net electricity generation in 2020, 25% in 2030 and 36% in 2050, demonstrating the growing need for flexibility in the power system. Wind onshore is expected to provide the largest contribution. Solar PV and biomass also increase over time. Hydro and geothermal remain roughly constant.

The share of nuclear decreases gradually over the projected period despite some life time extensions and new built, from 27% in 2015 to 22% in 2030.

REF2016 shows increasing volumes of electricity trade over time. The flow between regions increases from 17% in 2015 to 26% in 2020, 29% in 2030 and then stays almost stable for the remainder of the projection period reaching 30% in 2050. Main drivers are intermittent RES power generation and the resulting balancing requirements. Trade is facilitated by the assumed successful development of the ENTSO-E Ten-Year Network Development Plan 2014[29] as well as pan-European market coupling and sharing of reserves and flexibility across Member States.

Average retail electricity prices[30] (Figure 6) steadily increase up to 2030 by about 18% relative to 2010 levels, stabilising around 20% during 2030-2040, after which they start to gradually decrease. The structure of electricity costs changes over time, with the capital cost component (generation and grid costs) increasing significantly in the short term up to 2020, but decreasing afterwards in the longer term. From 2030, the fuel cost component remains stable despite the increase in fuel prices, due to a decreasing share of fossil-fuel combustion. Transmission and distribution costs increase significantly in the longer term, post-2030, partly linked to the need to cater for the increased presence of RES in the power generation mix.

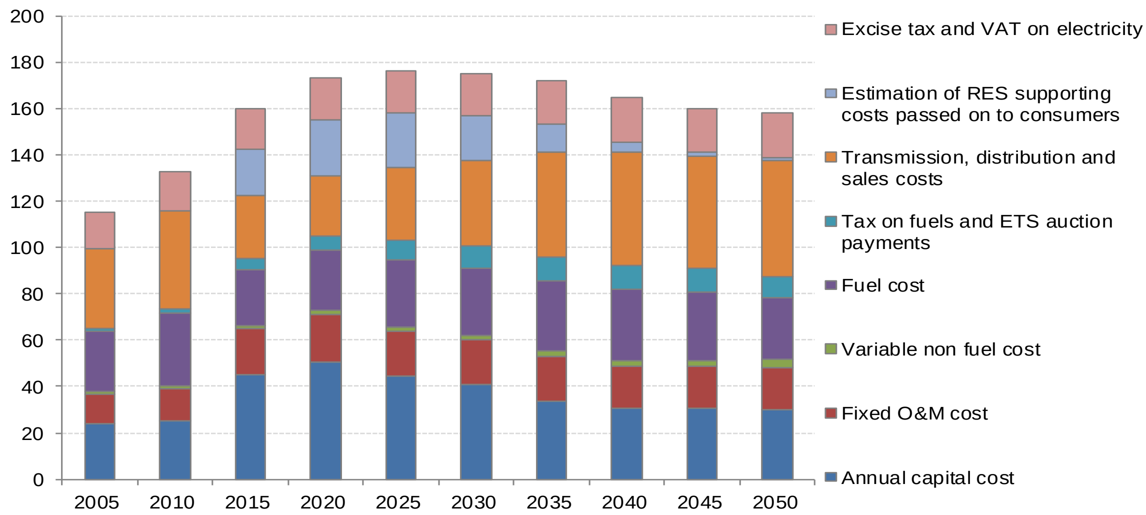

Figure 6: Decomposition of electricity generation costs and prices (€'2013 MWh)

Source: PRIMES

As a result of the modelling, the carbon price is projected to increase (Figure 7), reflecting both the steadily decreasing ETS cap and the stabilising effect of the Market Stability Reserve. However, the increase in electricity prices due to ETS remains limited despite the significant increase in CO_2 price, as the share of carbon-intensive power generation decreases.

29 Source: https://www.entsoe.eu/major-projects/ten-year-network-development-plan/ten%20year%20network%20development%20plan%202016/Pages/default.aspx

30 In the PRIMES model, prices differ per type of end-user.

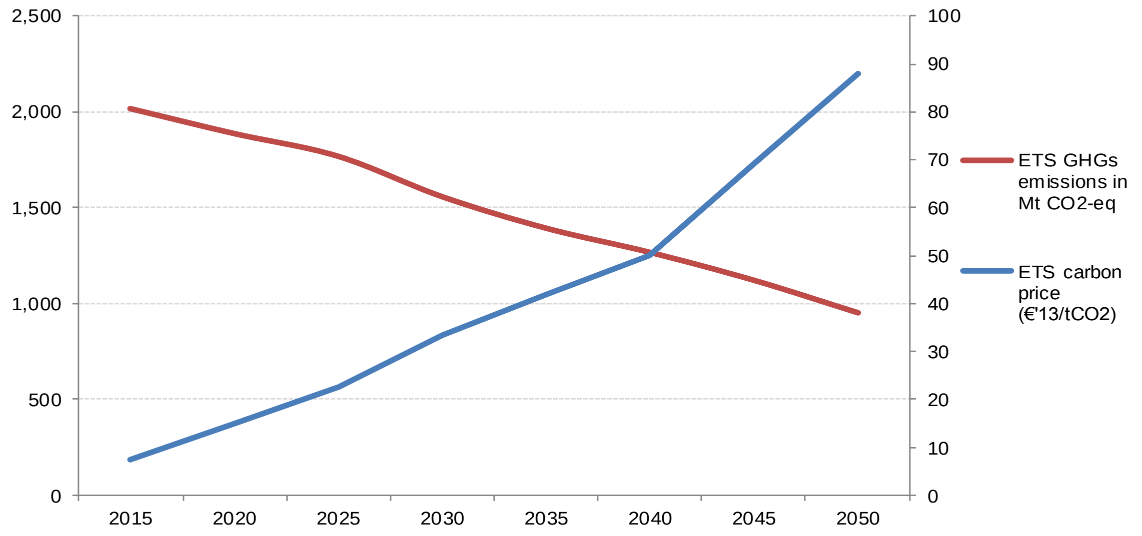

Figure 7: ETS emissions and carbon prices over time
Source: PRIMES, GAINS

Electricity prices for households and services are projected to increase moderately in the medium term and to decrease slightly in the long term. Prices for industry on the contrary are stable or decrease over time as energy intensive industry maintains an electricity demand profile compatible with base-load power generation and bears a small fraction of grid costs and taxes. Taxes apply mainly on prices for households and services.

Investment expenditures for power supply increase substantially until 2020 driven by renewables targets and developments, but slow down thereafter, until 2030, before increasing again from 2030 onwards notably due to increasing ETS carbon prices reflecting a continuously decreasing ETS cap based on the current linear factor. New power plant investment is dominated by renewables, notably solar PV and wind onshore. Nuclear investment mostly takes place via lifetime extensions until 2030 and in the longer term via new built, such as projected in, for instance, the UK, Finland, Sweden, France, Poland, and other Central European Member States. New thermal plant investment is mainly taking place in gas-fired plants.

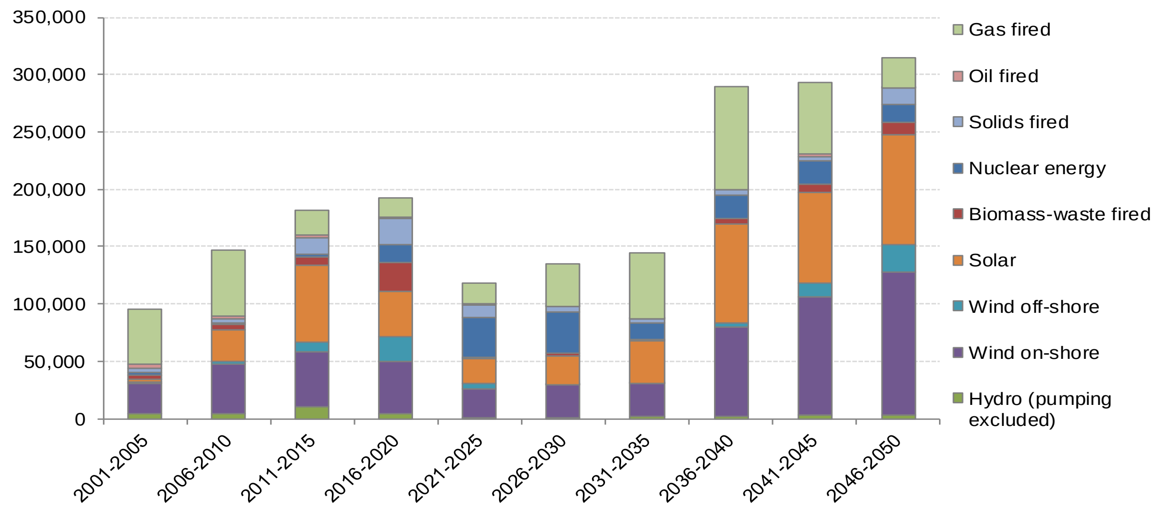

Figure 8: Net power capacity investments by plant type (MWh – for five year period)
Source: PRIMES

Investment expenditures in demand sectors (Figure 9 – left hand side) over the projected period will be higher than in the past. They notably peak in the short term up to 2020, particularly in the residential and tertiary sectors, as a result of energy efficiency polices. Post-2020 they slightly decline until 2030, before increasing again to 2050. On the supply side (Figure 9 – right hand side), investments peak towards 2020, followed by a decrease, notably explained by a decline in power generation investments.

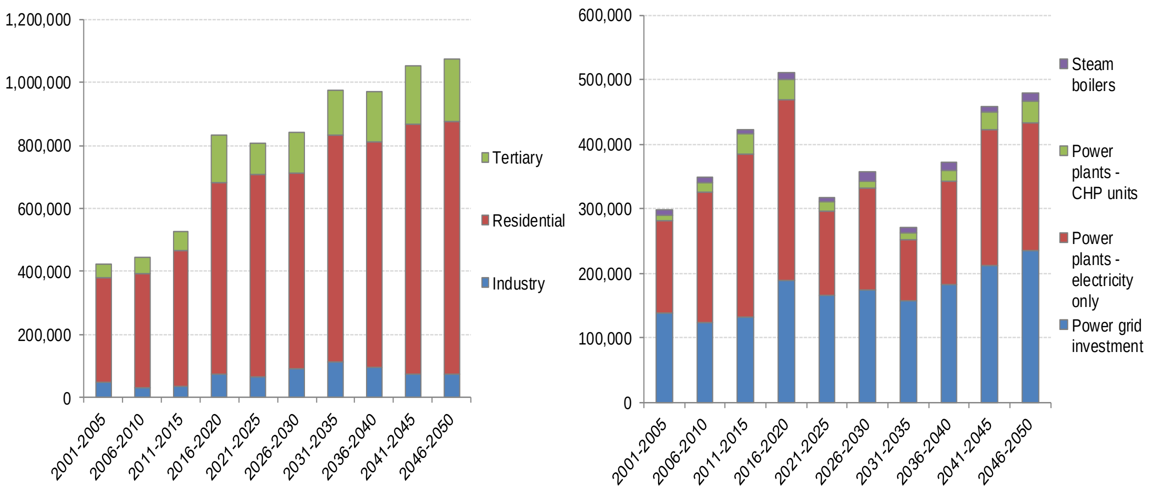

Figure 9: Investment expenditures (5-year period) - demand side, million €'2013 (left, excluding transport) and supply side, million €'2013 (right)
Source: PRIMES

Transport investments (expenditures related to the turnover of rolling stock) steadily increase over time but maintain a relatively stable share of GDP.

The relative weight of energy-related spending in households' expenditure[31] increases in 2020 compared to 2015 (7.5% compared to 6.8%), stabilising until 2030 before decreasing again until 2050 (6.1%).

Moderation of energy demand

In 2020, primary energy consumption decreases by 18.4% (relative to the 2007 baseline, *i.e.* how the energy efficiency target is defined), more than the sum of national Member States' indicative energy efficiency targets but still falling slightly short of the 2020 indicative EU energy efficiency target of 20%. In 2030, energy consumption is projected to decrease (again relative to 2007 baseline projections) by 23.9%. Primary energy demand and GDP continue to decouple (Figure 10), which is consistent with the trends observed since 2005. Energy efficiency improvements are mainly driven by policy up to 2020 and by market/technology trends after 2020.

[31] Share of energy system costs for the residential sector (fuel costs and annualised capital costs of energy related investment expenditures) in total households' consumption

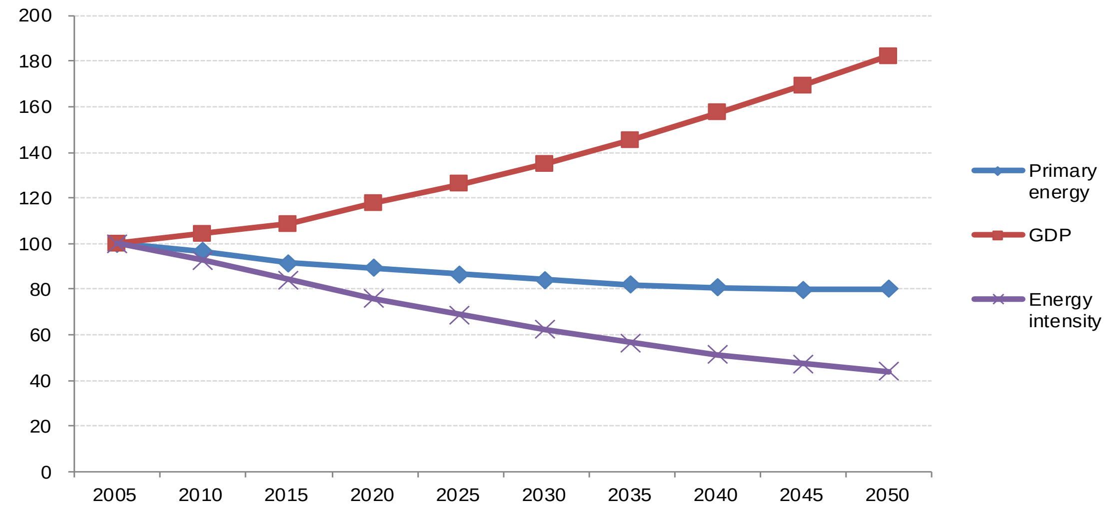

Figure 10: Decoupling of EU energy use and intensity from GDP (2005=100)
Source: Commission calculations based on PRIMES and GEM E3

The distribution of final energy consumption across sectors remains broadly similar to the current picture, all the way to 2050, with transport and the residential sector comprising the lion's share of final energy consumption (32% and 27% of final consumption, respectively, in 2030). Industry sees its share in final energy demand slightly decreasing, from 28% in 2005 to 23% in 2050, mostly due to improved energy efficiency in non-energy intensive industries. The tertiary (services and agriculture) sector keeps a stable share of about 17%.

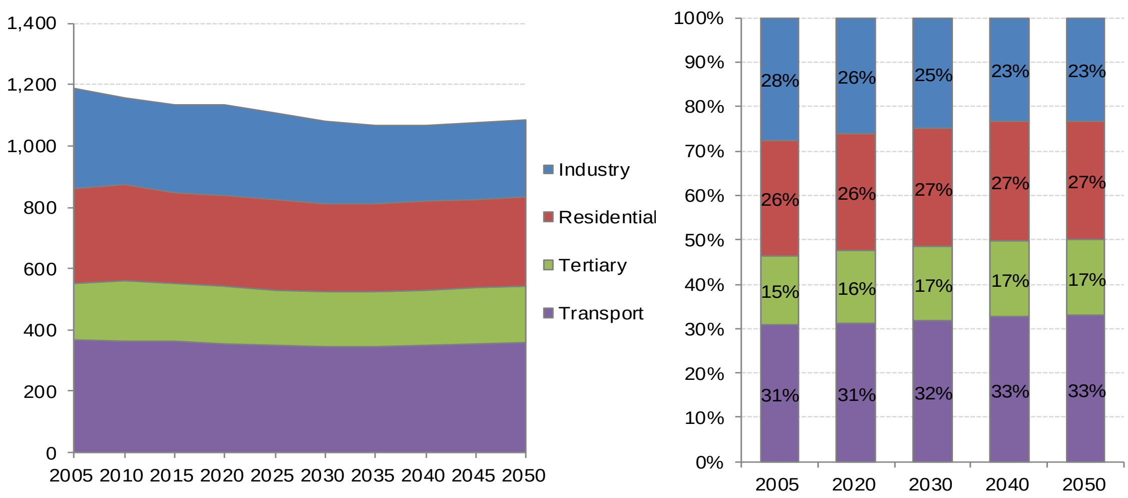

Figure 11: Evolution of final energy demand by sector (Mtoe – left, shares – right)
Source: PRIMES

With regard to the fuel mix in final energy, there is a gradual penetration of electricity (from 22% in total final energy use in 2010 to 28% in 2050). This is because of growing electricity demand as compared to other final energy use and to some electrification of heating (heat pumps) and to a limited extent in the transport sector.

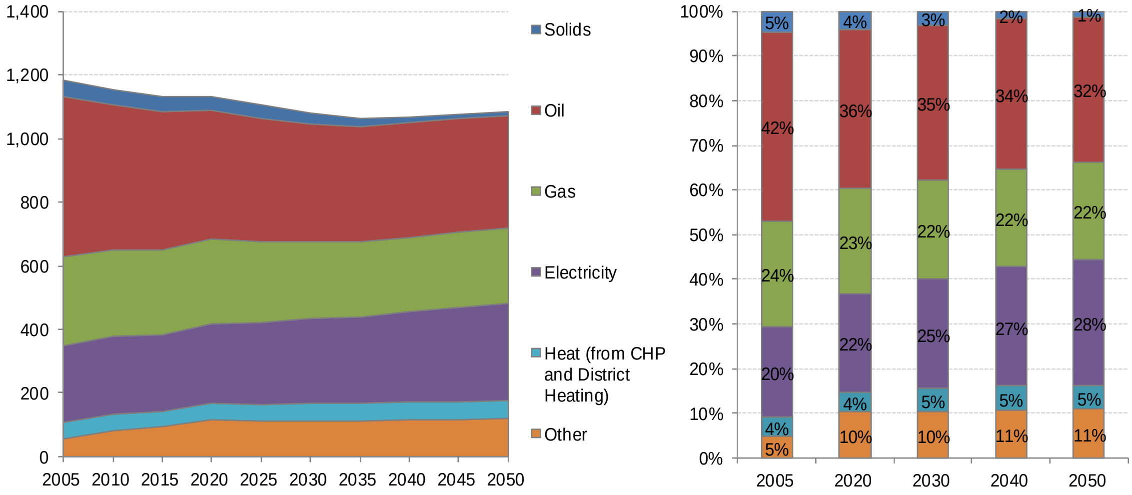

Figure 12: Evolution of final energy demand by fuel (Mtoe – left, shares – right)
Source: PRIMES

Energy intensity of the industrial sectors remains approximately constant in the medium term, as additional energy demand is due to the increase in production activity. In the long term however energy demand decreases, even though activity in terms of value added progresses. This is due to the energy efficiency embedded in the new capital vintages which replace old equipment and structural changes towards higher value added and less energy-intensive production processes, such as in iron and steel or non-ferrous metals.

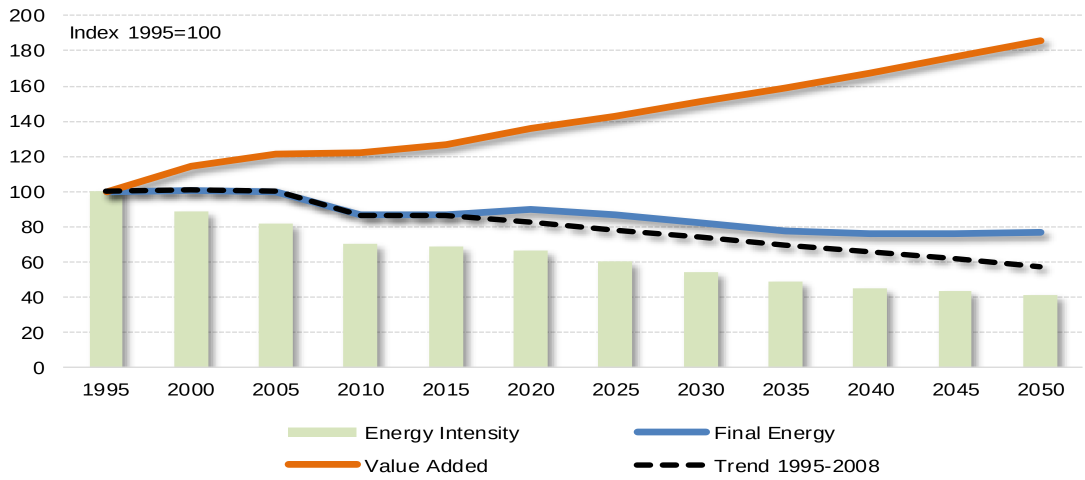

Figure 13: Industrial energy demand versus activity (value added)
Source: PRIMES

In the residential sector, energy demand remains below 2015 levels throughout the projection period. Energy demand decouples from income growth more than would be suggested by extrapolation of trends as the efficiency policies drive energy intensity improvements fast in the medium term; in the long term however the rate of improvements decreases due to the absence of additional policies.

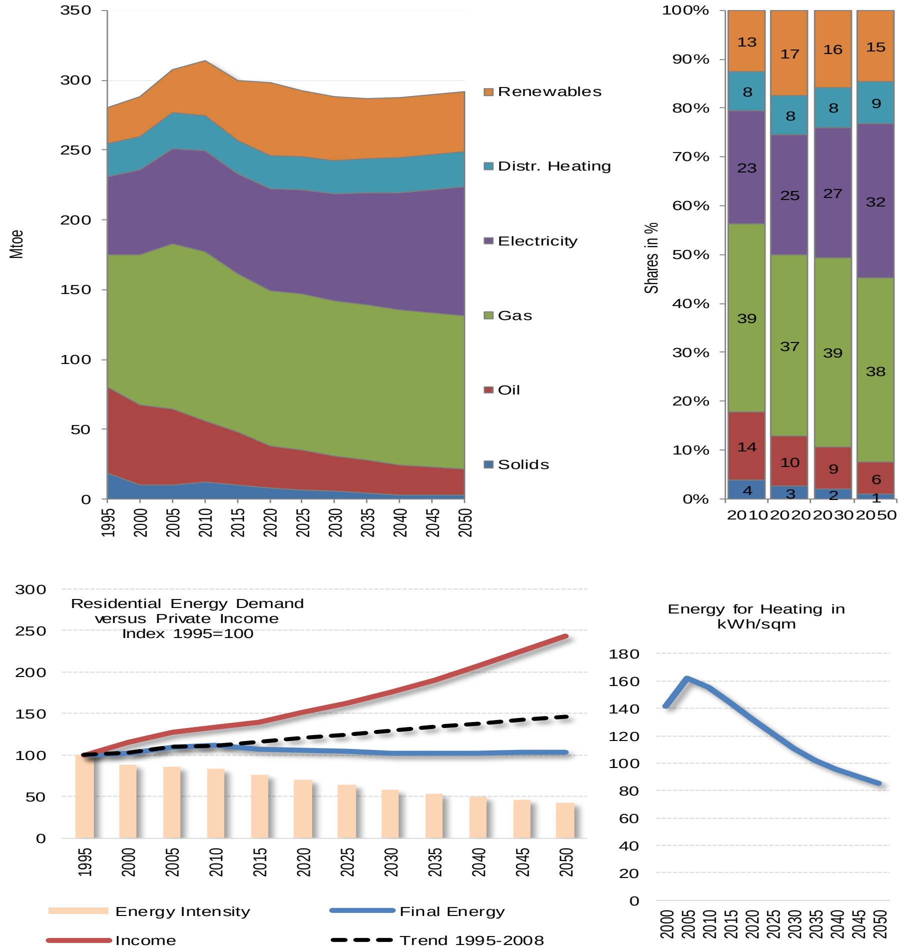

Figure 14: Final energy demand in the residential sector
Source: PRIMES

The activity of the transport sector shows a significant growth (Figure 15), with the highest increase in 2010 to 2030, driven by developments in economic activity. Historically, the growth of final energy demand in the transport sector has shown strong correlation with the evolution of transport activity. However, a decoupling between energy consumption and transport activity has been recorded in the past years. The decoupling between energy consumption and activity is projected to continue and even to intensify in the future.

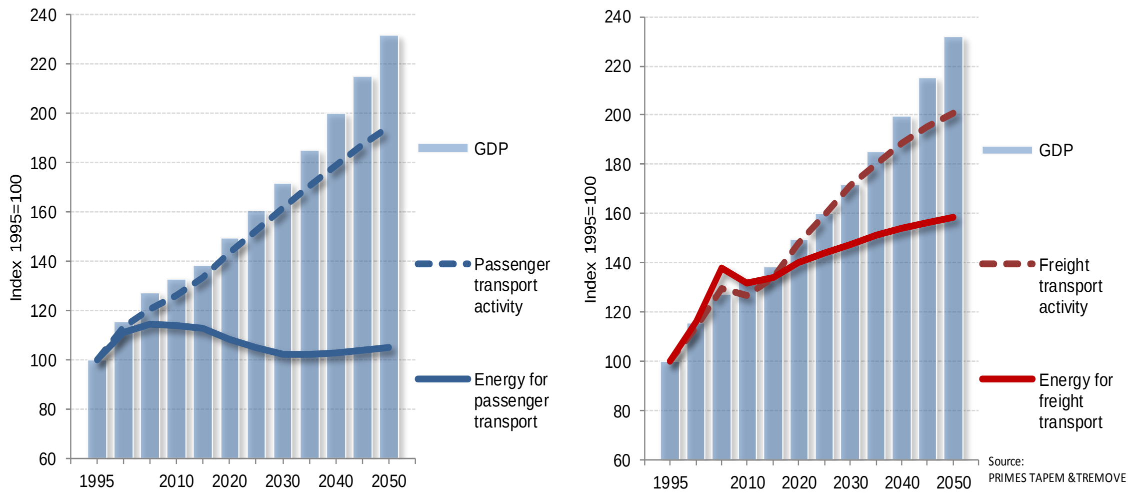

Figure 15: Trends in transport activity and energy consumption

Source: PRIMES and GEM-E3; For aviation, passenger transport activity includes domestic, international intra-EU and international extra-EU aviation

Electricity use in transport is expected to increase steadily as a result of further electrification of rail and the uptake of alternative powertrains in road transport. However, its share is projected to remain limited in REF2016, increasing from 1% currently to 2% in 2030 and 4% in 2050 (Figure 16). The uptake of hydrogen would be facilitated by the increased availability of refuelling infrastructure, but its use would remain low in lack of policies adopted beyond the end of 2014.

Liquefied natural gas becomes a candidate energy carrier for road freight and waterborne transport, especially in the medium to long term, driven by the implementation of the Directive on the deployment of alternative fuels infrastructure and the revised Trans-European Transport Network (TEN-T) guidelines which represent important drivers for the higher penetration of alternative fuels in the transport mix. However, the potential of gas demand developments in the transport sector do not fully materialise in REF2016, suggesting that additional policy incentives would be needed to trigger further fuel switching.

Diesel is projected to maintain its share in total final energy demand in transport by 2030, slowly decreasing its share only during 2030-2050. Consumption of gasoline declines considerably until 2030, continuing the declining trend from 1995 and stabilizes from thereon to 2050. Consumption of jet fuels in aviation increases steadily by 2050 due to the strong growth in transport activity and despite improvements in energy efficiency.

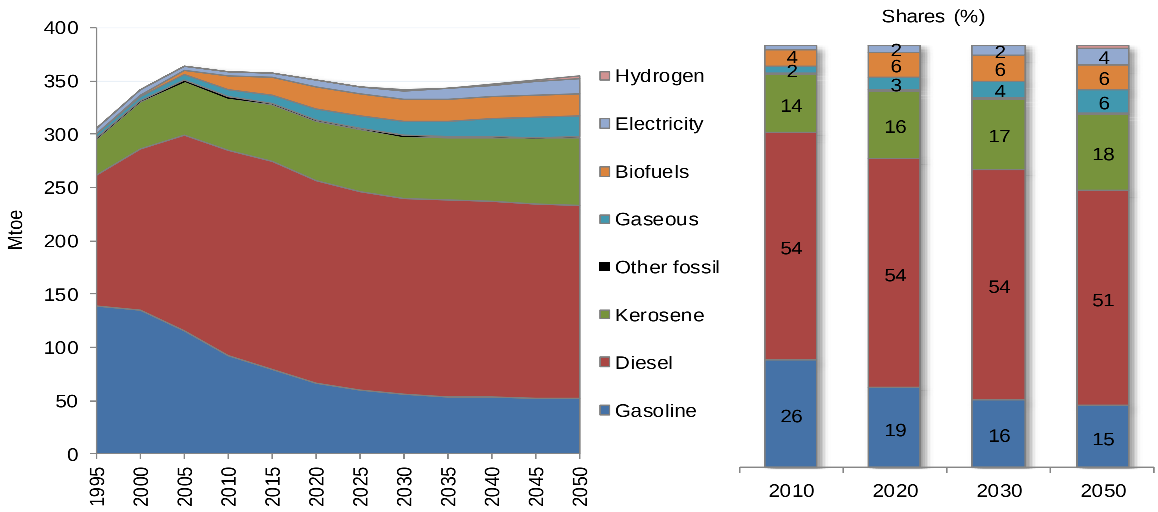

Figure 16: Final energy demand in transport by fuel type

Source: PRIMES-TREMOVE; Biofuels include biomethane used in transport

Oil products would still represent about 90% of the EU transport sector needs (including maritime bunker fuels) in 2030 and 86% in 2050, despite the renewables policies and the deployment of alternative fuels infrastructure which support some substitution effects towards liquid and gaseous biofuels, electricity, hydrogen and natural gas.

Decarbonisation:

CO_2 emission reduction

In REF2016, the binding energy and climate targets for 2020 will be met by assumption. However, current policy and market conditions will not deliver achievement of either the EU 2030 targets or the EU long-term 2050 decarbonisation goal.

Total CO_2 emissions are projected to be 22% below 1990 levels by 2020. In 2030, CO_2 emissions reduce (relative to 1990 levels) by 32%. Most of these emissions are energy related, and this part also determines the overall trends. Non-energy related CO_2 emissions mainly relate to industrial processes, and remain rather stable. Land-use related CO_2 emissions are discussed below in the LULUCF section.

Emission reductions in the ETS sectors are larger than those in sectors covered by the Effort Sharing Decision (ESD) as current legislation implies a continuation of the reduction of the ETS cap with 1.74% per year over the projected period leading to a carbon price driving long term emission reduction. In the ESD sectors there are no further drivers beyond market forces (*e.g.* rising fossil fuel prices) and the continued impact of adopted policies such as CO_2 standards for vehicles or energy performance standards for new building to further reduce energy and consequently emissions.

CO_2 emissions can be decomposed in the components GDP, Energy Intensity of GDP and Carbon Intensity of Energy. The Energy Intensity of GDP component declines due to structural changes in the economy and increasing energy efficiency in all sectors. The decrease of carbon intensity of energy supply becomes an increasingly significant component over the period. This is mainly due to Renewable Energy policies in the short term and the ETS in the medium to long term.

On a sectorial level, CO_2 emissions decrease in all sectors. Figure 17 shows a steep decrease in power generation, whereas emissions in the field of transport decrease at much slower pace between 2010 and 2050, and the transport sector becomes the largest source of CO_2 emissions after 2030. Non-energy and non-land use related CO_2 emissions (*e.g.* industrial processes) reduce only slowly throughout the projection period; however they only represent a small share of total CO_2 emissions.

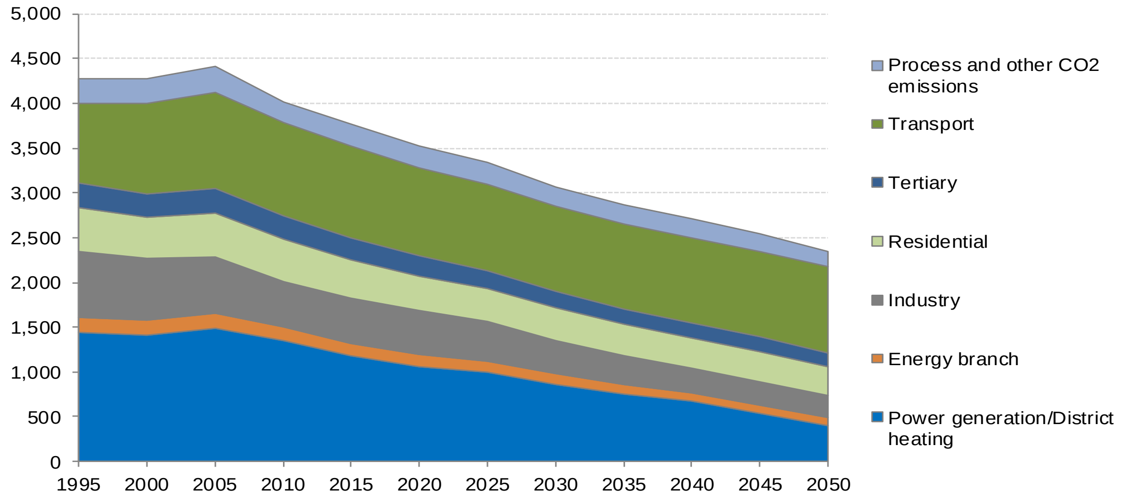

Figure 17: Evolution of CO_2 emissions (Mt) by sector

Source: PRIMES

Renewable Energy

In 2020, the renewables share in gross final energy consumption reaches 21% in 2020, while in 2030, it reaches 24%.

In the short term, the set of EU and national specific policies that promote renewables (notably implementation of supportive financial support such as feed-in-tariffs) drive significant penetration of renewables in power generation. By 2020, renewables in power generation are projected to increase to 35.5% (RES-E indicator[32]) or 37.2% of net electricity generation, of which 52% are projected to be variable renewables – wind and solar. This implies an acceleration compared to observed trends, in particular in those countries that currently facing difficulties to reach their targets. Beyond 2020 support schemes are phased out and further investments in renewables are more limited (reaching 43% in 2030), driven by market forces such as the ETS and the improvement in the techno-economic characteristics of the technologies.

[32] Calculated according to the definitions of the RES Directive used also for the pertinent provisions of Eurostat statistics

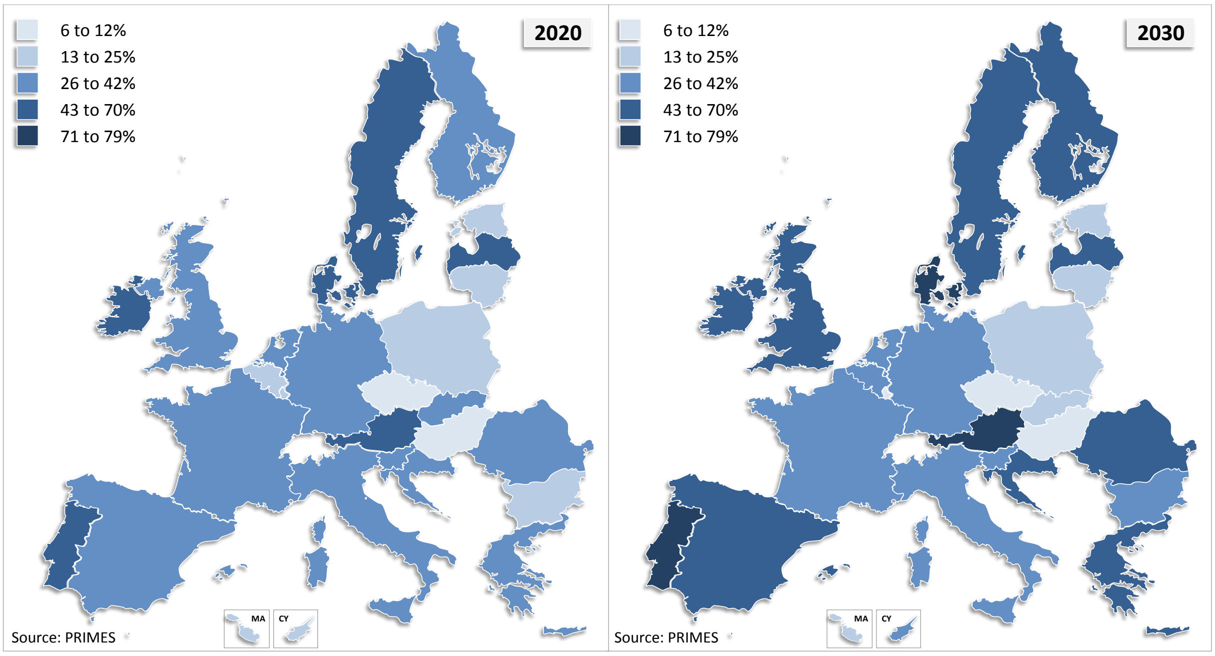

Figure 18: RES-E shares across EU Member States in 2020 and 2030

While renewables provide growing shares in electricity generation (up to 56% in 2050 of net power generation in overall EU28), the contribution of variable renewables (solar, wind as well as tidal/wave in the definition used here) remains significantly lower. These variable renewables reach 19% of total generation in 2020, 25% in 2030 and 36% in 2050. Wind off-shore capacities stagnate, as in the absence of support schemes this technology is not projected to be competitive.

Wind provides the largest contribution from renewables supplying 14.4% of total net electricity generation in 2020, rising to 18% in 2030 and 25% by 2050. A share of 24% of total wind generation is produced from wind off-shore capacities in 2020 (33GW installed capacity), but the share of offshore wind declines thereafter. Total wind capacities increase to 207 GW in 2020, 255 GW in 2030 and 367 GW in 2050, up from 86 GW in 2010. Wind onshore capacity and generation increases because of exploitation of new sites but also because of the progressive replacement of wind turbines with newer taller ones which are assumed to have higher installed capacity and higher load hours.

Generation from PV contributes 4.8% in net generation by 2020. Beyond 2020, PV generation continues to increase up to 7% in 2030 and 11% in 2050. PV capacity is projected to reach 137.5 GW in 2020, up from 30 GW in 2010. Investment is mostly driven by support schemes in the short term and the decreasing costs of solar panels and increasing competitiveness in the long term, in particular where the potential is highest, *i.e.* Southern Europe. PV capacities continue to increase due to the low costs and installed capacity reaches 183GW in 2030 and 299GW in 2050.

The use of biomass and waste combustion for power generation also increases over time, both in pure biomass plants (usually of relatively small size) and in co-firing applications in solid fuel plants. Biomass attains a share in fuel input in thermal power plants of 17.3% in 2020, 22% in 2030 and 31.5% in 2050[33]. Pure biomass/waste plant capacities

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

(excluding co-firing) reach 51.6 GW in 2020, up from 21.7 GW in 2010, 53.2GW in 2030 and 57.3 GW in 2050. The share of biomass products in total inputs rises from 68% in 2015 to 79% in 2050, whereas waste products, including industrial waste, represent the remaining quantities.

The relative contribution of hydro generation remains rather constant at 10-11% of total net generation, with small hydro slightly increasing. Net installed capacity increases by 19GW in the time period from 2010 to 2050; 8.5GW are planned investments in hydro-reservoirs between 2010 and 2020. Beyond this period the majority of investments are in small run-of-river plants.

Looking at the decomposition of change of RES-E relative to 2010, it is also important to highlight the negative contribution of electricity demand savings. This means that electricity demand increases over the period, and therefore requires even more RES investments than constant demand would otherwise suggest.

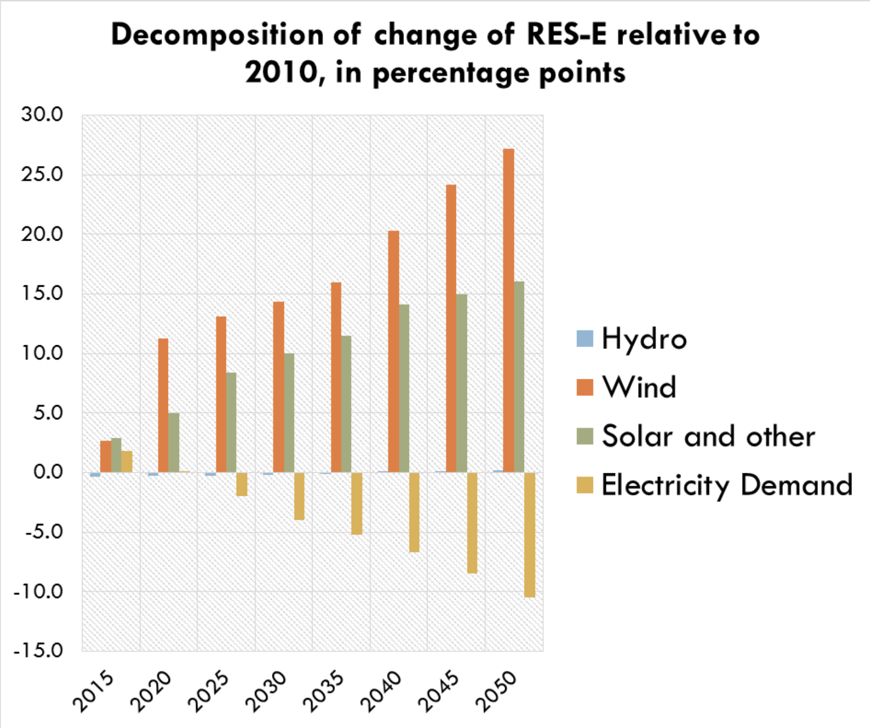

Figure 19: Decomposition of change of RES-E relative to 2010, in % terms
Source: PRIMES

The renewables share in heating and cooling increases from 17% in 2015 to 22% in 2020, reaching 25% in 2030. The use of renewables in final demand for heating and cooling is the main driver of RES-H&C increase in the short term, but its contribution first decreases and then stagnates in the long term. Final consumption of renewable energy in the industrial sector (excluding derived heat) is the second contributor to renewable energy in the heating and cooling sector. In the long-term, renewables in CHP and heat plants (*e.g.* district heating), as well some deployment of heat pumps, drive further increases of the RES-H&C share. In terms of district heating fuel input, the share of solids and oil decreases considerably, as well as the share of gas. Biomass and waste as well as other renewables and electricity in fuel input increase, representing almost 42% of fuel input in 2020 and 88% in 2050 (in comparison to 31% in 2010) – excluding heat from CHP. Energy efficiency, implying lower demand for heat in all sectors, is also an important driver in the medium and long term, as it tends to reduce demand for renewable heating and cooling, all else equal.

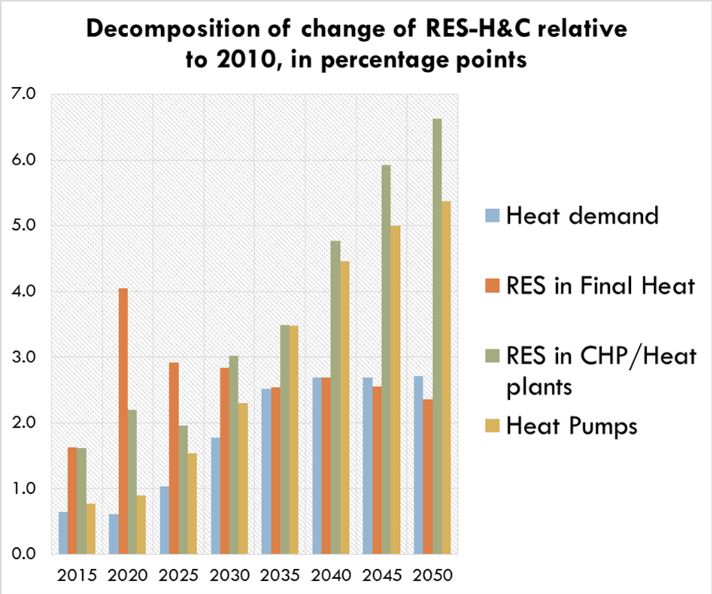

Figure 20: Decomposition of change of RES-H&C relative to 2010, in % terms
Source: PRIMES

The RES-T share reaches 11% in 2020. The development of bio-fuels is the main driver in the short term, but its contribution stagnates in the long term, as the share of biofuels in total fuels used in transport remains stable, around 6%. The biofuel penetration is mainly driven by the legally binding target of 10% renewable energy in the transport sector. Projections also take into consideration specific Member States' mandatory blending obligations and tax incentives, as well as the ILUC Directive. Renewables in electricity, combined with the relative increase of electricity use (albeit modest in share terms), is the main contributor to RES-T in the long term.

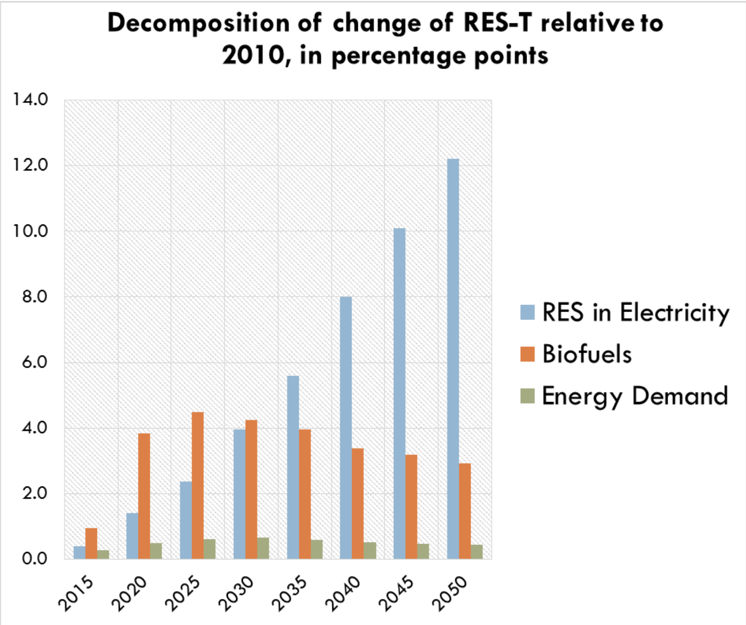

Figure 21: Decomposition of change of RES-T relative to 2010, in % terms
Source: PRIMES

Non-CO_2 emission reduction

Non-CO_2 emissions (CH4, N2O and F-Gases), account currently (2013) for 18% of total EU GHG emissions (excluding LULUCF). They have decreased significantly (32%) between 1990 and 2013. They are expected to further decrease by 29% below 2005 levels in 2030 (-46% compared to 1990 levels), and to stagnate later on. CH_4 emissions – which have the largest share in this aggregate - are projected to decrease above average (33% due to declining trends in fossil fuel production, improvements in gas distribution and waste management) and N_2O emissions fall below average (17%) until 2030, both remaining flat thereafter. F-Gases would reduce by half between 2005 and 2030, largely driven by EU and Member State's policies (*i.e.* the 2014 F-gas regulation and mobile air conditioning directive); F-gases would increase somewhat between 2030 and 2050 in line with economic developments. Except for a very minor fraction from some specific industries, non-CO_2 emissions fall under the ESD.

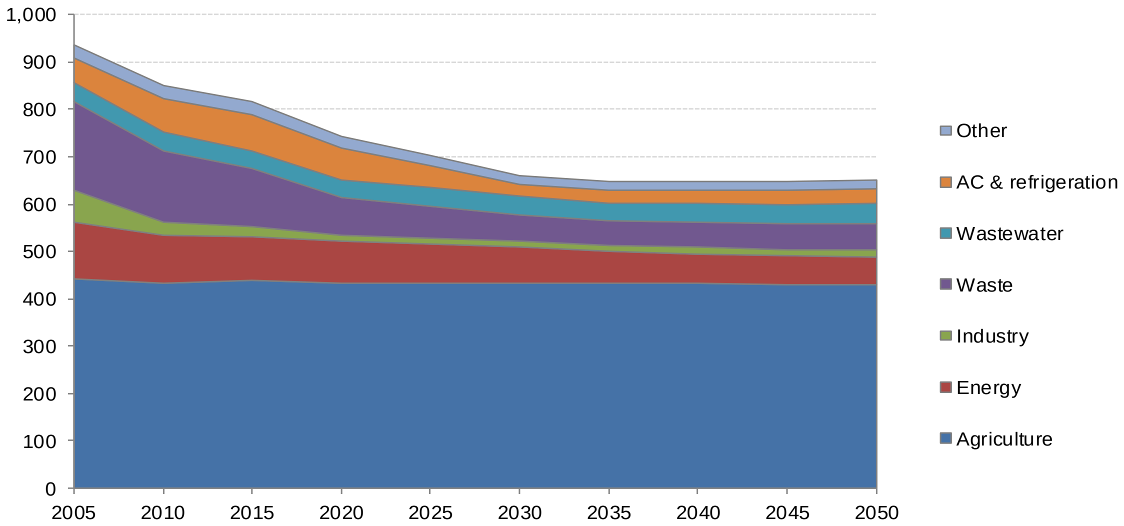

Figure 22: Non CO_2 GHG emissions
Source: GAINS

The non-CO_2 emission trends and their drivers vary by sector.

Agriculture is responsible for about half of all non-CO_2 emissions and is expected to increase its share in total non-CO_2 until 2030. While the agricultural non-CO_2 emissions have reduced by 22% between 1990 and 2013, they are projected to roughly stabilize at current levels as a result of different trends which compensate each other, such as decreasing herd sizes (both of dairy cows and of non-dairy cattle) but increasing milk yields. Slightly reduced use of mineral fertilizer through improved efficiency (2% less in 2030 than in 2005) leads to corresponding reductions in N_2O emissions from soils. Improved manure management (*e.g.* through anaerobic digestion) also delivers minor emission reductions. The Common Agricultural Policy influences, *inter alia*, livestock numbers/intensities and the Nitrogen Directive and the Water Framework Directive impact on the use of fertilizer.

Waste is currently the second most important sector emitting non-CO_2. There, a substantial reduction between 2005 and 2030 is expected (70%), strongly driven by environmental legislation, such as the Landfill directive and improvements in waste management as well as an update in inventory methodology of historic landfills that results in increased historic emissions and subsequent increased reductions of these emissions in the near to mid-term future. Also an increasing amount of CH_4 is recovered and utilised, thereby impacting on these trends towards lower emissions. After 2030, however, a moderate increase is projected, reflecting trends in economic development.

CH_4 and N_2O emissions from the **energy** sector (incl. transport) are expected to decrease by 36% from 2005 to 2030, and further 26% between 2030 and 2050. The main reductions come from less coal-mining and crude oil production in the EU, together with reduced emissions from power generation with fossil fuels. On the other hand, transport is expected to generate an increasing share of energy sector non-CO_2 emissions (N_2O from road transport being the most important contributor), growing from 12% in 2005 to 15% in 2030 and 20% in 2050 within the energy aggregate.

Emissions from **air conditioning and refrigeration** decrease by half from 2005 until 2030, also thanks to existing legislation (*i.e.* the new 2014 F-gas Regulation and the Mobile Air Conditioning systems Directive).

Most of the non-CO_2 emissions from **industry** – overall a minor non-CO_2 sector - are covered by the EU ETS (production of adipic and nitric acid, and of aluminium). The resulting incentive in combination with relatively cheap abatement options and (previous) national legislation cut emissions quite rapidly, to, in 2030, only a fifth of those in 2005. For the period after 2030 slight increases are projected in line with economic trends.

Emissions from the **wastewater** sector and remaining **other sectors** are projected to increase moderately in line with economic development over the whole period covered.

LULUCF emissions and removals

The EU28 Land Use Land Use Change and Forestry (LULUCF) sector is at present a net carbon sink which has been sequestering annually on average more than 300 Mt CO_2 over the past decade according to the UNFCCC inventory data[34]. In REF2016, the LULUCF sink is expected to decline in the future to -288 Mt CO_2 eq in 2030 from -299 Mt CO_2 eq. in 2005 and decreases further after 2030. This decline is the result of changes in different land use activities of which changes in the forest sector are the most important. These changes are driven partly by the increase in timber demand for all uses (including the increase in bioenergy demand that is expected in order to reach the RES targets in 2020). Figure 23 shows the projection of the total EU28 LULUCF sink in REF2016 and the contribution from different land use categories.

At present, the carbon sink in managed forest land (-373 Mt CO_2 eq. in 2010 without applying any accounting rules[35]) is the main component of the LULUCF sink. The managed forest land sink is driven by the balance of forest harvest and forest increment rates (accumulation of carbon in forest biomass as a result of tree growth). Forest harvest is projected to increase over time from 516 million m^3 in 2005 to 565 million m^3 in 2030 due to growing demand for wood for material uses and energy production. Along with the aging of EU forest – which reduces the capacity of forest to sequester carbon – the forest increments are projected to decrease from 751 million m^3 in 2005 to 725 million m^3 in 2030. As a consequence, the rate of accumulation of carbon (*i.e.* the sink) in

34 See: http://unfccc.int

35 The GHG accounting approach for LULUCF differs from other emission sectors. Notably, forest management is not accounted compared to historic emissions, but against a so called Forest Management Reference Level. This means that the accounted removals from the LULUCF sector are much smaller than the reported removals seen by the atmosphere.

managed forest land declines by 32% until 2030. This is partially compensated by a continuation of increasing trend in carbon sink from afforestation and decreasing trend of emissions from deforestation which decline from 63 Mt CO_2 in 2005 to 20 Mt CO_2 eq. in 2030. Carbon sequestration from afforested land increases steadily to 99 Mt CO_2 eq. by 2030, as new forests continue, albeit at slower rate, to be established. In addition, young forests that were established over the last 20 years get into a phase of high biomass production.

Activity in the agricultural sector (on cropland and grassland) has a smaller impact on the total LULUCF sink than the forest sector. Still, net carbon emissions from cropland are projected to decline by some 18% by 2030 compared to 2005 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 2030, 0.9 Mha of perennial crops are expected to be cultivated. The grassland sink increases to around -19 Mt CO_2 eq. in 2030 as land continues to be converted to grassland *e.g.* through cropland abandonment while at the same time the total grassland area slightly declines over time due to afforestation and the expansion of settlements.

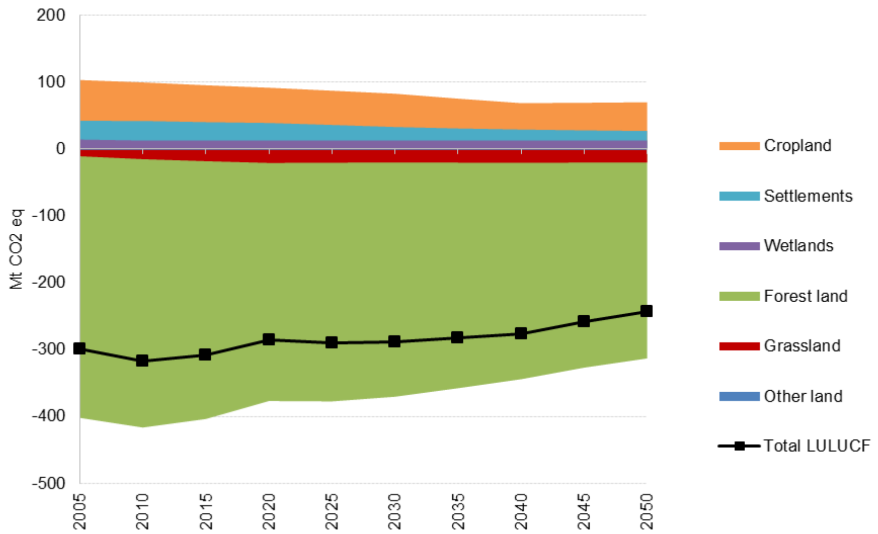

***Figure 23: Development of the EU28 emissions/removals in the LULUCF sector in Mt CO_2 until 2050*[36]**

Source: GLOBIOM-G4M

Research, innovation and competitiveness

Although REF2016 does not deal explicitly with research and innovation, it does tackle directly the penetration of new technologies. The approach is in two steps. First, assumptions are made on techno-economic characteristics and technological learning curves based on latest scientific evidence[37]. Figure 24 presents an illustration of the RES power technologies assumptions used in REF2016. Second, the model endogenously selects the most economically viable technologies at each point in time, leading to further technological cost reduction as technologies are deployed at increasingly larger scales.

36 Emissions from deforestation and harvested wood products are included in "Forest land" in contrast to UNFCCC inventories

37 See notably the European Commission's Joint Research Centre ETRI 2014 report, available at: https://setis.ec.europa.eu/publications/jrc-setis-reports/etri-2014

The development of solar photovoltaics (PVs) starts from lower costs than in the previous Reference Scenario and has a positive learning curve throughout the projection period. This translates into significant deployment of solar PVs in REF2016, especially in Southern Europe.

Although wind onshore costs are already competitive with many conventional technologies, the remaining potential for learning is estimated to be small, but costs can decrease due to the size of turbines and their height; very small scale wind is the only exception and still has high learning potential.

There remains large uncertainty about the costs for offshore wind and there have been cost increases due to previously unforeseen difficulties and logistics. Surveys have identified significant potential of cost decrease due to economies of scale and possibilities of improvement in logistics, but these cost decreases are likely to occur only towards 2030. As such, offshore wind developments in REF2016 are more conservative than in past exercises.

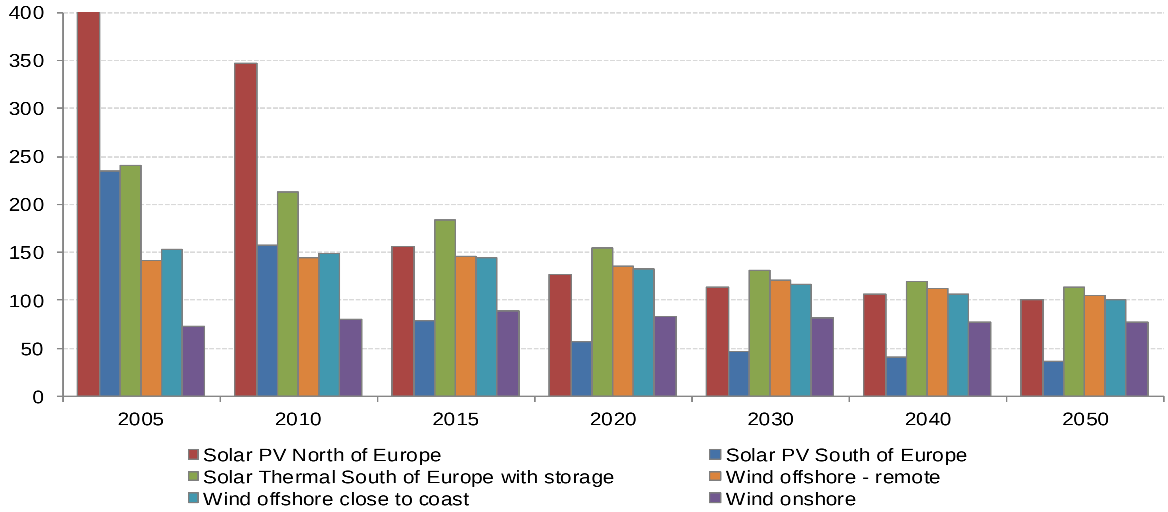

Figure 24: Illustrative levelized cost of electricity for selected RES technologies (expressed in €'2013/MWh-net)

Source: NTUA based on PRIMES

Compared to the previous Reference scenario, the costs of nuclear investment have increased and also the costs for nuclear refurbishments have been revised upwards. Although lifetime extensions of nuclear power plants remain economically viable in most cases, investments in new built plants are lower compared to previous projections.

The construction of power plants equipped with carbon capture and storage (CCS) technologies is developing at a very slow pace, and is dependent on public support (*e.g.* EEPR and NER300). Geological restrictions as well as current political restrictions on storage are also reflected. For these reasons, CCS costs are assumed higher than in previous Reference scenarios. Uptake of carbon capture and storage (CCS) in power and industry beyond supported demonstration plants remains very slow and occurs only towards the end of the projection period, driven by increasing ETS carbon prices.

On the demand side, demand for electric appliances continues to increase. However, there is an uncoupling between appliance stock and energy consumption due to the technological progress facilitated by eco-design regulations.

Car manufacturers are expected to comply with the CO_2 standards by marketing vehicles equipped with hybrid system, which are becoming more appealing to the consumers thanks to lower costs. Electrically chargeable vehicles emerge around 2020 and are kick-started by existing EU and national policies as well as by incentive schemes aiming to boost their penetration. The share of activity of total electric vehicles in the total activity of light duty vehicles reaches 15% in 2050 (Figure 25). Fuel cells would add an additional 2% by 2050. Other energy forms such as liquefied petroleum gas (LPG) and natural gas maintain a rather limited share.

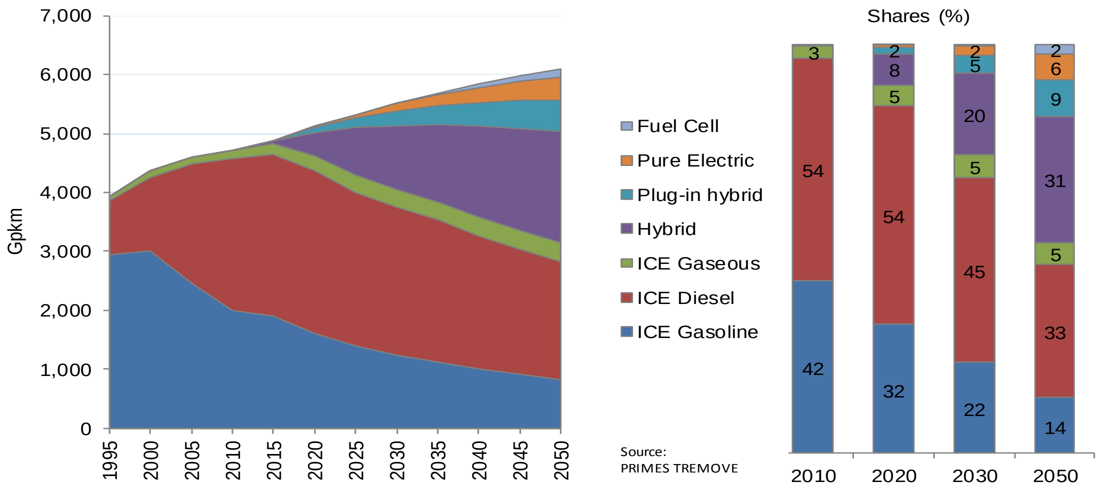

Figure 25: Evolution of activity of light duty vehicles by type and fuel[38]
Source: PRIMES-TREMOVE

Energy system costs (Figure 26) increase up to 2020. Large investments are undertaken driven by current policies and measures (Figure 26). Overall, in 2020 energy system costs constitute 12.3% of the GDP, rising from 11.4% in 2010 and 11.2% in 2015, also driven by projected rising fossil fuel prices[39]. Despite further fossil fuel price increases, between 2020 and 2030 the share remains stable and decreases thereafter, as the system reaps benefits from the investments undertaken in the previous decade (notably via fuel savings). In this period, the share of energy system costs in GDP is gradually decreasing, reaching levels close to 2005 by 2050.

38 Light duty vehicles include passenger cars and light commercial vehicles.

39 Total system costs include total energy system costs, costs related to process-CO_2 abatement and non-CO_2 GHG abatement.

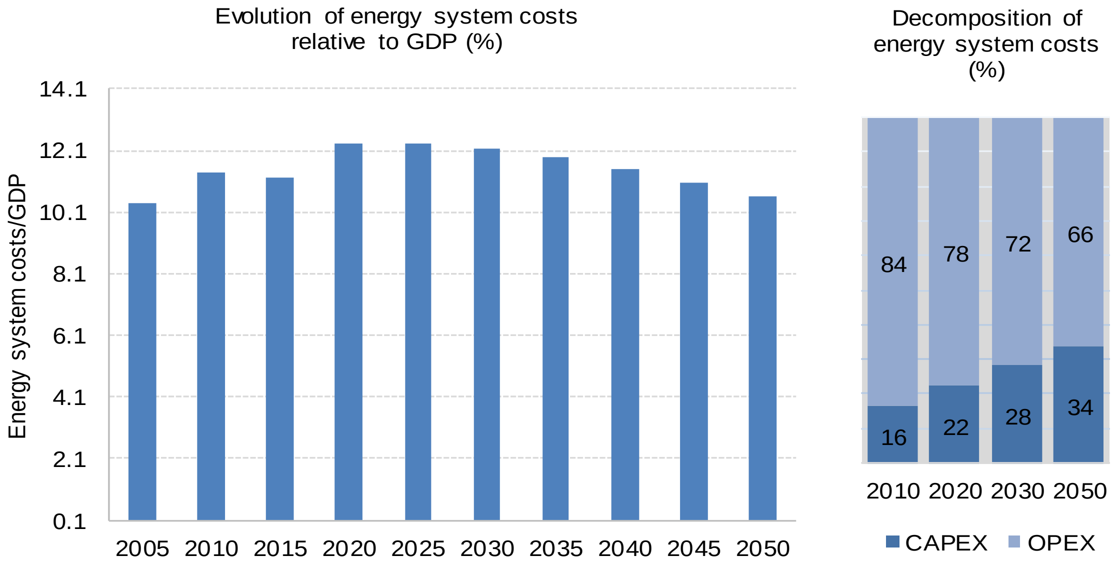

Figure 26: Projected evolution of energy system costs

Source: PRIMES, Energy system costs exclude ETS auction payments, given that they result in corresponding auction revenues.

3. Description of modelling set-up for the policy scenarios developed with PRIMES

Policy scenarios developed in this Impact Assessment rely first on a number of scenarios used in other impact assessments underpinning other 2016 Energy Union policy proposals, notably the Impact Assessments underpinning the Energy Efficiency Directive, the Effort Sharing Regulation, and the proposals on Electricity Market Design. All policy scenarios build on the EU Reference Scenario 2016[40].

In addition, coordination policies are assumed which enable long term decarbonisation of the economy. Coordination policies replace the "enabling conditions" which have been modelled in the 2030 framework Impact Assessment and the 2014 Impact Assessment on 2030 Energy Efficiency targets.

3.1. EUCO27

In October 2014, the European Council decided on the energy and climate 2030 framework.[41] The following was agreed among the Heads of States and Governments:

- Substantial progress has been made towards the attainment of the EU targets for greenhouse gas emission reduction, renewable energy and energy efficiency, which need to be fully met by 2020.
- Binding EU target is set of an at least 40% domestic reduction in greenhouse gas emissions by 2030 compared to 1990.

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[40] Full description of the EU Reference Scenario is available above

[41] http://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/145397.pdf.

- This overall target will be delivered collectively by the EU in the most cost-effective manner possible, with the reductions in the ETS and non-ETS sectors amounting to 43% and 30% by 2030 compared to 2005, respectively.
- A well-functioning, reformed Emissions Trading System (ETS) with an instrument to stabilise the market in line with the Commission proposal will be the main European instrument to achieve this target; the annual factor to reduce the cap on the maximum permitted emissions will be changed from 1.74% to 2.2% from 2021 onwards.
- An EU target of at least 27% is set for the share of renewable energy consumed in the EU in 2030. This target will be binding at EU level.
- An indicative target at the EU level of at least 27% is set for improving energy efficiency in 2030 compared to projections of future energy consumption based on the current criteria. It will be delivered in a cost-effective manner and it will fully respect the effectiveness of the ETS-system in contributing to the overall climate goals. This target will be reviewed by 2020, having in mind an EU level of 30%.
- A reliable and transparent governance system is to be established to help ensure that the EU meets its energy policy goals, with the necessary flexibility for Member States and fully respecting their freedom to determine their energy mix.

These requirements are reflected in the scenario called the European Council (EUCO) scenario with a 27% energy efficiency target for 2030 (EUCO27).

The table below summarises the assumptions on climate, renewable energy and specific energy efficiency policies in the EUCO27 scenario that have been modelled.

Table 1: Policy assumptions in EUCO27 scenario

EUCO27	**This scenario is designed to meet all 2030 targets set by the European Council:** • At least 27% share of renewables in gross final energy consumption • 27% primary energy consumption reduction (*i.e.* achieving 1369 Mtoe in 2030) compared to PRIMES 2007 baseline (1887 Mtoe in 2030). • At least 40% GHG reduction (wrt. 1990) • 43% GHG emissions reduction in ETS sectors (wrt 2005) • 30% GHG emissions reduction in Effort Sharing Decision sectors (wrt 2005) **Main policies and incentives additional to Reference:** **Revised EU ETS** • Increase of ETS linear factor to 2.2% for 2021-30 • After 2030 cap trajectory to achieve 90% emission reduction in 2050 in line with Low Carbon Economy Roadmap. **Renewables policies** • Renewables policies necessary to achieve 27% target, reflected by renewables values applied in electricity, heating & cooling and transport sectors. **Residential and services sector** • Increasing energy efficiency of buildings via increasing the rate of renovation and depth of renovation. In this model, better

	implementation of EPBD and EED, continuation of Art 7 of EED and dedicated national policies are depicted by the application of energy efficiency values (EEVs). • Financial instruments and other financing measures on the European level lowering the cost of capital for investment in thermal renovation of buildings. This, together with further labelling policies for heating equipment, is depicted by a reduction of behavioural discount rates for households from 12% to 11.5%. • More stringent (than in Reference[42]) eco-design standards banning the least efficient technologies. **Industry** • More stringent (than in REF2016) eco-design standards for motors. **Transport** • CO_2 standard for cars: 85g/km in 2025; 75g/km in 2030 and 25 gCO_2/km in 2050[43]. • CO_2 standards for vans: 135g/km in 2025; 120g/km in 2030; 60g/km in 2050[44]. • 1.5% average annual energy efficiency improvements for new conventional and hybrid heavy goods vehicles between 2010 and 2030 and 0.7% between 2030 and 2050. • Measures on management of transport demand: - recently adopted/proposed measures for road freight, railways and inland navigation[45]; - gradual internalisation of transport local externalities[46] as of 2025 and full internalisation by 2050 on the inter-urban network. **Non-CO_2 policies** • In 2030 carbon values of EUR0.05 applied to non-CO_2 GHG emissio order to trigger cost-effective emission reductions in these sectors inclu in agriculture. • After 2030, carbon values set equal to EU ETS carbon price level).

3.2. EUCO30 scenario

The table below summarises the assumptions on a specific energy efficiency policy scenario reaching a 30% energy efficiency target. As this scenario built on EUCO27, only the differences that illustrate the increases level of ambition are listed. Assumptions are further explained below the table.

Table 2: Assumptions in EUCO30 scenario

42 REF2016 does not include the revisions of existing ecodesign measures that are required by their implementing regulations or any future measures under this directive which are currently under discussion.

43 On current test-cycle

44 On current test-cycle

45 Directive on Weights & Dimensions, Fourth railway package, NAIADES II package, Ports Package

46 Costs of infrastructure wear & tear, congestion, air pollution and noise

<table>
<tr><td>EUCO30</td><td>As EUCO27 except:
30% primary energy consumption reduction target is set (i.e. achieving 1321 Mtoe in 2030) compared to PRIMES 2007 baseline (1887 Mtoe in 2030). This equals a reduction of primary energy consumption of 23% compared to historic 2005 primary energy consumption (1713 Mtoe in 2005).
Main policies and incentives additional to Reference:
<u>Energy efficiency policies:</u>
Residential and services sector
Further increasing of energy efficiency values compared to EUCO27.
More stringent (compared to EUCO27) eco-design standards banning the least efficient technologies.
Policies facilitating uptake of heat pumps
Transport
CO_2 standard for cars: 80g/km in 2025; 70g/km in 2030 and 25 gCO_2/km in 2050.
CO_2 standards for vans: 130g/km in 2025; 110g/km in 2030; 60g/km in 2050.
Additional measures on management of transport demand
- Modulation of infrastructure charges for HDVs according to CO_2 emissions leading to faster fleet renewal.
- Eco-driving.
- Deployment of Collaborative Intelligent Transport Systems.
Non-CO_2 emissions reduction policies
No policy incentive until 2030.</td></tr>
</table>

3.3. EUCO3030 scenario

This scenario builds on the EUCO30 scenario, but increases the share of renewable energy to 30%, via the use of renewables values mimicking further developments of unspecified policies across Member States and sectors. Other assumptions are kept the same as in EUCO30. The exception is the modelling of ETS and non-ETS: GHG emission reductions are allowed to go beyond the greenhouse gas reduction targets as agreed in the 2030 framework, both in the ETS (in practice the ETS carbon price trajectory was kept the same as in EUCO30) and the non-ETS sectors.

3.4. CRA scenarios and variants

CRA scenario

Building on the EUCO27 scenario, a specific renewable energy baseline policy scenario – reaching the same targets – was developed. Instead of focusing on a cost-effective development of renewable energy across the EU, it assumes the continuation of current support policies by Member State, and further differentiates investment costs assumptions in power generation across Member States and technologies. All other assumptions, notably as regards ETS and electricity market functioning, are kept unchanged. Regarding ETS in particular, the ETS price is an outcome of the modelling work.

The main characteristics of this scenario are described in the table below, with additional details on input assumptions provided afterwards.

Table 3: Assumptions in CRA scenario

CRA	**As EUCO27 except:** • Support schemes in 2020 reflect policy developments under preparation, mostly feed in premium schemes to be granted after auctions. This is different than in REF2016 or the EUCO scenarios, where only policies in place by end of 2014 were reflected, by construction of REF2016. • In contrast to Reference Scenario and EUCO scenarios, a continuation of Member States' support schemes policies for renewable energy in the power generation sector post-2020 is modelled; such policies phase out post-2030. • In contrast to REF2016 and EUCO Scenarios, additional differentiation in risk premium factors is applied to renewables technologies in the power sector (as add-ons) and these are differentiated by technology and by Member State (in REF2016 and EUCO Scenarios, no country-specific risk premiums are introduced). Regarding technologies, less mature technologies (with higher WACCs than onshore wind or solar PV for instance) include tidal, geothermal, offshore wind, biogas, biomass solid and bioliquids. Regarding Member States, differences in WACC reflect the outcome of the DiaCore project[47], but are recalibrated to be in line with the WACCs taken by PRIMES for other investment projects. • Renewables values for the power sector are put to 0 in 2025 and 2030 and replaced by detailed modelling of specific policies in power generation. • No Priority Dispatch as a general rule. Specific exemptions are applied for certain categories, *e.g.* (a) small scale renewables, (b) emerging technologies and (c) industrial CHP. • Grid connexion charges reflect current practices per Member State, which means notably deep costs (and not shallow) for offshore wind • Incentives, absence of them or even effective banning of certain resources from the market like self-generation and small scale generation reflecting current practices. This notably means no net metering allowed beyond what is considered in Reference scenario

CRA_regio

[47] See http://diacore.eu/

This variant builds on the main CRA scenario, but includes the following changes: instead of national support, support to renewables is being regionalised. Specifically, the EU is split into 5 main regions:

- Nordic/Baltic countries: this region includes the following countries: SE, FI, LV, LT, EE
- British Isles: this region includes the following countries: UK, IE
- Central Europe: this region includes the following countries: DK, NL, BE, LU, FR, DE, PL, HU, CZ, SK, SI, AT
- South East Europe: this region includes the following countries: IT, BG, RO, EL, CY, MT, HR
- Iberian Peninsula: this region includes the following countries: ES, PT

Concretely, this means that within each region, support levels are harmonised, per technology. In addition, the WACC assumed for investment decisions is also harmonised. Specifically, an average weighted WACC for the region is calculated, based on initial WACCs per Member State and taking account of the relative share in renewables investments in the CRA scenario for each country in the region. In addition, since a broad market at regional level implies broadening the funding, the procedures and the guarantees, a small reduction of the weighted average WACCs is being applied. The difference from the weighted average does not exceed 0.5pp.

It is also important to note that this variant aims at mirroring, to the extent possible, the overall renewables investment levels of the CRA scenario at EU level and within each region. This is necessary to ensure comparability of the results, and to test implications on deployment of renewables across countries and impacts on overall investment and system costs. As such, support levels necessary to reach the renewables deployment of the CRA scenario and ETS prices are an outcome of the modelling work.

CRA_crossborder

This variant is an intermediate case between the main CRA scenario, and the CRA_regio variant. Specifically, it has been constructed by assuming that it uses in 2030 85% of CRA assumptions (support levels and WACC) and 15% of CRA_regio. The percentages are 90% and 10% respectively in 2025.

CRA_countryspec

This variant builds on the CRA scenario, but assumes that for the Member States with the initially highest WACCs for renewables investment projects, a guarantee scheme is put in place, reducing the cost of debt of the project, and therefore the overall WACC. The assumption is that the WACC decreases by 15% for all technologies in the selected Member States. This scenario also tries to mirror overall renewables investment levels, to ensure comparability of the results, as mentioned above in the case of CRA_regio.

CRA_techspec

This variant focuses on the sector specific risks of renewables investments projects. That is, contrary to CRA_countryspec, the focus is not on specific Member States but rather on specific renewables technologies, namely, tidal, geothermal, offshore wind, biogas, biomass solid and bioliquids. These are the technologies with initially a risk premium in the CRA scenario as compared to more mature renewables technologies. As in

CRA_countryspec, a 15% decrease in the WACC is assumed for these projects, on the basis of the expected benefits of a guarantee of the debt finance of the project.

3.5. Modelling input parameters for the PRIMES scenarios and variants

RES values

Renewables policies necessary to achieve 27% target (in EUCO27 and in EUCO30) and 30% (in EUCO3030) are reflected by renewables values applied in electricity, heating and cooling and transport sectors. Renewables values are used in order to ensure cost-efficient renewables target achievement at European level.

The renewables value is a shadow price, a signal of potential costs per unit of renewable energy not achieved (relative to the target) which is internalized in the optimizing behaviours of actors and thus leads to higher renewables uptake. Renewables values do not describe in detail the renewables supporting policies, but are introduced if needed, in addition to the supporting policies, so as to complement them and reach the renewables target. The renewables value should not be confused with feed-in tariffs or green certificates, because it does not model any sort of power purchasing agreement with the renewables developers and the renewables projects compete on equal economic grounds with other forms of energy.

Renewables values needed to be slightly increased with more ambitious energy efficiency efforts in 2030 to achieve a share of renewables of at least 27%. They needed to be increased even more to reach a share of 30% renewables in the case of EUCO3030. However, as described above, the renewables values are significantly reduced in the CRA scenario, as they are replaced in the power generation sector by concrete policies, differentiated by Member State, and mimicking existing renewable support policies.

The decrease in renewables values for heating and cooling between Reference Scenario and policy scenarios is due to the impacts of additional energy efficiency in those scenarios.

Energy Efficiency values

The EEV, as described above in modelling terms, are used to simulate increasing energy efficiency obligations related to thermal integrity of houses and buildings, implying reduced consumption of fuels and electricity. Currently, such obligations are chiefly driven by the Art 7 of the EED but in addition some Member States have also put in place national policies aiming at renovation of the building stock (notably fiscal policies and financial incentives). As EEV increase step-wise by scenario and in time, they drive a faster pace of investments in renovations (as demonstrated by renovation rates) as well as increasing depth of renovations from an energy perspective (as demonstrated by the increased energy savings of the renovations). Other energy efficiency policies such as eco-design, labelling etc. act in addition to the EEV by influencing the choice of equipment technologies and their turnover over time.

All details on the use of energy efficiency values can be found in the Energy Efficiency Directive Impact Assessment. The table below shows, that significant energy efficiency values are needed to achieve higher energy efficiency levels. To achieve 23.9% of energy reductions in 2030, only EUR5 per toe are necessary. To achieve 27%, an EEV of EUR338 per toe is already needed. This values needs to be increased to EUR713 toe to achieve an energy efficiency level of 30% in 2030. No further changes were performed in the dedicated renewables scenarios, when compared to the EUCO scenario they build upon.

Table 4: Main policy variables

Main policy variables (2030)	**Ref2016**	**CRA**	**CRA_regio**	**CRA_crossborder**	**CRA_countryspec**	**CRA_techspec**	**EUCO27**	**EUCO30**	**EUCO3030**
Carbon price ETS sectors (EUR'13/ t of CO_2)	34	38	41	38	38	29	42	27	27
Carbon value non-ETS sectors (EUR'13/ t of CO_2)	0	0	0	0	0	0	0	0	0
Average Renewables value (EUR/ MWh)	11	4	4	4	4	4	7	16	58
Average Renewables value - Power generation (EUR/ MWh)	0	0	0	0	0	0	6	23	51
Average Renewables value - heating and cooling sector (EUR/MWh)	20	6	6	6	6	6	6	6	62
Average Renewables value - Biofuels support (EUR/MWh)	12	12	12	12	12	12	12	12	16
Energy efficiency value (EUR/ MWh)	5	338	338	338	338	338	338	713	713

Source: PRIMES

Modelling of Eco-design regulations

The Eco-design policy aims at reducing energy consumption of energy-related equipment and appliances by promoting product varieties which embed higher energy efficiency. Depending on implementing measures and voluntary agreements, the eco-design regulations certify specific energy consumption by product variety and eventually provides for mandatory requirements for certain products. The requirements impose a minimum bound on energy performance of products. The bounds are set for the next two to five years. This implies that the menu of technologies for consumer choices in the future is restricted to product varieties which have performances exceeding the minimum threshold value. The menu will still allow selecting technologies which perform above minimum threshold value; the choice will depend on relative costs, perception of technical risks and the policy context. The Eco-design regulations, combined with the labelling directive, are playing an important role to remove uncertainties regarding technical risks and those stemming from lack of information.

PRIMES considers equipment in an aggregated manner, looking at the equipment performance in heating and cooling, water heating, cooking, lighting and (white and black) appliances.

REF2016 is assumed to include the currently adopted eco-design regulations. The effects additional of Eco-design regulations are then simulated to intensify towards the 2030 horizon relative to REF2016 and across the energy efficiency scenarios. Moving from 2030 to 2050, the effects are simulated to intensify further relative to the 2020-2030 period and approach technical potential in the very ambitious cases. The learning effects are modelled to be relatively lower until 2030 than after 2030.

Modelling of transport policies

CO_2 standards for new cars and light commercial vehicles

The tightening of CO_2 standards post-2020 is a key assumption, leading to improvements in energy efficiency and CO_2 emissions reduction in transport. The CO_2 standards assumed in the policy scenarios are provided in Table 5 for cars and in Table 6 for light commercial vehicles.

Table 5: Assumptions on CO_2 standards (gCO_2/km) for new cars across scenarios[48]

Scenario	**CO_2 standards (gCO_2/km) for new cars**		
	2025	**2030**	**2050**
EUCO27	85	75	25
EUCO30	80	70	25

Source: PRIMES

Table 6: Assumptions on CO_2 standards (gCO_2/km) for new light commercial vehicles across scenarios[49]

Scenario	**CO_2 standards (gCO_2/km) for new light commercial vehicles**		
	2025	**2030**	**2050**
EUCO27	135	120	60
EUCO30	130	110	60

Source: PRIMES

Vehicle efficiency of new heavy duty vehicles

The following improvements in specific fuel consumption of new heavy duty vehicles were assumed:

- 1.5% per year on average in all scenarios. EUCO27, EUCO30

48 On current test-cycle
49 On current test-cycle

Recently adopted/proposed measures

Measures adopted after the cut-off date of Reference scenario 2016 (*i.e.* Directive on Weights & Dimensions[50]) and measures already adopted by the Commission and in discussion by co-legislators (*i.e.* Fourth railway package[51], NAIADES II package[52], and the Ports Package[53]) are assumed to apply in all scenarios. The input for modelling draw on the respective Impact Assessments.

Fair and efficient pricing for sustainable transport

Gradual internalisation of the costs of infrastructure wear & tear, congestion, air pollution and noise in the pricing of road transport on the inter-urban network is assumed from 2025 onwards. For rail, internalisation of the costs of air pollution, noise and congestion is assumed from 2030 onwards; for inland waterways internalisation of the costs of air pollution is assumed from 2030 onwards. In scenarios EUCO27 and EUCO30, the levels of the charges are gradually increased from 2025/2030 to 2050, when they become equal to the values of the 2014 Handbook on external costs of transport[54]

Modulation of the infrastructure charges according to CO_2 emissions for heavy goods vehicles (HGVs) is assumed to apply in all scenarios except for EUCO27; it is assumed to apply on the inter-urban network from 2025 onwards. Starting from the average infrastructure charge in each Member State, a linear incremental variation is assumed for HGVs with higher emissions than average; a similar linear variation is assumed for HGVs with lower emissions than average (by HGVs category). The measure is assumed to apply similarly to the Euro class-differentiation of network-wide tolls and implies revenue neutrality.

Collaborative Intelligent Transport Systems (C-ITS)

Deployment of C-ITS in road transport has been assumed in all scenarios except for EUCO27.

1. In scenarios EUCO30, the input assumption for modelling draws on the central scenario of a Cost Benefit Analysis (CBA) study carried out by Ricardo AEA[55]

Eco-driving

Promotion of eco-driving is assumed in all scenarios except for EUCO27; the input assumption used for modelling draw on "EU Transport GHG: Routes to 2050?" project.[56] It is assumed that virtually all drivers would be trained by 2050 (for road and rail). Savings from training decline to 2050 due to technology effects. No variation in the level of intensity of the measure is assumed between scenarios.

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50 SWD(2013)109 final

51 SWD(2013) 10 final

52 SWD(2013) 324 final

53 SWD(2013) 181

54 Source: http://ec.europa.eu/transport/themes/sustainable/internalisation_en.htm

55 Source: http://ec.europa.eu/transport/themes/its/c-its_en.htm

56 "EU Transport GHG: Routes to 2050?" final report is available at: http://www.eutransportghg2050.eu/cms/assets/EU-Transport-GHG-2050-Final-Report-22-06-10.pdf

Coordination policies

In this modelling exercise, all scenarios (except Reference) achieve decarbonisation in 2050 and hence assume an overall policy framework which enables this. Given that concrete policies will most likely have to be proposed in order to fulfil the necessary conditions in infrastructure, technology, market coordination, the elements of this framework which go beyond the drivers and policies specified in the policy scenarios are called coordination policies. Coordination policies replace the "enabling conditions" which have been modelled in the 2030 framework IA (in decarbonisation scenarios) and the 2014 IA on energy efficiency target.

In the past modelling exercises, enabling conditions were present in all decarbonisation scenarios. Enabling conditions meant that because of good anticipation of future GHG emission reduction commitments, all conditions were met in infrastructure, technology learning, public acceptance and market coordination so as to enable the decarbonisation. In other words, enabling conditions enabled to maximize the effectiveness of policy instrument which aim at driving strong GHG emission cuts. These enabling conditions were fully costed in decarbonisation scenarios.

These assumptions have been revisited considering that concrete policies will most likely have to be proposed in order to fulfil the necessary conditions in infrastructure, technology, market coordination, etc. Consequently, enabling conditions are replaced by coordination policies as indicated in the list included in Table 7. These coordination policies will be proposed by the Commission post 2020. Coordination policies are fully costed in the scenarios, as it was the case with enabling conditions. It is important to make a distinction between 2 types:

- coordination policies related to ongoing infrastructure developments that will enable a larger exploitation of cost-effective EE, RES, GHG abatement options after 2020.
- coordination policies related to R&D and public acceptance that are expected to be needed to meet long term decarbonisation objectives, and have effects post 2030

Table 7: Summary of coordination policies assumed

Enabling conditions in the 2030 Impact Assessment	New approach
Intelligent grids and metering (also for EVs)	Coordination policy post 2020 (Partly accomplished in REF2016 2016 - implementation of the 3rd Internal Energy Market package).
Infrastructure to harvest decentralised as well as remote RES for power generation	Coordination policy post 2020
Carbon transportation and storage infrastructure and acceptance	coordination policy post-2030 (CCS is indispensable for decarbonisation towards 2050)
Gas and hydrogen: (technological progress enabling mix of hydrogen and bio-gas in gas supply and possibility to use hydrogen-	coordination policy post-2030 (advanced storage is necessary and in that time perspective)

Enabling conditions in the 2030 Impact Assessment	New approach
based storage for balancing RES power)	
Battery technology development (for electric and plug-in hybrid vehicles) and fuel cells	Reference scenario 2016 has assumptions on battery technology development and fuel cells which are rather conservative, consistent with the logic of a Reference scenario, *i.e.* without additional policies stimulating R&D, infrastructure or purchase. For the decarbonisation scenarios, increased R&D, expectations and learning effects lead to lower technology costs for electrification technology (for electric and plug-in hybrid vehicles) and fuel cells.
Recharging infrastructure	Coordination policy post 2020 (based on the Directive on the deployment of alternative fuels infrastructure)
Market acceptance (of electrification)	Coordination policies post 2020 (supported by the implementing measures following the Directive on the deployment of alternative fuels infrastructure)
Innovation in biofuels	Coordination policy with impacts post 2030 These are biomass related innovation and agriculture policies assumed to develop so as to allow the development of new generation bio-energy feedstock (basically lingo-cellulosic crops) at large scale. As a result, a new industry would emerge ranging from agriculture, industrial-scale collection and pre-treatment, bio-refineries with new conversion technologies, product standardization and commercialisation.
Overcoming some market barriers to Energy Efficiency in Buildings	Part of 2020-2030 policy mix as described in assumptions on policy options.
Heating equipment and appliances technology uptake in the domestic sector	As above
Energy efficiency innovation diffusion in Industry	As above

4. Set-up of modelling scenarios in the various impact assessments underpinning the 2016 energy union policy proposals

This section aims at describing how modelling scenarios were designed, how they can be used to describe a baseline or policy scenario and which questions they try to address in the Impact Assessments (IA) underpinning the various 2016 Energy Union proposals.

Role and use of the EU Reference Scenario 2016

A common starting point to all Impact Assessments is the EU Reference Scenario 2016 ('REF2016'). It projects greenhouse gas emissions, transport and energy trends up to 2050 on the basis of existing adopted policies at national and EU level and the most recent market trends. This scenario was prepared by the European Commission services in consultation with Member States. All other PRIMES scenarios build on results and modelling approach of the REF2016.

Although REF2016 presents a comprehensive overview of the expected developments of the EU energy system on the basis of the current EU and national policies, and could be considered as the natural baseline for all IA, it fails doing so for an important reason. This scenario does not have in place the policies to achieve the 2030 climate and energy targets that are already agreed by Member States in the European Council Conclusions of October 2014. It also does not reflect the European Parliament's position on these targets.

Therefore, although it was important for all initiatives to have a common "context" in order to ensure coherent assessments, each Impact Assessment required the preparation of a specific baseline scenario, which would help assess specific policy options relevant for the given Impact Assessment.

A central policy scenario: EUCO27

Because of the need to take into account the minimum agreed 2030 climate and energy targets (and the 2050 EU's decarbonisation objectives) when assessing policy options for delivery of these targets, a central policy scenario was modelled. This central policy scenario, (called "EUCO27"), reaches by construction the 2030 targets (40% greenhouse gas emissions reductions compared to 1990, a split of 43% and 30% in emissions reduction between the ETS and ESD sectors, compared to 2005, a share of renewables of 27% and an energy efficiency target of 27%).

Concrete specifications on assumptions were made by the Commission in order to reach the relevant targets by using a mix of concrete and yet unspecified policies. A detailed description of the construction of this scenario is presented in Chapter 4 of the EED IA and in its Annex IV.

This scenario is the central scenario for all Impact Assessments. Additional baseline and/or policy scenarios were prepared for each Impact Assessment, addressing the specific issues to be assessed by each initiative, notably which measures or arrangements have to be put in place to reach the 2030 targets, how to overcome market imperfections and uncoordinated action of Member States, etc.

This approach of separating a central policy scenario reaching the 2030 targets in a cost-effective manner and specific scenarios that look into specific issues related to implementation of cost effective policies enables to focus on "one issue at a time" in the respective separate analysis. It enabled to assess in a manageable manner the impacts of several policy options and provide elements of answers to problems specified in the respective 2016 Impact Assessments, without the need to consider the numerous possible combinations of all the options proposed under each respective initiative.

The Impact Assessment accompanying the proposal on an Effort Sharing Regulation (ESR)

The EUCO27 and EUCO30 scenarios were used in the Impact Assessment underpinning the Effort Sharing Regulation Proposal of July 20 2016 to assess the implications for specific Member States of setting national targets to reduce greenhouse gas emissions in the ESR sectors, following the guidance provided by EU leaders to use a methodology that reflects fairness, solidarity and cost-effectiveness.

In this Impact Assessment, the projections in the non ETS sectors of the EUCO27 and EUCO30 scenarios, representing the cost effective implementation of the agreed 2030 climate and energy targets, are compared with 2030 targets defined purely on the basis of GDP per capita criterion only, as well as other important elements such as starting point of the target trajectory and additional flexibilities, to assess any concerns related to cost efficiency, fairness and environmental integrity.

The Impact Assessment accompanying the proposal for the revision of the Energy Efficiency Directive

Regarding the Impact Assessment accompanying the proposal for a revised Energy Efficiency Directive, one central question to be addressed concerned the level of the energy efficiency target for 2030. This reflects the European Council conclusions from October 2014 which leave the issue of 2030 energy efficiency target still open.

In this context, the baseline is a situation where the EU would achieve the minimum commonly agreed target among the three EU Institutions, that is, 27% energy efficiency, or the EUCO27 policy scenario. Additional policy scenarios were then developed leading to higher energy efficiency levels, notably the EUCO30 scenario as well as scenarios achieving energy efficiency savings going up to 40% (30, 33, 35 and 40% respectively). The additional policy scenarios were then compared to EUCO27 baseline in order to identify the impacts of increasing energy efficiency level only.

The Impact Assessment accompanying the proposal for the revision of the Renewable Energy Directive

Regarding the Impact Assessment accompanying the proposal for a revised Renewable Energy Directive, various scenarios are developed, building on the central EUCO27 policy scenario. Each scenario focuses on specific issues to be addressed in each renewable energy sector, namely, electricity, heating and cooling, and transport.

Regarding the electricity sector, a scenario was built focusing on what the continuation of current practices would mean for reaching the overall RES target. In fact, EUCO27 considers harmonised additional incentives to renewable electricity projects as well as the same financing conditions across Member States (but not technologies) for renewable electricity investments over the 2020-2030 period. Contrary to the EUCO27 scenario, the baseline scenario (so-called Current Renewables Arrangement – 'CRA') models continuation of current national specific renewable support schemes, designed at national level, also after 2020, in order to reach the 27% target. A continuation of differences in investment environments and financing conditions for renewable electricity projects across Europe is therefore assumed. Additional details on the construction of the CRA scenario are presented above. Policy scenarios build on this baseline scenario by testing the impacts of various designs and scopes of renewable support schemes, direct financial support or collaboration across borders to develop renewable electricity projects with the aim of establishing which policies can contribute best to further improve cost efficiency related to renewables deployment.

Regarding the heating and cooling sector, the EUCO27 scenario considers a set of yet unspecified policies in the heating and cooling sector, contributing in a cost effective manner to achieving the overall 2030 target. However, given the absence of evidence of concrete policies by Member States post-2020, it is also relevant to consider as a baseline scenario a case where such policies would not materialise. REF2016 was then used as an approximation for such a baseline scenario. Various policy options are then compared to this baseline, with in mind comparing policies that could ensure a deployment of renewables in the heating and cooling sector in line with deployment occurring in the central policy scenario.

Finally, for the transport sector, it is pertinent to consider as baseline the EUCO27 scenario. Under this scenario, Member States, as in REF2016, are assumed to maintain post-2020 biofuels blending obligations, where those exist thus maintaining the 7% cap on food-based bio-fuels. The key policy question to be assessed for this sector concerns the implications of additional policies promoting the use of advanced biofuels and the phase-out of food-based biofuels as well as dedicated measures for maritime and aviation sector. Policy scenarios used to illustrate different choices in these matters build on the EUCO30 scenario in order to keep consistency with scenarios used in Strategy for Low-emission Mobility (see below) and for the reasons specified below. These policy scenarios are, in some cases, more ambitious in terms of the transport sector contribution to the overall 2030 RES target, which would imply smaller role of other sectors.

Staff Working Document accompanying Strategy for Low-emission Mobility

While the SWD does not analyse policy options like an IA would do, it analyses impacts of the EUCO27 and EUCO30 scenarios in transport sector and presents several pathways/scenarios that are even more ambitious options in three fields: low- and zero-emission vehicles; low emission alternative energy for transport; efficiency of the transport system. Those additional, more ambitious pathways/scenarios are built on EUCO30 scenarios in order to combine ambitious energy efficiency with other actions. Two key scenarios on bio-fuels (BIO-A and BIO-B) are common with the transport section of the IA for revision of the Renewable Energy Directive. In addition, the same transport-related measures have been used to define the more ambitious pathways/scenarios in the SWD on Low-emission mobility and the more ambitious policy options in the Energy Efficiency Directive IA; they have been however packaged differently to address their respective purpose.

The Impact Assessment accompanying the Market Design Initiative

Similar to the other 2016 Energy Union initiatives, EUCO27 was chosen as the starting point (*i.e.* context) of the baseline for the Market Design Initiative (so-called "Current Market Arrangements" – CMA). The EUCO27 scenario is the most relevant to the objectives of the initiative, as it provides information on the investments needed and the power generation mix in a scenario in line with the EU's 2030 objectives.

As all analysis focuses on the power sector, all assumptions exogenous to the power sector were taken from the EUCO27 scenario. This also applied for the energy mix, the power generation capacities at each period, the fuel and carbon prices, electricity demand, technology costs etc. The scenario achieves the 2030 targets as in EUCO27.

However and importantly, the CMA scenario differs from the EUCO27 scenario by including existing market distortions, as well as current practices and policies on national and EU level. It assumes implementation of the Network Codes, including the Capacity Allocation and Congestion Management and the Electricity Balancing Guidelines (the latter in their proposed form). CMA does not consider explicitly any type of existing support schemes for power generation plants, neither in the form of RES-E subsidies nor in the form of capacity remuneration mechanisms. A full description of this scenario is included in Annex IV of the Market Design Impact Assessment. Policy scenarios are then prepared to address specific issues covered by the market design initiative, and are compared to the CMA baseline scenario.

Higher energy efficiency levels and the role of the EUCO30 scenario

Because the specific target for energy efficiency in 2030 remains an open question, it was also necessary to take into account in all Impact Assessments the potential impacts of higher energy efficiency levels, notably of 30% target which is explicitly mentioned by the European Council conclusions. The achievement of this 30% energy efficiency target, in combination with other agreed 2030 targets, is illustrated by the 'EUCO30' scenario.

The EUCO30 scenario is one of the policy scenarios investigated in detail in the Energy Efficiency Impact Assessments and one of the central scenarios used in the SWD accompanying the Strategy for Low-emission Mobility. It was also used in the Effort Sharing Regulation Impact Assessment to test the potential implications of higher energy efficiency levels on the cost-effective level of greenhouse gas emissions reductions at Member State level in the non-ETS sector.

The EUCO30 scenario results are also presented in the Renewable Energy Directive Impact Assessment. Regarding the electricity market design, changing the level of energy efficiency has marginal effects on the issues to be addressed in the power generation sector, and therefore this scenario is not used for comparing results of policy options in that sector. Regarding the heating and cooling sector, the implications are, however, more significant, and therefore, this issue is addressed in more detail in the relevant sections of the Impact Assessment.

Likewise, in the transport sector, the policy scenarios presented in the Renewable Energy Directive Impact Assessment build on the results of the EUCO30 scenario. This is because compared to EUCO27 scenario, EUCO30 includes a set of specific energy efficiency policies in the transport sector which have a bearing on policy options directly related to the use of biofuels. For instance, EUCO30 leads to higher market penetration of electric vehicles, which needs to be taken into account before looking at the remaining needs for additional biofuels policies.

5. Description of analytical models used – other models

5.1. Whole-electricity System Investment Model (WESIM)[57]

WESIM is a comprehensive electricity system analysis model simultaneously balancing long-term investment-related decisions against short-term operation-related decisions, across generation, transmission and distribution systems, in an integrated fashion. In this context, WESIM is a holistic model that enables optimal decisions for investing into generation, network and/or storage capacity (both in terms of volume and location), in order to satisfy the real-time supply-demand balance in an economically optimal way, while at the same time ensuring efficient levels of security of supply. A key feature of WESIM is in its capability to simultaneously consider system operation decisions and infrastructure additions to the system, with the ability to quantify trade-offs of using alternative smart mitigation measures, such as DSR, new network technologies and distributed energy storage, for real-time balancing and transmission and distribution network and/or generation reinforcement management. The model also captures potential conflicts and synergies between different applications of distributed resources (*e.g.*

[57] Source: http://www.wholesem.ac.uk/documents/icl-model-summary

demand side response - DSR) in supporting variability management at the national level and reducing necessary reinforcements in the local distribution network.

The objective function of WESIM is to minimise the overall system cost, which consists of cost of investment in generation, network, interconnection and emerging flexible network, storage and DSR technologies and cost of operating the system, which includes generation operating cost and cost of supply interruptions. The problem is subject to power balance constraints, reserve and adequacy constraints, carbon emission constraints, power flow limits in transmission, distribution and interconnection, generation plants' dynamic characteristics, and DSR and storage operational constraints.

WESIM can be used to assess the electricity infrastructure development and system operation within UK or EU. Different network topologies are generally used to balance the complexity and accuracy of modelling. Different levels of market integration can be modelled in WESIM through distinctive levels of energy exchanges cross-border, sharing of security or various operating reserves, *e.g.* country, regional, EU levels. WESIM optimises the generation, storage, and DSR dispatches taking into account diversity of load profiles and renewable energy profiles (hydro, wind, PV, CSP) across Europe, in order to minimise the additional system capacity to meet security requirements.

Regarding the local distribution networks, WESIM uses a set of representative networks that follow the key characteristics of different type of real GB (and EU member states) distribution network. These representative networks are calibrated to match the actual electricity distribution systems. The mismatches in control parameters between the actual GB and representative networks characterised using this process, are less than 0.1%.

Regarding DSR modelling, WESIM broadly distinguishes between the following electricity demand categories: (i) weather-independent demand (ii) heat-driven electricity demand (space heating / cooling and hot water), (iii) transport demand and (iv) smart appliances' demand. Different demand categories are associated with different levels of flexibility. Losses due to temporal shifting of demand are modelled as appropriate. Flexibility parameters associated with various forms of DSR are obtained using detailed bottom-up modelling of the different types of DSR.

5.2. Description of the modelling set-up for the policy options tested with WESIM

Hourly electricity prices are modelled with WESIM for five separate years: 2020, 2025, 2030, 2040 and 2050. The scenarios modelled used a number of common assumptions, as presented in the table below.

Table 8: Common assumptions

Assumption	Description
Price base	Monetary values are in Euros and were converted to 2015 price base.
Modelling Years	2020, 2025, 2030, 2040, 2050
Countries modelled	• All EU Member States (28 countries) • Non-EU countries: Switzerland, Norway, Albania, Serbia, Montenegro, Bosnia, Macedonia.

Hourly demand profiles	Hourly demand was derived using PRIMES annual electricity demand projections in combination with hourly demand profiles taken from ENTSO-E's TYNDP 2016.[58] The following demand profiles were used: • 2020: ENTSO-E's 'Expected 2020' hourly demand profiles by country. • 2025: Apply the average of 2020 and 2030 hourly profiles, *i.e.* if the weighting of hour one in 2020 was 1% and the weighting of hour one in 2030 was 2%, use a weighting of 1.5% for hour one in 2025. • 2030: ENTSO-E's 'Vision 3' hourly demand profiles. • 2040/2050: Assume no change in demand profile after 2030. Peak demand was calculated as the maximum hourly demand (GW) for a given country in a given year.
Fuel prices	Coal, oil and gas prices were taken from PRIMES and converted to constant 2015 prices. Biomass fuel cost forecasts were supplied by Parsons Brinkerhoff and uranium prices from ENTSO-E's TYNDP 2016.
ETS prices	Taken from PRIMES EUCO27 scenario results
Technology costs (RES-E)	Fixed and variable O&M costs: provided by Parsons Brinkerhoff. Capex costs: sourced from PRIMES.
Technology costs (Conventional technologies)	Fixed and variable O&M: provided by Imperial College London. Capex costs: Build on PRIMES
RES-E generation profiles	Country and technology specific generation profiles were used to capture variable renewables generation. These were based on profiles used for the EC's Roadmap 2050 study.
Electricity storage	Assumed only pumped hydro storage. Distribution level storage was not captured, as WESIM does not model distribution networks.

Results from PRIMES scenarios were used to calibrate the deployment mix for both renewable and conventional technologies in EU Member States. Still, due to difference in models, some unavoidable differences remain in the exact power generation mix between the two approaches. The table below summarises the links between the WESIM scenarios and the PRIMES scenarios.

In addition, the same approach was followed to calibrate WESIM for each Member State's annual electricity demand. As an input, WESIM used data on final electricity demand, plus transmission and distribution losses as a measure for annual electricity demand.

[58] Malta is not a member of ENTSO-E. However, we received 2015 hourly electricity demand data from the Maltese energy regulator, and following an assessment of the similarities in the load profile between Malta and Cyprus we opted to use the ENTSO-E load profile for Cyprus, as a proxy for Malta's projected load profile.

For non-EU countries, deployment scenarios were developed based on ENTSO-E TYNDP 2016 forecasts where possible, supplemented by forecasts from National Renewable Electricity Action Plans (primarily for the Balkan countries). No change in capacity mix was assumed after 2030 for these countries. Projections from ENTSO-E's TYNDP 2016, Vision 3 were used for electricity demand.

Table 9: PRIMES sources for the different WESIM scenarios

	Scenario	Deployment scenario
1	WESIM27	PRIMES EUCO27
2	WESIM30	PRIMES EUCO30
3	Removal of preferential market rules	PRIMES EUCO27

Interconnection capacity was calibrated in WESIM using ENTSO-E's TYNDP 2016. Assumptions on transmission capacity were equivalent across scenarios/ sensitivities. As part of WESIM's cost minimisation algorithm, WESIM also endogenously adds additional interconnection capacity if it was efficient to do so. The following assumptions:

- 2020: Used ENTSO-E reference interconnection capacities for 2020 as an input into WESIM.
- 2025: Transmission capacity of projects of common interest (PCIs) with a commissioning date on or before 2025 were added to the 2020 capacity values. Capacity and commissioning dates for PCIs were taken from ENTSO-E TYNDP 2016.
- 2030: Used ENTSO-E interconnection capacities for 2030 as an input into WESIM.
- 2040/50: No additional interconnection capacity was assumed to have been installed after 2030. WESIM's optimisation process forecast additions to interconnection capacity.

Demand response is another important assumption for this modelling work. The characterisation of DSR is based on the concept of achievable potential, which describes the total amount of demand resources that could be realistically expected to be deployed if enabling policies are put into practice. In the modelling, a distinction was made between curtailable DSR and shiftable DSR, with the split between the two being 60:40 in terms of overall achievable potential. Differentiation between countries was also performed based on the level of DSR they would likely require in the future given renewables penetration and additional needs for flexibility in the electricity system. The table below shows the level of achievable potential assumed across scenarios/ sensitivities, defined as a % of daily electricity demand.

Table 10: DSR potential

Curtailable DSR potential	Shiftable DSR potential	Total DSR potential
6%	4%	10%

Finally, the last important assumption for this modelling work concerns priority dispatch. Priority dispatch is a market access rule which places an obligation on transmission system operators to schedule and dispatch RES-E generators ahead of all other types of generation. The purpose of priority dispatch is to provide certainty to renewable generators that they will be able to sell electricity into the grid at all times (reducing volume risk) and to enable a more rapid integration of RES-E generators into the power system. Currently, priority dispatch is being combined with other forms of support (*e.g.* FITs & CfDs in UK) that make it profitable to sell electricity on the wholesale market at any price (even below marginal cost). It is implemented for renewable electricity generators, but is relevant only for those with non-zero marginal costs, namely biomass. By default, it is assumed that renewable would continue to receive priority dispatch indefinitely. However, a sensitivity was conducted in which priority dispatch for all renewables was removed from 2020 onwards.

ANNEX 5 - KEY INDICATORS

1. Options to increase renewable energy in the electricity sector (RES-E)

This section presents an overview of the detailed numerical results used in section 5.1. of the Impact Assessment to analyse and compare the different policy options. First, a detailed discussion is included on the potential funding gap that an absence of support schemes for renewable electricity projects would entail. Second, the relevant results of the various PRIMES runs used to assess and compare options are presented.

1.1. Detailed analysis on viability of RES projects and on the need for support schemes in the electricity sector post-2020

This subsection presents in detail the modelling approaches and the results of an analysis of the impacts of the absence of support schemes on the viability of renewables projects over the 2020-2030 period, as summarised under the assessment of policy options in section 5.1 of this Impact Assessment.

Lessons learned from the main PRIMES scenarios

EU Reference Scenario 2016

The EU Reference Scenario 2016 (REF2016) assumes no additional policies post-2020. From a RES perspective, it means no additional policy support beyond the already adopted policies and the assumed additional policies necessary to implement the current EU acquis in the RES area, namely reaching the binding 2020 RES targets.

In this context, by 2020, RES in power generation are projected to increase to 35.5% (RES-E indicator) or 37.2% of net electricity generation, of which 52% are projected to be variable RES (wind and solar). Beyond 2020, support schemes are phased out and further investments in RES are driven by market forces, the ETS and the improvement in the techno-economic characteristics of the technologies.

Still, such additional investments are insufficient to contribute to achieving the 27% RES target. Overall, RES-E reaches 42.5% in 2030 (RES-E indicator), or 42.8% of net electricity generation.

To conclude, no additional policy in any energy or climate field beyond 2020 would lead to a shortfall in RES investments, hampering the achievement of the RES (and of the GHG emission reductions) targets. However and importantly, many initiatives have been or will be implemented in various relevant climate and energy fields, and therefore, REF2016 only very partially answer the question on the need for additional support schemes for renewable energy.

The EUCO27 scenario

As opposed to REF2016, the EUCO27 scenario was constructed with in mind a cost-effective achievement of the 2030 climate and energy targets. A detailed description of this scenario is presented in Annex 4.

This scenario assumes implemented the proposal for a revised ETS post-2020, including a new linear reduction factor. It also models a set of concrete policies in the field of energy efficiency and transport, as well as some additional unspecified policies via the use of energy efficiency values in the residential and tertiary sectors. This scenario also considers improved electricity market functioning and uses RES values to model yet unspecified dedicated policies in the RES sectors to reach the 27% target. In the electricity sector, such RES values are on average equal to 6 €/MWh. Finally, under this scenario, financing conditions are assumed to be the same across Member States (similar WACC) as specific country risks, as in Reference Scenario, are assumed inexistent.

Under this scenario, the RES-E share reaches 47.3% in 2030, or 47.6% of net electricity generation. Installed capacity for RES technologies increases by 34% between 2020 and 2030.

This scenario suggests that under the right framework conditions, namely a reformed ETS, good electricity market functioning, a cost effective set of energy efficiency policies, and equal financing conditions across the EU, it is possible for the majority of RES investments to develop such that they effectively contribute to the overall achievement of the RES target. However, there remains a gap, visible because RES-E values had to be used in the model to trigger the necessary investments to achieve a 27% share of renewable energy by 2030.

The EUCO30 scenario

Similar to the EUCO27 scenario, this scenario aims at reaching 2030 targets (in this case 30% energy efficiency in addition to 40% GHG emissions and 27% RES), in a cost effective manner. Again, in this scenario, RES-values are used to simulate the impact of unspecified policies necessary to reach the 27% RES target. The average renewables value is 16€/MWh, more than in the EUCO27 scenario. This implies that more stringent policies would be needed to reach the 27% RES target in case of a more ambitious energy efficiency target. This result is explained by the higher RES value used in the electricity sector (23€/MWh instead of 6€/MWh), which, in turn, is the result of a lower ETS carbon price in EUCO30 than in EUCO27. In other words, this scenario suggests that the investment gap for RES-E projects would increase in the case of more ambitious energy efficiency policies, as such policies tend to decrease the carbon price needed to reach the ETS target, and therefore make renewable electricity projects relatively less profitable.

The CRA scenario

In contrast to the EUCO27 scenario, the CRA scenario is based on the assumption of the continuation of current Member States policies and practices in the renewable energy field. The description of this scenario is detailed in Annex 4, and has similar assumptions in non-RES-related policy fields than the central policy scenario (EUCO27).

The first assumption that this scenario considers is that Member States continue supporting renewable electricity projects, on a national basis, with no additional provision considered in the Revised RES Directive. Potential provisions would be left entirely to the revised, post-2020 State Aid guidelines. Therefore, a continuation of nationally-based support schemes is assumed, while complying with the current State-Aid guidelines provisions. The second assumption made is that Member States support renewable electricity projects in such a way that the overall 27% RES target is achieved.

The third assumption made for the preparation of this baseline scenario is that current distortions in the financing cost of renewable electricity projects across countries remains until 2030.

Regarding other assumptions, this scenario assumes, as in the central policy scenario (EUCO27) an improved functioning of the ETS, in line with the Commission's proposal for a revised ETS, as well as efficient market functioning. In other words, this scenario differs in its design compared to the EUCO27 scenario via two main features: i/ the cost-effective support reflected by the use of similar RES-E values across Member States in the EUCO27 scenario is replaced by explicit, nationally-based and differentiated support schemes; and ii/ financing conditions for RES projects differ per Member State.

Under this scenario, as under any other PRIMES scenario, the RES investments resulting from the overall policy and economic context as well as incentives 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 from the financial incentives are considered as given by the market model which then 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. In that respect, this scenario does not try to directly answer whether an investment gap would necessarily emerge, but rather that the continuation of current policies and practices would lead to policy support driving more than half of EU investments in renewable electricity projects.

More specifically, one of the results of the CRA scenario is that 59% of RES investments over the 2021-2025 period would be based on public support. This share decreases to 51% for the 2026-2030 period. The following table presents the split by technology and by region. The results show mature RES technologies can be more easily financed without public support, in particular in regions with the highest potential (*e.g.* Southern Europe for solar, Nordic region for wind onshore). Differences also exist in general between regions, as RES projects seem in general less profitable in British Isles and Central Europe than in other regions.

% of GW new investment driven from support schemes (CRA scenario		2021-2025	2026-2030
Nordic region	Wind onshore	16%	21%
Nordic region	Wind offshore		
Nordic region	Solar and other		100%
Nordic region	Biomass solid	0%	0%
Nordic region	**Sum**	**15%**	**19%**
British Isles	Wind onshore	100%	100%
British Isles	Wind offshore	100%	100%
British Isles	Solar and other	100%	100%
British Isles	Biomass solid	100%	100%
British Isles	**Sum**	**100%**	**100%**
Central Europe	Wind onshore	81%	58%
Central Europe	Wind offshore	98%	100%

Central Europe	Solar and other	67%	22%
Central Europe	Biomass solid	93%	91%
Central Europe	**Sum**	**84%**	**61%**
Southern Europe	Wind onshore	0%	0%
Southern Europe	Wind offshore	100%	100%
Southern Europe	Solar and other	1%	4%
Southern Europe	Biomass solid	18%	58%
Southern Europe	**Sum**	**2%**	**2%**
Iberian Peninsula	Wind onshore	15%	1%
Iberian Peninsula	Wind offshore	100%	100%
Iberian Peninsula	Solar and other	20%	26%
Iberian Peninsula	Biomass solid	38%	27%
Iberian Peninsula	**Sum**	**19%**	**20%**
EU28	**Sum**	**59%**	**51%**

Source: PRIMES – description of which countries are included in each region is provided in Annex 4

Lessons learned from electricity market simulation tools

In addition to PRIMES, which is an energy-system model notably looking at interactions across sectors and variables, it is possible to investigate the viability of RES projects using specific analytical tools focusing on electricity market functioning only.

WESIM

The issue of viability of RES investments has first been investigated with the use of the WESIM model. As described in Annex 4, WESIM is a comprehensive electricity system analysis model simultaneously balancing long-term investment-related decisions against short-term operation-related decisions, across generation, transmission and distribution systems, in an integrated fashion.

For the purpose of this analysis, WESIM has been calibrated to mirror investment patterns as projected by PRIMES in the EUCO27 scenario. The focus of the analysis presented below is to assess whether wholesale electricity market revenues would be sufficient, on their own, to finance the necessary RES investments as projected by PRIMES over the 2020-2030 period. However, this analysis does not consider investment profitability issues for conventional power generation technologies, an issue assessed in detail in the market design IA via other tools.

Assuming overall framework conditions similar to the ones used to build the EUCO27 scenario (*e.g.* in terms of interconnection, market functioning, ETS prices[59]), WESIM determines hourly electricity prices and dispatching and uses this to project a stream of revenues for all RES generation technologies. By comparing overall RES investment and

59 The noticeable exception is that the main scenario developed with WESIM still assumes priority dispatch for biomass generation over the 2020-2030 period.

operational costs to this stream of revenues, it is possible to assess the viability of RES projects.

The difference between total annual investment as projected with PRIMES in the EUCO27 scenario and the ones that are not estimated to be viable with WESIM provides an indication of a potential investment gap. This investment gap corresponds to the share of RES investments estimated to not be able to be financed by wholesale electricity market revenues on their own. The analysis performed with this model concludes that the investment gap will amount to EUR 13 billion in 2020; EUR 12 billion in 2025 and EUR 9 billion in 2030[60]. It is important to note that this does not correspond to the level of public support which would be needed, as only a fraction of the investment cost might need to be supported for the project to become viable.

More specifically, the model results show that only 41% of investments in 2020 could be financed by the market. This share increases to 54% in 2025 and 66% in 2030. Onshore and solar PV become gradually profitable and by 2030, such projects could be financed entirely by the markets, under the specific assumptions considered in this scenario. Conversely, technologies such as offshore wind investments cannot be yet fully financed via electricity market revenues by 2030.

Required annual investment (€ bn)	Biomass	Geothermal	Hydro reservoir	Hydro ROR	Offshore wind	Onshore wind	Solar PV	Tidal	TOTAL
2020	0.48	0.00	0.26	0.04	5.54	7.21	8.09	0.24	**21.88**
2025	0.77	0.00	0.41	0.14	8.74	9.43	5.33	0.37	**25.19**
2030	0.94	0.23	0.09	0.69	9.61	8.93	6.75	0.50	**27.74**
Total investment gap (€bn)	**Biomass**	**Geothermal**	**Hydro reservoir**	**Hydro ROR**	**Offshore wind**	**Onshore wind**	**Solar PV**	**Tidal**	**TOTAL**
2020	0.48	0.00	0.23	0.00	5.54	3.55	2.91	0.24	**12.95**
2025	0.00	0.00	0.34	0.00	8.74	0.00	2.26	0.37	**11.71**
2030	0.00	0.00	0.00	0.00	8.99	0.00	0.00	0.50	**9.49**
Share of investment financed by the market	**Biomass**	**Geothermal**	**Hydro reservoir**	**Hydro ROR**	**Offshore wind**	**Onshore wind**	**Solar PV**	**Tidal**	**TOTAL**
2020	1%		12%	100%	0%	51%	64%	0%	41%
2025	100%		18%	100%	0%	100%	58%	0%	54%
2030	100%	100%	100%	100%	6%	100%	100%	0%	66%

Source: CEPA, central scenario

Two sensitivity analyses were performed. First, the assumption of priority dispatch for biomass was lifted. In this context, biomass units are not forced to operate when their marginal cost is lower than the electricity price in absence of operational support, and therefore, average electricity prices tend to increase. This increases the viability of (other) RES projects and in this context, the share of investments that could be financed

60 For additional details on viability gap of RES-e technology assessed with WESIM methodology, see Annex 4

based on electricity market revenues increases as follows: 52% in 2020, 61% in 2025 and 89% in 2030.

Second, another sensitivity was performed to investigate potential impacts of different expectation regarding ETS prices. This extreme case scenario considers that investors in each year take as given the prevailing ETS price, and assume that it remains constant over the life of their project, and do not expect the price to increase over time. This is obviously a simplification, only aiming at illustrating the impact of extreme boundary conditions on the viability of RES projects. Wholesale market revenues received by RES-E generators were amended to reflect this change of assumption. Given that it is difficult to accurately determine the contribution of carbon costs to the total wholesale price in every hour, a less granular approach was therefore used, using average yearly prices instead. Overall, under this assumption, 35% of investments in 2020 could be financed via these revised (theoretical) market revenues, 48% in 2025 and 54% in 2030.

PRIMES market simulation tools

The issue of whether wholesale electricity market revenues would be sufficient to finance investments in power generation is addressed in detail in the MD Impact Assessment.

First, the MD IA simulates market revenues taking as a constant the level of investments provided by the EUCO27 scenario (PRIMES/IEM). It identifies viable and non-viable power generation technologies based on various electricity market functioning assumptions, from status quo to a scenario removing all existing barriers. Potential revenues on day-ahead, intraday and balancing markets are then calculated, and the net profits or losses, as compared to overall costs of investments, are determined. Second, additional projections are provided, where investment decisions become endogenous (PRIMES/OM). A detailed analysis of the results is provided in the MD IA.

Focusing on the most important results from a RES generators perspective, the analysis shows first that onshore wind across the EU from 2025 and solar PV in the South Europe (excluding small scale) from 2030 make profits on energy-only markets. However, this is not the case of the other RES technologies. The benefits of improving the energy-only market are then assessed in the MDI IA but from a RES generation investment profitability perspective, the results are not significantly amended.

To complement this analysis, it is important to also look at the dynamic behaviour of markets and how markets can also provide investment signals. A different model was used, PRIMES/OM, in the MDI IA. The following table summarises the results for RES technologies. It confirms that mature RES technologies are among the profitable technologies by 2030. Conversely, less mature technologies, such as wind offshore, biomass or solar thermal, remain unprofitable.

	Profit or Loss by plant type in M€'13		
	2020	**2025**	**2030**
Lakes	13 384	15 132	17 435
Run of River	10 382	12 065	13 219
Wind onshore	0.323	6 152	20 231
Wind offshore	-0.205	-3 152	-3 262
Solar PV (large)	-3 207	-0.141	3 644
Solar thermal	-1 786	-2 080	-2 900

Geothermal	0.158	0.242	0 323
Tidal	-2 705	-2 833	-0 320
Biomass	-5 938	-7 432	-6 160
CHP biomass	-2 958	-3 094	-3 075
RES (small)	-9 486	-8 525	-4 126

Source: PRIMES/OM

Conclusions

The various modelling approaches used to analyse the potential viability of RES investments based on market revenues alone, as well as in an overall energy-system context, all converge around the following conclusions:

- Profitability of RES technologies will improve over the 2020-2030 period. The combination of technological progress, improved market functioning, and increasing ETS prices, among other factors, lead to more and more RES investments being projected to be viable without support.
- The situation is contrasted depending on the level of maturity of RES technologies. Even if some less advanced RES technologies would need support to emerge as part of the power generation mix towards 2030, this is likely not the case anymore for most mature technologies, at least towards the end of the 2021-2030 period, such as hydro, wind onshore and solar PV (at least in some parts of Europe).
- Improving electricity market functioning will overall be beneficial to RES investments profitability. This is also true as regards confidence of investors in the evolution of ETS prices. Anticipating on future ETS price increases improve the profitability of RES investment projects.

1.2. *Main indicators used to compare results of electricity policy options modelled with PRIMES*

This subsection presents tables summarising the main results of the various PRIMES modelling scenarios used for the assessment of policy options in the electricity sector. Detailed explained for these results are included in the main part of the report (section 5.1.).

Electricity indicators (2030)	**Ref2016**	**CRA**	**CRA countryspec**	**CRA techspec**	**CRA regio**	**CRA crossborder**	**EUCO27**	**EUCO30**
Net Electricity Generation (*TWh*)	3390872	3372371	3373067	3374239	3363306	3369539	3396680	3285630
- Renewable share	43%	50%	49%	52%	50%	49%	47%	49%
of which hydro share (%)	11%	11%	11%	11%	11%	11%	11%	11%
of which wind onshore share (%)	14%	15%	15%	15%	15%	15%	17%	17%
of which wind offshore share (%)	4%	8%	8%	11%	6%	8%	4%	4%
of which solar share (%)	7%	9%	9%	8%	11%	9%	9%	9%
of which Biomass &	7%	7%	7%	7%	7%	7%	7%	8%

waste share (%)								
Average Electricity prices	158	166	166	166	168	166	161	157
Average cost of electricity generation	101	108	108	108	109	107	103	100
ETS carbon price	34	38	38	29	38	41	42	27

Source: PRIMES

Energy system costs	**Ref2016**	**CRA**	**CRA countryspec**	**CRA techspec**	**CRA regio**	**CRA crossborder**	**EUCO27**	**EUCO30**
Total System Costs in bn €'13 *(average annual 2021-30)*	1928	1952.5	1951.0	1961	1951.2	1951	1943	1952
change in system costs compared to Ref2016 (in bn €'13)	0	24.3	22.8	32.6	23.0	23.2	14.9	24
Total System Costs as % of GDP *(average annual 2021-30)*	12.28%	12.43%	12.42%	12.48%	12.42%	12.42%	12.37%	12.43%
Total System Costs as % of GDP increase *(average annual 2021-30)* compared to REF16 in % points	0.00%	0.15%	0.14%	0.21%	0.15%	0.15%	0.10%	0.15%
Total System Costs in bn €'13 *(average annual 2021-2050)*	2130	2275	2273	2281	2273	2274	2264	2255
change in system costs compared to Ref2016 (in bn €'13)	0	145	143	151	143	144	134	125
Total System Costs as % of GDP *(average annual 2021-2050)*	11.62%	12.41%	12.41%	12.45%	12.40%	12.41%	12.35%	12.31%
Total System Costs as % of GDP increase *(average annual 2021-2050)* compared to Ref2016 in % points	0.00%	0.79%	0.781%	0.83%	0.78%	0.79%	0.73%	0.68%

Source: PRIMES

Investment indicators (2030)	**Ref2016**	**CRA27**	**CRA countryspec**	**CRA techspec**	**CRA regio**	**CRA crossborder**	**EUCO27**	**EUCO30**
Investment expenditures in power generation (2021-2030 period)	311663	552761	544188	649884	558000	542093	395403	393970
Investment expenditures in renewables (2021-2030 period)	150431	404130	394090	502666	406862	393311	240131	245414
% of RES investments in total investments in power generation	48%	73%	72%	77%	73%	73%	61%	62%
% of total RES investments in wind	62%	70%	70%	77%	54%	69%	59%	58%

% of total RES investments in solar	29%	18%	19%	13%	31%	19%	36%	36%
% of total RES investments in biomass-waste	4%	8%	8%	7%	11%	9%	2%	2%
% of total RES investments in other renewables (hydro, tidal, etc.)	5%	3%	3%	3%	3%	3%	3%	1%
Share of top three MS in overall RES-E investments	54%	67%	63%	74%	58%	65%	47%	44%
Share of bottom ten MS in overall RES-E investments	0.7%	0.6%	0.8%	0.4%	2.0%	0.6%	2.2%	2.8%

Source: PRIMES

Social impacts and affordability issues (2030)	Ref2016	CRA27	CRA countryspec	CRA techspec	CRA regio	CRA crossborder	EUCO27	EUCO30
Electricity price - households (€/MWh)	212	226	224	226	231	225	218	215
RES supporting costs passed on to consumers	19	26	25	31	25	25	19	20
Electricity price - industry (€/MWh)	100	104	104	104	102	103	100	98
Energy related production cost - industry	376363	381358	381293	379351	380087	380917	377935	374087

2. Options to increase renewable energy in the heating and cooling sector (RES-H&C)

2.1. Mainstreaming renewables in heating and cooling supply

Dimension	Indicator	Option 0	Option 1-1	Option 1-2	Option 2-1	Option 2-2	Source
Social	Average share of small-scale companies under HCOS (in energy supply)	N/A	18%	18%	2%	2%	Fraunhofer-own assessmnet
	Maximal share of small-scale companies under HCOS (in energy supply)	N/A	100%	100%	25%	25%	Fraunhofer-own assessmnet
Economic	Standard deviation of additional effort in terms of RES-H&C shares at MS level compared to cost-effective	N/A	2.80%	3.20%	2.80%	3.20%	PRIMES+own calculations
Political	Maximal additional effort asked to a single MS vs. cost-effectiveness	0%	4%	6%	4%	6%	PRIMES+own calculations

2.2. Facilitating the uptake of renewable energy and waste heat in district heating and cooling systems

Dimension	Indicator	Option 0	Option 1	Option 2	Option 3	Source
Social	Consumers empowerement	0	0	+	+++	Öko Institut and EC-own assessment
Economic	Potential impact on district heating operators	0	0	-	-	Öko Institut and EC-own assessment
Environmental	Potential fuel-switching to RES in H&C	0	0	20%	20%	Öko Institut and EC-own assessment
Administrative burden	Potential impacts on administrative costs	0	+	-	-	EC-own assessment

3. Options to increase renewable energy in the transport sector (RES-T)

Dimension	Option 0	Option 1	Option 2 (variant 1)	Option 2 (variant 2)	Option 2 (variant 3)	Option 3	Option 4 (variant 1)	Option 4 (variant 2)	Option 4 (variant 3)
Social	0	+	0/+	+	+	+	+	+	+
Economic	0	-	-	- -	-	-	- -	-	-
Environmental	0	+	++	+++	+++	+	+	+++	+++

4. Options to empower and inform consumers of renewable energy

4.1. Empower consumers to generate, self-consume and store renewable electricity

Dimension	Indicator	Option 0	Option 1	Option 2	Option 3 (variant 1)	Option 3 (variant 2)	Source
Social	Potential level of consumers participation	0	+	+	+++	++	PRIMES, EC own assessment
Economic	Potential impact on grid costs	0	-	-	---	-	EC own assessment
Environmental	Potential contribution of rooftop solar PV to RES-E	0	-	+	+		PRIMES, EC own assessment

4.2. Disclosing information for renewable electricity

Dimension	Indicator	Option 0	Option 1	Option 2	Option 3	Source

Social	Transparency and data reliability	0	+	++	++	EC own assessment
Economic	Data coverage: % of the energy system covered by GOs	0	Natural change – approx. 50% RES	All RES - E	All electricity sources	EC own assessment
	Changes in financial flow	0	No change	Some change	Some change	EC own assessment
	Reduction in administrative cost	0	Marginal impact	Marginal impact	--	EC own assessment
Environmental	Potential for encouraging consumers to switch to RES contracts	0	+	++	+++	EC own assessment
	Consumer data on CO_2 emissions through GOs	0	None	None	+	EC own assessment

4.3. Tracing renewable fuels used in heating and cooling and transport

Dimension	Indicator	Option 0	Option 1	Option 2	Option 3	Source
Social	Increase ability of consumers to choose renewable fuels	0	++	+	+	EC own assessment
Economic	Fraud prevention through better tracking	0	+	+	+++	EC own assessment
	Minimise administrative burden	0	+	+	+	EC own assessment
Environmental	Reduce sustainability concerns of the fuels	0	+	++	+++	EC own assessment

5. Options to ensure the achievement of at least 27% renewable energy in 2030

5.1. Baseline of 2020 targets

Dimension	Indicator	Option 0	Option 1	Source
Social	Impact of consumer groups	0	-	EC own assessment
Economic	Reduced cost of capital	0	+	EC own assessment
Environmental	Reduced GHG emissions	0	+	EC own assessment

5.2. EU Trajectory 2021-2030 for achievement of the EU renewables target

Dimension	Indicator	Option 0	Option 1	Option 2	Source

Social	Consumer impacts through avoiding changes in policy	0	++	+	EC own assessment
Economic	Encouraging long term investment in renewables	0	++	+	EC own assessment
Environmental	Reducing GHG emissions	0	++	+	EC own assessment

5.3. Mechanisms to avoid an "ambition gap" to the EU renewables target

Dimension	Indicator	Option 0	Option 1	Option 2	Option 3	Source
Social	Avoids distributional impact	0	+	+	+	EC own assessment
Economic	Incentivises investment in RES	0	+	++	++	EC own assessment
Environmental	Avoids increase in emissions by correcting any ambition gap	0	+	++	++	EC own assessment

5.4. Mechanisms to avoid and fill a "delivery gap" to the EU renewables target

Dimension	Indicator	Option 0	Option 1	Option 2	Option 3	Option 4	Source
Social	Avoids distributional impact	0	+	+	+	+	EC own assessment
Economic	Incentivises investment in RES	0	+	+	++	++	EC own assessment
Environmental	Avoids increase in emissions by correcting any delivery gap	0	+	+	++	++	EC own assessment

6. Other results of energy-system modelling scenarios, including a sensitivity scenario and a RES decomposition analysis

This section summarises first the energy-system results of various core scenarios used in this Impact Assessment, while also presenting the results of the sensitivity scenario projecting an increase of renewable energy to 30% in 2030 (EUCO3030 scenario).

In a second subsection, a RES decomposition analysis is provided, presenting in detail the contribution of the various subsectors to the achievement of the overall RES target in the various scenarios considered.

6.1. Evolution of energy system indicators and variables in main scenarios used in this Impact Assessment

This section presents the results of REF2016, of the CRA scenario (baseline scenario for assessing electricity policy options), the EUCO27 scenario, the EUCO30 scenario and the EUCO3030 scenario. This last scenario corresponds to a sensitivity analysis performed, looking at the specific impacts of higher ambition level in renewable energy[61]. These scenarios help illustrate the scale of the challenge in each renewable energy sector depending on assumptions as regards overall policy ambition and specific targets in other areas than renewable energy alone.

6.1.1. Energy system indicators

The table below presents the outcome of the various scenarios regarding main energy system indicators. Except in REF2016, the overall renewables share in 2030 is an exogenous input to the scenarios, as scenarios are meant to achieve specific shares of renewable energy. The same logic applies for primary energy consumption, in line with various potential energy efficiency targets.

On the contrary, renewables shares per sector are an outcome of the model. Here, it can be seen that the various scenarios in line with a 27% share in renewable energy do not fundamentally differ, although a scenario with additional energy efficiency (EUCO30) indicates an extra contribution from the electricity and transport sectors, as an overall decrease in heating and cooling demand leads to smaller requirements for renewable energy in that sector. Looking at the variant reaching a 30% share of renewables by 2030, together with 30% energy efficiency, it can be seen that a significant increase in the share of renewable energy in all sectors is projected, and notably in the electricity sector.

Energy System indicators (2030)	Ref2016	CRA	EUCO27	EUCO30	EUCO3030
Overall RES share (% of GFEC)	24%	27%	27%	27%	30%
RES-E share	42%	49%	47%	49%	54%
RES-H&C share	25%	27%	27%	26%	30%
RES-T share	14%	18%	18%	19%	21%
Total RES consumption (Ktoe)	272957	295374	291507	279377	310262
Gross final consumption of RES for heating and cooling	123824	127007	128049	116637	132899
Gross final consumption of electricity from RES	128391	147848	142971	142436	156049
Biofuels consumption	20742	20519	20486	20304	21314
Gross Final Energy Consumption (Ktoe)	1133091	1085207	1086070	1040139	1038151

[61] In this case, a 30% share of renewables by 2030 is assumed, together with 30% energy efficiency levels.

Electricity	302437	299252	302057	292307	287843
Heating and Cooling	485055	455346	453540	422926	424876
Transport	274253	256245	256086	251778	252237
Primary Energy Consumption (Ktoe)	1436069	1358072	1369069	1321337	1306157
Final Energy Demand (Ktoe)	1081368	1031259	1031401	987097	986214

Source: PRIMES

6.1.2. Environmental indicators

The following table illustrates the GHG emission reductions in the various scenarios. By construction, the CRA, EUCO27 and EUCO30 scenarios are meant to achieve the same level of GHG emissions reductions, overall and between ETS and ESD sectors. This is not the case for the EUCO3030 scenario, where emission reductions are not constrained. In this scenario, much more additional GHG emission reductions come from the ETS sector, which is notably explained by the exogenous assumption of keeping constant the ETS price, as compared to EUCO30. The carbon intensity of power generation is also reduced by 15% compared with EUCO30, mostly due to the decrease of gas use. As such, this scenario illustrates potential additional deployment in the renewable electricity sector, although the scenario outcome does not reflect interactions with the ETS carbon market and would not be in line with the current Commission proposal for a reformed ETS.

Higher ambition in energy efficiency leads to additional GHG emission reductions in demand sectors. Conversely, no drastic change is projected between the CRA and the EUCO27 scenario in decarbonisation patterns.

Environmental indicators (2030)	Ref2016	CRA	EUCO27	EUCO30	EUCO3030
Total GHG emissions (% change to 1990)	-35.2%	-40.8%	-40.7%	-40.8%	-43.2%
ETS sectors emissions (% change to 2005)	-37.7%	-43.4%	-43.1%	-43.1%	-48.1%
ESD sectors emissions (% change to 2005)	-23.7%	-30.1%	-30.2%	-30.3%	-30.7%
CO_2 emissions (in kt CO_2) thermal power plants	881933	760720	773423	756853	646027
Carbon intensity power generation (per MWhe+MWhth)	0.202	0.177	0.179	0.182	0.157
Power generation, CHP and district heating GHG emissions (%	*-41%*	*-49%*	*-48%*	*-49%*	*-56%*

change compared to 2005)					
Industry (only energy related) (Mt CO_2 eq), (% change)	*-41%*	*-43%*	*-44%*	*-44%*	*-46%*
Residential GHG emissions (% change compared to 2005)	*-25%*	*-35%*	*-35%*	*-40%*	*-41%*
Tertiary GHG emissions (% change compared to 2005)	*-33%*	*-42%*	*-43%*	*-46%*	*-47%*
Transport GHG emissions (% change compared to 2005)	*-12%*	*-18%*	*-18%*	*-19%*	*-19%*
Power generation, CHP and district heating GHG emissions (Mt of CO_2 eq for REF and % change from REF for other scenarios	*977.5*	*-13%*	*-12%*	*-14%*	*-26%*
Industry (energy + processes) (Mt CO_2 eq), (% change)	*375.8*	*-3%*	*-5%*	*-5%*	*-9%*
Residential (Mt CO_2 eq), (% change)	*360.8*	*-13%*	*-12%*	*-20%*	*-20%*
Tertiary (Mt CO_2 eq), (% change)	*183.2*	*-15%*	*-15%*	*-21%*	*-21%*
Transport (Mt CO_2 eq), (% change)	*946.9*	*-6%*	*-6%*	*-8%*	*-8%*

Source: PRIMES, GAINS

6.1.3. Social impacts indicators

From a social impacts perspective, it can be seen that the CRA scenario lead to a higher increase in electricity prices, as compared to EUCO scenarios, showing signs of lack of efficiency in the continuation of current practices, as opposed to a situation where renewables deployment is more cost-effective. This is even more visible when focusing on the calculated renewables supporting costs passed on to final consumers, which increase significantly in CRA as opposed to EUCO scenarios.

On the demand side, the energy purchases are more affected by energy efficiency requirements than by different renewables pathways, as most significant differences appear when comparing EUCO27 and EUCO30 results.

Social impacts and affordability issues (2030)	Ref2016	CRA	EUCO27	EUCO30	EUCO3030
Avg. electricity price incr. compared to 2010 price (%)	18%	25%	21%	18%	21%

RES supporting costs passed on to consumers	19	26	19	20	21
Energy Purchases in bn EUR'13 (average annual 2021-30)	1448	1422	1415	1388	1391
Industry	272	273	271	269	268
Residential	417	413	410	397	400
Tertiary	249	245	243	235	236
Transport	510	492	491	486	487

Source: PRIMES

6.1.4. Energy security impacts indicators

Deployment of renewables – together with energy efficiency – is expected to contribute to increased energy security, by lowering the needs for non-diversified energy imports. This can be observed by comparing the results of the various EUCO scenarios, where, as energy efficiency and/or renewable energy ambitions increase, the volume and value of imports decrease. Significant savings in terms of fossil fuel import bills are therefore projected, in particular in the case of the EUCO3030 scenario. In this latter scenario, due to the higher rate of renewables deployment, import dependency is the lowest of all scenarios. However, the increasing net import dependency for biomass (energy and non-energy uses, including food) should be taken into account.

Impacts on energy security (2030)	Ref2016	CRA	EUCO27	EUCO30	EUCO3030
Net Energy Imports Volume (2005=100)	93	86	86	82	79
Solid	67	57	57	59	53
Oil	88	80	80	79	78
Gas	116	110	110	97	89
Renewable Energy Forms	796	846	848	804	863
Import Dependency	57%	55%	54%	53%	52%
Gas imports (bcm)	325	306	306	270	248
reduction compared to REF2016 (in bcm)	0	-18	-18	-54	-77
reduction compared to	0%	-6%	-6%	-17%	-24%

REF2016 (% change)					
Value of Fossil Fuel Net Imports (bn EUR'13) ***(average annual 2021-30)***					
Oil	326	309	309	307	306
Gas	111	107	107	102	99
Solid	12	11	11	12	11
Fossil Fuels Import Bill: absolute results for REF2016 and % change compared to REF2016 for other scenarios (bn EUR '13 - cumulative 2021-30)	4494	-4.6%	-4.9%	-6.4%	-7.2%

Source: PRIMES

6.1.5. Total system costs

The table below presents the evolution of overall energy system costs across the scenarios. The most striking feature in the context of this impact assessment is that system costs increase in the CRA scenario as compared to EUCO27, showing the negative overall impacts of the continuation of current practices and policies. This is true for the 2021-2030 period as well as for the whole period up to 2050. As opposed to more energy efficiency or renewable energy scenarios, there are no trade-offs in this case between short and long term costs for the energy system.

The most ambitious scenario, the EUCO3030 scenario, is also the most costly over the 2021-2030 period. The increase in system costs compared to EUCO30 over the 2021-2030 period corresponds to € 4 billion on average annually. Conversely, costs of EUCO3030 are among the lowest over the 2030-2050 period and EUCO3030 system costs fall closer to EUCO30 results when looking at the 2021-2050 period.

Energy system costs	Ref2016	CRA	EUCO27	EUCO30	EUCO3030
Total System Costs in bn EUR'13 ***(average annual 2021-30)***	1 928	1 953	1 943	1 952	1 956
change in system costs compared to Ref2016 (in bn EUR'13)	0	24	15	24	28
Total System Costs as % of GDP (average annual 2021-30)	12.28%	12.43%	12.37%	12.43%	12.46%
Total System Costs in bn EUR'13 ***(average annual 2021-2050)***	2130	2274.7	2264	2255	2257

change in system costs compared to Ref2016 (in bn EUR'13)	0	145	134	125	127
Total System Costs as % of GDP (average annual 2021-2050)	11.62%	12.41%	12.35%	12.31%	12.32%

Source: PRIMES

6.1.6. Macro-economic and employment impacts

Macro-economic impacts (including employment and GDP) have been estimated using the E3ME model and the GEM-E3 model, mirroring the approach used in the Impact Assessment for the revision of the Energy Efficiency Directive. The description of these two models and the methodology used for testing potential macroeconomic impacts are presented in detail in the Energy Efficiency Impact Assessment (see for instance Annexes 4.8 and 4.9 of the EE IA).

Both models use as input energy system and investment developments coming from PRIMES scenarios. In the context of this Impact Assessment, the E3ME and GEM-E3 models were calibrated and run for the CRA and EUCO3030 scenarios. Results developed in the context of the Energy Efficiency Impact Assessment, namely for assessing the macroeconomic impacts of REF2016, EUCO27 and EUCO30 scenarios, are also reported.

In terms of methodology, one important element to highlight concerns the treatment of the CRA scenario. In the CRA scenario, the financing conditions for renewable electricity projects are different than in the other scenarios reported in this section, reflecting different status-quo (and more difficult) access to capital market conditions across EU Member States. As such, as compared to EUCO27 results, investment costs are higher, but not so much due to increased capacity installed but rather due to higher risk premiums assumed for the financing of investments. In the GEM-E3 model this has been modelled by the introduction of inefficient capital (i.e. increasing the cost of capital to deliver the same service without increasing the demand for equipment). In the E3ME model, the different financing costs across Member States were also reflected, mirroring the different access to capital market conditions across Member States.

The following tables present the main results:

Levels (bln €2013) for REF2016 and EUCO27 and % change wrt to EUCO27 for the rest of scenarios	**REF2016**	**EUCO27**	**CRA**	**EUCO30**	**EUCO3030**
	GDP (bln €2013)	GDP (bln €2013)	GDP	GDP	GDP
E3ME					
no crowding out	17,928.1	18,044.9	-0.08%	0.39%	0.53%
partial crowding out	17,928.1	18,044.9	-0.08%	0.39%	0.53%
GEM-E3					
loan based	16,954.6	16,961.7	-0.06%	0.26%	0.13%

self-financed	16,954.6	16,907.4	-0.08%	-0.22%	-0.49%

Source: Cambridge Econometrics E3ME modelling and National Technical University of Athens, E3M-Lab, GEM-E3 modelling

In terms of GDP, the CRA scenario leads to lower GDP levels in 2030 than the EUCO27 scenario. This is a direct consequence of the inefficiencies considered in the financing of renewable energy projects in this scenario. This result is confirmed in both models used and for each variant considered.

The EUCO3030 scenario leads to additional RES investments, compared to EUCO30. In the case of the E3ME model, this leads to additional GDP benefits, with very limited changes between the partial crowding out[62] and no crowding out variants, as investment levels are not sufficient to breach the output growth constraint imposed in the partial crowding out case[63].

In the case of the GEM-E3 model, EUCO3030 results are overall less positive (or more negative) than for the EUCO30 scenario. Additional RES investments tend to shift away investments from other productive sectors in the economy. The increasing share of RES translates into higher average electricity prices and production costs, since additional investments need to be recovered via higher prices and therefore costs for electricity users, hence reducing the initial positive impact resulting from additional RES deployment. Still, overall, GDP effects remain positive in 2030, compared to EUCO27, in the loan-based variant, that is, when increased financial liquidity and the possibility for borrowing is considered[64], as crowding out effects tend to rather materialise post-2030. It can be noted that, under current market conditions, RES investments are financed in majority through borrowing, either from banks or capital markets. When interpreting the scenario results, a key determinant will be the opportunity to finance additional RES – or other energy-related – investments without immediate crowding out on investments in other sectors of the economy.

Levels (mln people)	REF2016	EUCO27	CRA	EUCO30	EUCO3030

62 The "partial crowding out" imposes a constraint on activity expansion by introducing a rule that would set a maximum amount that the sectors benefiting from the energy union target setting would be allowed to increase by, without adversely affecting other economic activities. This rule entails a 15% limit on additional energy-related policy induced output growth by 2030. For more information please see the section on macroeconomic impacts of the 2016 Impact Assessment for the revised Energy Efficiency Directive

63 However, as investment requirements increase with more ambitious renewable and/or energy efficiency levels, this constraint is manifested by limiting the potential output growth in the partial crowding out case versus the no crowding out case. Please see the section on macroeconomic impacts of the 2016 Impact Assessment for the revised Energy Efficiency Directive for more discussion on this

64 In the case of GEM-E3, the two versions are referred to as loan-based finance and self-financing. In the former, businesses and households can borrow in the markets, whereas in the latter no borrowing is possible and economic agents finance the required additional energy investments via firms increasing their prices and households spending less on other items. The self-financing variant corresponds to immediate financial closure in GEM-E3 and thus implies that the model will show full crowding out effects, meaning that any upward deviation from optimal baseline investments requires consumption to be reduced or investments in other parts of the economy to be cancelled. The loan-based variant mitigates such crowding out effects and defers these to later periods via increasing financial liquidity and allowing for borrowing to take place

for REF2016 and EUCO27 and % change wrt to EUCO27 for rest of scenarios	Employment (mln people)	Employment (mln people)	Employment	Employment	Employment
E3ME					
no crowding out	233.1	233.5	-0.03%	0.17%	0.18%
partial crowding out	233.1	233.5	-0.03%	0.17%	0.18%
GEM-E3					
loan based	216.4	216.6	-0.03%	0.20%	0.14%
self-financed	216.4	216.0	-0.03%	-0.18%	-0.29%

Source: Cambridge Econometrics E3ME modelling and National Technical University of Athens, E3M-Lab, GEM-E3 modelling

In terms of employment, the CRA scenario leads to negative impacts compared to EUCO27, due to the inefficiencies discussed above, and in line with GDP developments. Employment impacts for the EUCO3030 scenario are very similar to EUCO30 when considering the E3ME results. Using GEM-E3, employment impacts are more negative or less positive (depending on the variant) than for EUCO30, in line with GDP developments projected by the model and the resulting changes in sectorial labour intensities.

Overall, the results of these macroeconomic simulations are rather intuitive: inefficiencies in renewable electricity investments captured in the energy system impacts of the CRA scenario also lead to inefficiencies, and GDP losses, when looking at the macroeconomic implications. Regarding the scenario leading to a 30% RES share in 2030, its overall macroeconomic impacts very much depend on whether the additional RES investments it entails could be financed and implemented without negatively affecting the potential availability of finance for other sectors, or in other words without constraining the monetary liquidity of the overall economy.

6.2. A decomposition analysis of RES developments in the various policy scenarios modelled with PRIMES

6.2.1. <u>Contribution of each RES sector to overall RES increases</u>

The following figure presents the RES share evolution per sector, between 2010 and 2030, per main scenario. First, it can be seen that the most important contribution is expected to be from the electricity sector, followed by heating and cooling. Contributions from transport and from reduced energy demand are at similar lower levels.

The graph also highlights the fact that the CRA scenario projects an additional contribution from the electricity sector in the total renewables increase as compared to the other scenarios. It also clearly shows that additional energy efficiency translates into a lower contribution from the heating sector, while overall reduction in demand contributes more, by decreasing the denominator used to calculate the share of renewables.

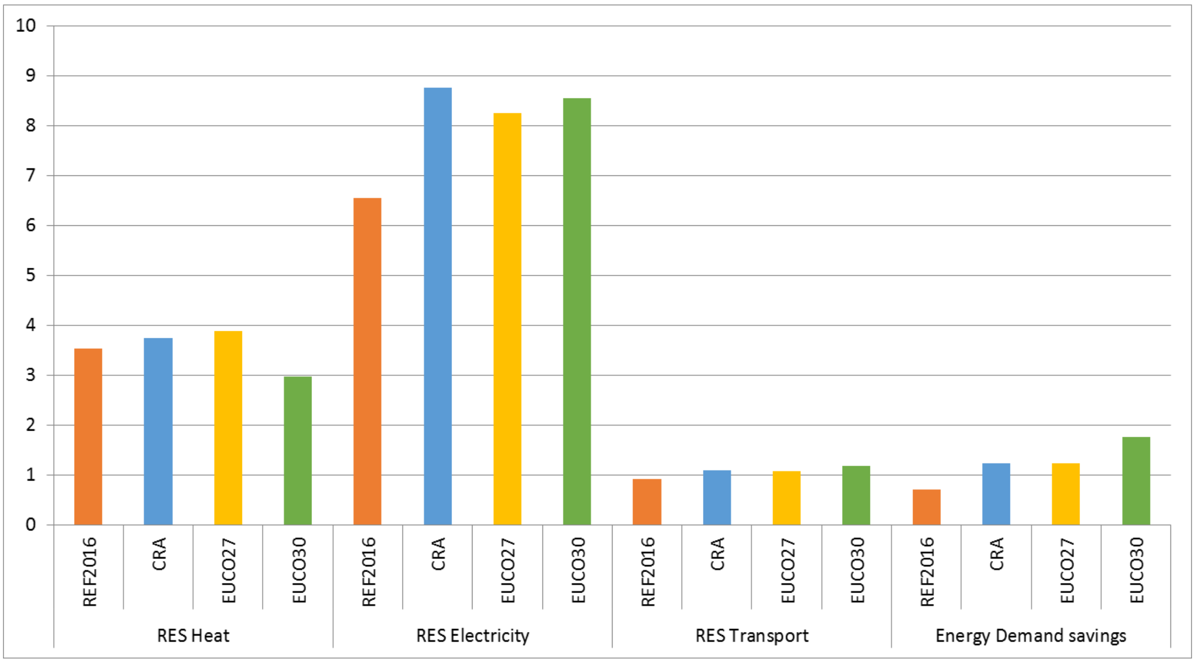

Figure 1: Decomposition of change of overall RES Share in 2030 relative to 2010, in percentage points – Main Scenarios
Source: PRIMES

6.2.2. Decomposition analysis for the renewable electricity sector

The figure below focuses on the evolution within the electricity sector across the main scenarios and variants. In all scenarios, the main contributor to the increase in RES-E share is wind. It influences more the overall increase than all other RES technologies put together.

Within this overall context, there are also important variations in the specific split between wind and other RES technologies. For instance, the CRA scenario leads to much more significant investments in wind, particularly wind offshore, than in solar. This is due to a mix of factors, including more favourable financing conditions in regions more favourable to wind than in regions more favourable to solar. The CRA_regio variant shows in this respect a much more balanced evolution in RES technology developments. This is also the scenario closest to the central policy scenario (EUCO27) in terms of RES deployment across technologies. The other three variants to the CRA scenario show much more limited impacts as compared to the baseline (CRA) scenario.

Finally, electricity demand negatively contributes to the evolution of the RES-E share. This is because electricity demand increases in all scenarios, and therefore this requires even more RES investments to increase the renewable electricity share than under constant electricity demand.

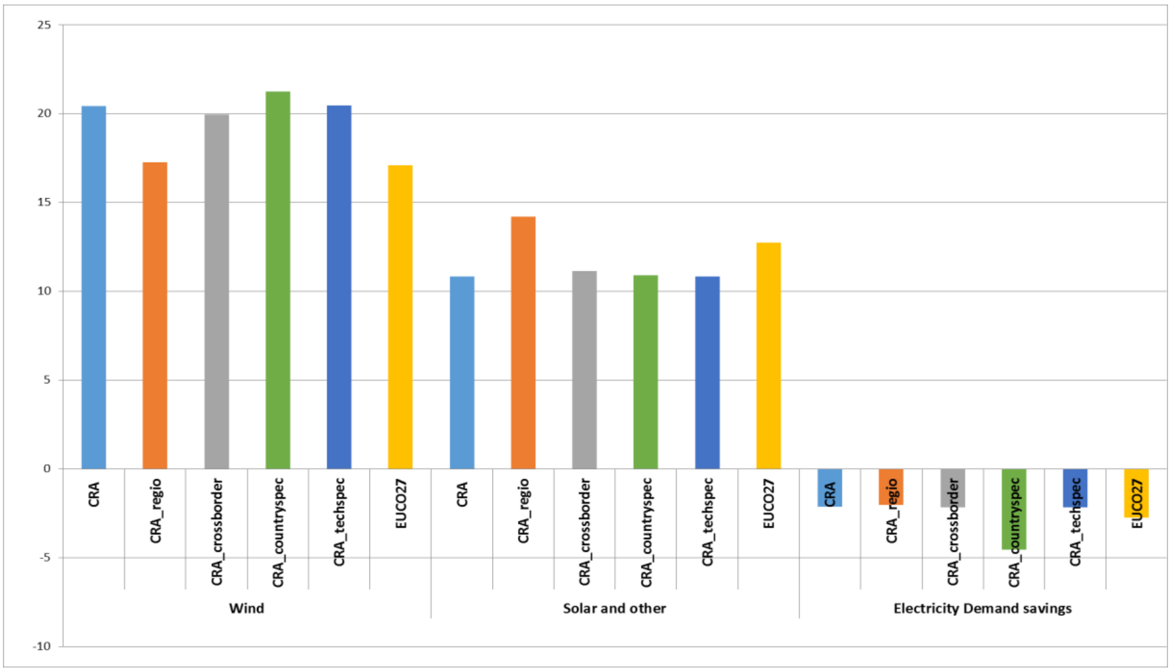

Figure 2: Decomposition of change of RES-E share in 2030 relative to 2010, in percentage points -- various scenarios
Source: PRIMES

6.2.3. Decomposition of RES H&C share

The figure below represents the evolution of the various determinants of RES H&C in 2030, as compared to 2010, across scenarios.

The main determinant of the developments of RES H&C very much depends on the scenario considered. In the case of the Reference and of the EUCO27 scenarios, the main factor is the increase in RES in final heat, followed by heat pumps, RES in CHP and heat demand savings. However, in the case of EUCO30, the main determinant is heat pumps, followed by heat demand savings. This suggests that higher ambition in energy savings lead to, all else being equal, lower needs for additional investments in RES in final heat sector.

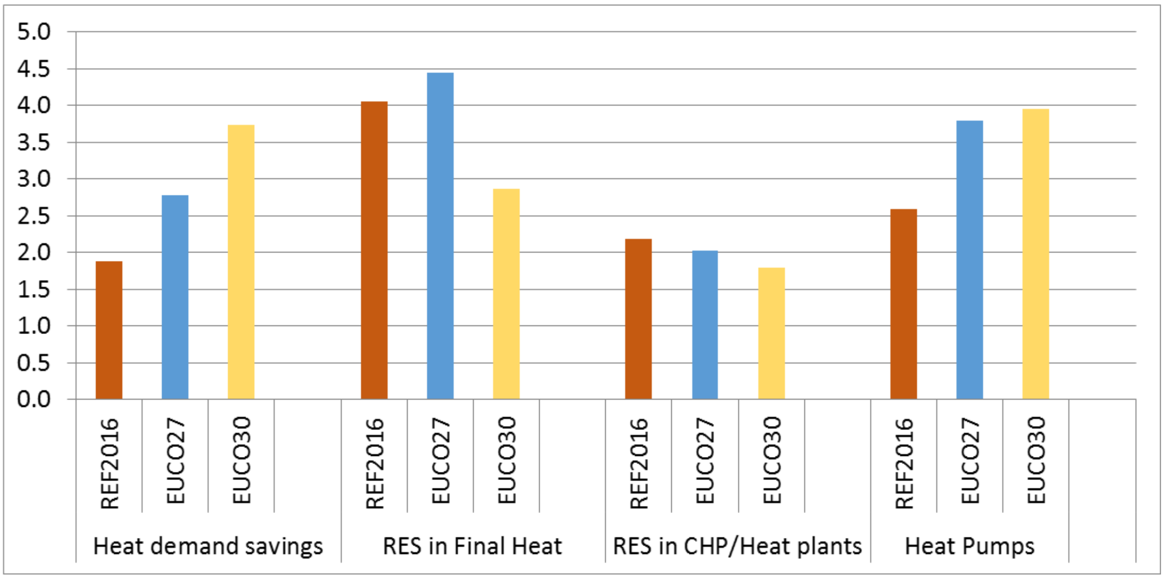

Figure 3: Decomposition of change of RES-H&C share in 2030 relative to 2010, in percentage points -- various scenarios
Source: PRIMES

ANNEX 6 - WHO IS AFFECTED AND HOW

Member States could be affected by the procedure to deliver pledges within their national renewables development path, as well as by the provisions for gap-filling instruments in case of difficulties in reaching the at least 27% target.

Local communities and **municipalities** will also be affected in the effort to coordinate national level and local level renewables planning. This might imply some additional administrative costs for coordination between governmental levels, but also ensure that local authorities are involved from the start so that public resistance issues can be better addressed.

The Revised RES Directive will also impact **non-renewables producers** and **suppliers** with regard to their market share as a consequence of the deployment of more renewables across the EU energy market.

Provisions on permit granting and authorisation could contribute to lower administrative and transaction costs associated with renewables project development, therefore impacting **renewables projects developers** at large and especially SMEs active in the industry.

As per **renewables technology producers** and **renewables installers**, the post 2020 renewables and Energy Union Governance policy framework could foster investment security and increase cross border business opportunities.

The **investors** and the **financial sector** will factor in an increased investment security in the post-2020 renewables provisions.

Businesses in general could benefit from the renewables cost reductions expected from new requirements for support to renewables and administrative procedures.

Transmissions service operators and **distribution service operators** could be affected by provisions to ensure that renewable electricity production and injection into the grids is guaranteed without discrimination *vis-á-vis* non-renewable electricity.

The Revised RES Directive could put in place a regulatory framework to enable consumers to self-produce and self-consume, and sell surplus renewable electricity (which so far only exists in 19 Member States) across the EU. This would enable **energy consumers** to become active market participants.

Energy service providers (ESCOs) and **aggregators** could exploit a new avenue both for entrepreneurs and consumers.

Citizens should be impacted in terms of higher local acceptance of renewables projects and increased utilisation of renewable energy in their energy mix, therefore reaping the ultimate benefit of a lower-carbonisation of the economy at large and related lower degrees of pollution.

ANNEX 7 - OVERVIEW OF BIOFUELS MANDATES IN MEMBER STATES

Table 1 : Biofuel mandates in the EU[65]

EB: Energy basis Vol: vol. basis	Year	Overall mandate	Biodiesel mandate	Bioethanol mandate	Double counting	Comments
Austria	2012	5.75 % EB	6.3 % EB	3.4 % EB	Y	
Belgium			6.0 %vol.	4.0 %vol.	N	
Bulgaria	2012 2015 2018 2019 2020		6 %vol.	 7 %vol. 8 9 10	N N N N N	
Croatia	2014 2015 2016 2017 2018 2019 2020	3.18 %EB 3.88 4.89 5.89 6.92 7.85 8.81			Y Y Y Y Y Y Y	
Czech Republic	 2014- 2016 2017- 2018 2019- 2020	 5.71 %EB 8.0 10.0			 N N N	Min. GHG red. 35 % 50 % 60 %
Denmark	2010 2020	5.75 %EB 10 proposed			N	
Estonia						5 %EB 2016, 10 % 2020 proposal rejected 2015
Finland	2014 2015	6 % EB 8			N N	
EB: Energy basis Vol: vol. basis	**Year**	**Overall mandate**	**Biodiesel mandate**	**Bioethanol mandate**	**Double counting**	**Comments**
France	2010- 2013 2014 Future?		7 % EB 7.7 min. 0.35 % double counted 8 %	7 % EB 7 min. 0.25 % double counted	 Y	
Germany	 2015 2017 2018 2020	 3.5 % GHG red. 4 4 6			 N N N N	Min. GHG red. 35 % 50 % 60 % for new plants No co-processing
Hungary	2014- 2015		4.9 % EB	4.9 % EB 304 ktoe	Y	

[65] Biofuel Mandates in the EU by Member State. GAIN report GM15015. USDA 7/13/2015

	2020		202 ktoe			
Ireland	2010-2012 2013	4.166 6.383 %vol			N Y	
Italy	2014 2015 2018 2022	5 %EB. 5			Y N	“Adv. Biofuels” mandate 0.6 %EB 1 %
Latvia	2010	5.75 %EB				No later info available
Lithuania						No information available
The Netherlands	2011 2012 2013 2014 2015 2016 2017 2018 2019 2020	4.0 %EB 4.5 5.0 5.5 6.25 7.0 7.75 8.5 9.25 10	Min 3.5 % Min 3.5 % Min 3.5 % Min 3.5 % No longer required as of 2015	Min 3.5 % Min 3.5 % Min 3.5 % Min 3.5 % No longer required as of 2015	Y Y Y Y Y Y Y	Mandates in place since 2007 A certificate system has been introduced in 2015. Renewable fuels accepted since 2015
Poland	2014-2016 2017 2018	7.1 %EB 7.8 8.5			N Y?	The on double counting proposition did not pass parliament as planned in 2015, expected for 2016[66].
Portugal	2014 2015-2016 2017-2018 2019-2020	5.5 %EB 7.5 9 10		 2.5 %EB 2.5 2.5	Y Y Y Y	Ethanol includes also ETBE
Romania	2014-2015 2016		5 %EB 6	4.5 %EB 4.5	? ?	
Slovak republic	2015 2016 2017 2018 2019 2020	5.5 %EB 5.5 5.8 7.2 7.5 8.5	6.8 %EB 7.0 7.0 7.0 7.0 7.0	4.5 %EB 4.6 4.7 5.9 6.2 7.0	N N N N N N	ETBE 3 % in gasoline, 1.41 % bio-ethanol
Slovenia	2010	5 %EB			Y	
EB: Energy basis Vol: vol. basis	**Year**	**Overall mandate**	**Biodiesel mandate**	**Bioethanol mandate**	**Double counting**	**Comments**

66 Poland to postpone double-counting biodiesel ruling to 2017. Platts March 1 2016. https://www.platts.com/latest-news/agriculture/london/poland-to-postpone-double-counting-biodiesel-26383952

Spain	2013-	4.1 %EB	4.1 %	3.9 %	?	
Sweden	2007-				Y	Tax based system eligible for approved renewable fuels. Co-processing accept. Proposal for new system 2017?
UK	2013- 2017 2018	4.75 vol % in overall supply			Y	RTFO system in place > 50 % GHG red. eligible > 60 % GHG red. eligible for new installations New rules on co-processing expected April 2016?

Table 2: Classification of BIO, CCUS, e & Hydrogen transport fuels

Classification of BIO, CCUS, e & Hydrogen Transport Fuels					
	Raw material	**Technology**	**Type of biofuel**	**Status TRL[1]**	**Application**
Conventional	Sugar*	Fermentation	Ethanol	Commercial	Gasoline blend, E10, E85, E95,
	Starch*				
	Vegetable oils*	Esterification or transesterification	FAME/Biodiesel		Diesel blend, B7, B10, B30, 100%
	Fats				
	Food crops	Biogas production & removal of CO_2	Biomethane		100% in heavy duty transport, captive fleets, injected in the gas grid
	Waste streams of oils & fats	Esterification or transesterification	FAME/Biodiesel	Commercial	Diesel blend, B7, B10, B30, 100%
	MSW[2], sewage sludge, animal manures, agricultural residues, energy crops	Biogas or landfill production & removal of CO_2	Biomethane		100% in heavy duty transport, captive fleets, injected in the gas grid
	Vegetable oils*, fats, used cooking oils, liquid waste streams & effluents[7]	Hydrotreatment	Hydrogenated		Diesel drop-in or 100%, bio-kerosene

Advanced	Lignocellulosics, MSW, *solid* industrial waste streams/residues[3]	Enzymatic hydrolysis + fermentation	Ethanol	TRL 8-9	Gasoline blend, E10, E85, E95, upgrade to biokerosene
			Other alcohols	TRL 6-7	
		Gasification + fermentation	Ethanol	TRL 6-7	
	Lignocellulosics, MSW, *liquid* industrial waste streams & effluents[5] or intermediate energy carriers[6]	Gasification + catalytic synthesis	Synthetic[4]	TRL 6-7	Depends on fuel type; can be used for blends with diesel, gasoline, kerosene, bunker fuel , drop-in
	Algal oils[8] and other non-food oils	Hydrotreatment	Hydrogenated	TRL 5-6	Diesel drop-in or 100%, bio-kerosene
		Esterification	FAME/Biodiesel	TRL 5-6	Diesel blend, B7, B10, B30, 100%
	Pyrolysis oils from lignocellulosics, MSW, waste streams	Hydrotreatment	Hydrotreated	TRL 4-5	Diesel drop-in or 100%
		Co-processing in existing petroleum refineries[9]	Ethanol, diesel, kerosene	TRL 5-6	All of the above
	Non-lignocellulosic biomass, (algae, non-food biomass)[10]	Various as above	Ethanol, diesel, hydrogenated	TRL 5-6	Various as above
	Sugars [11] (cellulosic, non-food)	Microbial	Ethanol, diesel	TRL 5-6	Diesel drop-in or 100%, bio-kerosene
	Supply of waste/byproduct gases	**Technology**	**Type of biofuel**	**Status**	**Application**
CCUS	Steel & Chemical Industry	Fermentation	Ethanol	TRL 6-7	Gasoline blend, E10, E85, E95,
		Upgrading & Catalysis	Methanol	TRL 5-6	Shipping, blends with gasoline
			Methane	TRL 5-6	100% in

					heavy duty transport, captive fleets, injected in the gas grid
	Waste polymers, plastics, non-biodegradable fraction of MSW	Gasification + catalytic synthesis	Synthetic[4]	TRL 6-7	Depends on fuel type; can be used for blends with diesel, gasoline, kerosene, drop-in
	CO_2 from RES systems	Reaction with RES H_2	Synthetic[4]	TRL 6-7	Depends on fuel type; can be used for blends with diesel, gasoline, kerosene, drop-in
e-Fuels	**Supply of H2**	**Technology**	**Type of biofuel**	**Status**	**Application**
	RES electricity	Catalysis	Methanol	TRL 6-7	Shipping, blends with gasoline
	RES electricity		Methane	TRL 7-8	100% in heavy duty transport, captive fleets, injected in the gas grid
	RES electricity		Synthetic[2]	TRL 5-6	Depends on fuel type; can be used for blends with diesel, gasoline, kerosene, drop-in

RES H2	**Source**	**Technology**	**Type of Biofuel**	**Status**	**Application**
	RES electricity	Electrolysis	H_2	TRL 5-8	Fuel cells, H2 engines, natural gas grid
	Ethanol or Methanol[12]	Reforming (on vehicle)	H2		
	Methane[12]	Reforming	H2		

ANNEX 8 - MODELLING METHODOLOGY FOR THE GHG EMISSION REDUCTION OPTIONS

ICCT assessment tool for option 4

The model used to estimate potential alternative fuel volumes, greenhouse gas impacts, costs and jobs for the various scenarios presented in this memo was developed by Dr. Stephanie Searle and Dr. Chris Malins at the International Council on Clean Transportation. The model is private and has not undergone peer review or been discussed with external experts. The model was developed specifically for understanding the impacts of various potential alternative fuel policies in the EU in the year 2030.

The model structure is linear. The amount of alternative fuel supplied in each scenario is multiplied by its carbon intensity value and then compared to the carbon intensity of diesel or petrol in order to calculate greenhouse gas savings. Alternative fuel amounts are multiplied by projected fuel prices for each type and compared to the projected price of diesel or petrol to calculate total cost of each fuel type in each scenario. The number of permanent jobs that would be directly supported by the production of each type of fuel was estimated on a per ton oil equivalent basis, and this was multiplied by alternative fuel volumes to calculate total jobs that would be supported by each fuel type in each scenario. Maximum volumes of advanced fuel technologies that have not yet been widely commercialized (cellulosic ethanol and synthetic diesel from pyrolysis or Fischer Tropsch processes) were calculated by estimating the number of facilities that could plausibly be constructed in each year from the present to 2030 with strong policy support. The estimated maximum volume of these advanced fuel technologies was not directly input into any of the scenarios presented in this memo, but was used as a comparison point to contextualize whether particular scenarios were likely achievable or not. The volumes of each type of alternative fuel in each scenario were largely determined by (a) the GHG reduction target in each scenario, and (b) the amounts of biodiesel and ethanol that could be consumed with current blend limits in diesel and petrol. REF2016 used in this modelling exercise was provided by the European Commission; volumes of specific fuel types was inferred from the given material using the information available.

Because the model projects future conditions, there is inherent and unavoidable uncertainty in the results. The maximum potential volumes of each type of fuel in 2030 will depend heavily on a number of factors, including but not limited to: the perceived strength of policy support, technology development, diesel and petrol prices, financial markets, and local policies and regulations throughout the EU. This model relies on inputs from several other sources that each carry uncertainty – for example, the fuel price projections taken from the UK Transport Energy Task Force report have uncertainty associated with them, and actual fuel prices in 2030 will depend on a variety of factors, including technology development and petroleum prices. There is uncertainty in the estimates of indirect land use change emissions used in this model, and to a lesser extent, in our assumptions on direct production emissions for alternative fuels in 2030. The number of permanent agricultural jobs that would be directly supported by the production of each type of alternative fuel was estimated in a simple approach by looking at the EU agricultural sector as a whole, and this estimation could be refined. The estimates of jobs both in feedstock production and in facility operation were made considering current conditions, but the number of jobs in alternative fuel production could change to 2030 depending on technology development. Uncertainty in this model has been minimized by focusing on the factors that most strongly influence the policy conclusions. For example, assumptions about ILUC emissions greatly affect the results about the net GHG impacts of each scenario; we therefore present results using two sets of ILUC emission estimates that were produced for the European Commission (the IFPRI study and the GLOBIOM study). The quality of the results from this model were otherwise assured by relying on published studies for the assumptions when such information was available.

Modelling assumptions for GHG mandate

GHG savings: It is assumed that the 60% GHG reduction requirement for direct lifecycle emissions under the RED sustainability criteria will continue to apply, and that some operators will achieve higher GHG savings. Food-based biodiesel is assumed to have an average direct GHG savings of 65% and food-based ethanol of 70%. All non-food based fuels are assumed to have higher GHG savings. For all scenarios, it is assumed that ILUC accounting will not apply towards eligibility or reportable GHG savings. In estimating real GHG savings including ILUC, ILUC results from the 2011 IFPRI study are used (Laborde, 2011). The composition of food-based biodiesel and ethanol by crop was taken from the 2020 EU crop mix in Valin et al. (2015).

Potential volumes: A 7% blendwall is assumed to apply for biodiesel blended in diesel and a 10% blendwall for ethanol blended petrol. 20% of the gasoline pool was assumed to be E85 (51-83% ethanol blended in gasoline, at an average blending rate of 75%) for scenarios B1, B2, and B3, and 5% of the gasoline pool was assumed to be E85 for all other scenarios under Options B, C, and D. While E85 availability may increase in the EU, the experience from the US, where corn ethanol consumption is strongly supported by the Renewable Fuel Standard, shows that biofuel mandates are an inadequate driver for increased use of higher biofuel blends, as the high cost of infrastructure changes presents a significant barrier (*e.g.* see EPA, 2016). The blendwall does not apply to drop in fuels, such as hydrogenated vegetable oil (HVO) or pyrolysis synthetic diesel. For the purpose of estimating volumes under the blendwall, diesel and gasoline projections are taken from REF2016 provided by the European Commission. Volumes of second generation fuels, such as cellulosic ethanol or cellulosic synthetic diesel, are estimated based on a deployment model, and are assumed to have preferential access under the blendwall when it applies. The use of electricity in vehicles follows Lutsey (2015). A category for “Other Annex IX fuels” is intended to include alternative fuels from glycerine and other sources for which individual projections are not possible at this time. A category for “Other advanced fuels” is intended to include non-biological fuels from waste, and other, unforeseen, types of low carbon, alternative fuels. The blendwall is not assumed to apply to “Other Annex IX fuels” and “Other advanced fuels.”

Cost: Cost estimates from the UK’s Transport Energy Task Force report are used for the cost of different types of fuel, including diesel, petrol, waste and crop-based biodiesel, and crop-based and cellulosic ethanol in the year 2030.[67] The cost of pyrolysis and Fischer Tropsch synthetic diesel and other advanced fuels are assumed to be the same as for cellulosic ethanol in 2030. Other Annex IX fuels are assumed to be slightly less expensive to produce. HVO is assumed to be slightly more expensive than crop-based biodiesel. The cost to obligated parties of electricity used in vehicles is assumed to be related to charger installation costs, which were estimated for level 2 home chargers in the year 2030 from EPA (2012). Only a portion of this cost is included in this analysis because other policies such as efficiency standards and purchase and tax incentives for

[67] "Data and outputs spreadsheet": http://www.lowcvp.org.uk/projects/transport-energy-task-force.htm

electric vehicles contribute to electric vehicle deployment and thus petroleum displacement by electric vehicles; this cost therefore cannot be attributed solely to a low carbon fuel policy.

Employment: Only direct, permanent jobs were estimated; construction jobs and indirect employment impacts were not assessed here. For second generation ethanol, pyrolysis diesel, and Fischer Tropsch diesel, feedstock collection jobs were derived from Turley et al. (2013), using values for straw collection. For other advanced fuels and other Annex IX fuels, it was assumed that a portion of fuel would be waste-based with fewer feedstock collection jobs. For food-based crops, feedstock production jobs were estimated as the average number of agricultural jobs per harvested hectare in the EU in 2010, using employment data from Eurostat[68] and crop production data from FAOSTAT.[69] The fraction of additional crop demand from food-based biofuel that would be met with increased agricultural production in the EU was taken from the recent GLOBIOM study (Valin et al., 2015). It is assumed that second generation fuel production (*e.g.* cellulosic ethanol from wheat straw) would result in 100% new feedstock collection in the EU. Biofuel facility jobs for second generation fuels was taken from a review in Pavlenko et al., (2016). Facility jobs for first generation biofuels was assumed to be half of this, per unit fuel on an energy equivalent basis, because second generation biofuel facilities tend to be more complicated than first generation facilities. The number of jobs created by electricity used in vehicles was estimated as labour required to install electric chargers (assuming 8 hours per charger, following costs from EPA (2012)); a portion of the employment created in charger installation was considered attributable to the low carbon fuel policy. Waste collection jobs were not included.

68 http://ec.europa.eu/eurostat/statistics-explained/index.php/Agricultural_census_2010_-_main_results#Agricultural_labour_force. It was assumed that half of total agricultural jobs are in crop production, as opposed to livestock or other types of jobs.

69 http://faostat.fao.org/

ANNEX 9 - REFIT EVALUATION

The REFIT evaluation concluded that the objective of sustainably increasing the share of renewable energy in the EU final energy consumption has been successful. The binding national targets, the National Renewable Energy Action Plans and the biennial monitoring[70] provided for by the RES Directive have been particularly effective for promoting transparency for investors and other economic operators, and have ensured high quality information on renewable energy markets and policies in the Member States. This is illustrated by the rapid deployment increase after the date of adoption of the Directive, passing from 10.4% share of renewables in 2007 to 17% in 2015[71].

These legal provisions, together with additional national policies and other non-regulatory measures, have contributed to the overall achievement of EU's energy and climate policy goals, resulting in greenhouse gas emission saving, increased security of energy supply, innovation leadership, employment creation, public acceptance and regional development. They have proved their relevance, coherence, efficiency, effectiveness and added value for the overall EU energy and climate change objectives. Renewable energy is, currently, the only decarbonisation option in the power sector deployed at a rate that is close to what is required under long-term IEA scenarios to limit global temperature rise to 2°C above pre-industrial levels[72].

However, even if the EU and all but one Member States are currently on track towards its overall renewable energy 20% target for 2020, target achievement by 2020 will only be secured if Member States continue to meet their increasingly steep trajectories. Furthermore, further efforts are necessary to increase the current progress rate of renewables deployment in transport to ensure the sectorial 10% target is met. The regulatory uncertainty caused by the long political discussion on ILUC, the late adoption of the amendments on ILUC to the RES Directive and the lack of a post-2020 policy for transport, together with the lack of commercial availability of alternative fuels and advanced biofuels at the needed scale and pace, have had a negative impact in the deployment of renewables in the transport sector.

In addition, the effectiveness of the national targets, based on a flat-rate/GDP approach (as opposed to an approach based on national potential, which would have been more cost effective, but considered less equitable[73]) was, however, compromised by the fact that flexibility and trading options were not utilised by the Member States as expected during the reference period. However, intergovernmental negotiations that were held in 2015 and 2016 amongst several potential "selling" and "buying" Member States, demonstrate increasing mobilisation of efforts towards concluding the first renewable energy cooperation agreements.

Another issue which requires follow-up is the level of investments in renewable energy. Their decline after 2011 due to undermined inverstor confidence and some external factors highlights the need to reflect on how investors' legitimate interests can be better

[70] National Renewable Energy Action plans and biennial national renewable energy progress reports are legal requirements set out in Art. 4 and Art.22 of the Renewable Energy Directive

[71] EUROSTAT

[72] IEA, 2015

[73] "Package of Implementation measures for the EU's objectives on climate change and renewable energy for 2020", 2008, SEC(2008) 85

protected.The REFIT evaluation of the RES Directive also pointed to a number of shortcomings in the Renewable Energy Directive:

- *National renewable energy action plans*: While the national renewable energy action plans provided transparency and information for investors on Member States' plans for renewable energy development, they eventually became outdated as the RES Directive does not require their regular updating to adjust them to policy and global economic changes. This shortcoming was largely compensated by biennial national RES progress reports that provided regular updates on national regulatory and financial measures in the renewable energy space. In the context of the new 2030 Climate and Energy Framework and Energy Union Governance process, the current legal provisions on the planning and reporting will need to be revised for post 2020 period.

- *Cooperation mechanisms*: The cooperation mechanisms set out in the RES Directive have not yet been used to any significant extent by Member States, with exception of the joint Swedish-Norwegian support scheme. In the RES Directive, the use of cooperation mechanisms is voluntary and Member States have so far, for various reasons, preferred to use national renewable energy sources for target achievement. The opportunity given by the RES Directive to share the efforts to achieve the renewable energy target cost-effectively has, therefore, been rather underused. However, as national interim trajectories become steeper after 2015, a number of Member States are currently in active phase of negotiations aiming to conclude such cooperation mechanisms, in the form of a partial opening of national support schemes, or statistical transfers. .

- *Renewable energy support schemes:* Pursuant to Article 3(3) of Directive 2009/28/EC, support schemes are but one instrument - amongst others - that can be chosen by Member States to achieve the binding national renewable targets. The majority of the Member States though used them as part of their renewable policies. In the absence of clear principles established in the RES Directive, Member States had wide discretion in their decisions on the design and scope of renewable energy support schemes. As the cost of renewable energy technologies fell, several national support schemes were unable to be adapted rapidly enough. As a result, technology bubbles were encouraged, resulting in market distortion and fragmentation.

- *Administrative procedures*: Administrative and planning systems are very diverse across the EU Member States and progress in simplifying them has been hampered due to the large margin of discretion left in the legal provisions of Article 13(1). Clear and transparent rules are not yet in place in all Member States and at all necessary levels. The absence of clear legal requirements to establish one administrative entity (one-stop shop) for the permit granting procedures and the absence of maximum time-limits for permit granting in Member States are still perceived as major administrative obstacles and an additional cost burden to project developers. In view of tackling investment bottlenecks and lengthy project approval procedures, further reinforcement of these provisions might need to be considered for the amended post 2020 legislation[74].

[74] Building on the previous rather general requirement set out in Directive 2001/77/EC for Member States to take action to reduce and simplify administrative procedures, the impact assessment

- *Renewable energy in heating and cooling supply and in buildings:* The RES Directive recommended Member States to promote and integrate renewable energy in the urban and local environment (*e.g.* newly developed areas, district heating and cooling systems), and to mandate renewable energy use through buildings codes for new buildings as of 2015, while leaving full discretion to the Member States as regards implementation modes. Despite the long term decarbonisation goal in the heating and cooling sector and in buildings, the existing framework did not provide sufficient incentives for fuel switching from fossil to renewable energy in the heat supply and buildings. Further reinforcement of these provisions might need to be considered in the revision of the Directive for post-2020.

- *Grid access rules*: Certain provisions of the RES Directive are not specific enough (*e.g.* providing deadlines for their implementation) for the purpose of enabling better monitoring and enforcement. The Directive also leaves discretion to Member States on whether shallow or deep grid charging is applied, which considerably changes the risk and thus the cost for new renewable installations across Member States. In view of the intended wider electricity market reform, some of the current legal provisions on RES electricity integration might need further streamlining and integration with the electricity market legislation.

- *Self-consumption*: The RES Directive does not contain specific provisions on self-consumption of renewable electricity, which has given Member States a wide discretion to regulate this type of emerging trend of consumers' empowerment. This has led to a wide range of policies across the EU, some of them hampering the cost-effective development of self-consumption. The benefits of introducing a EU framework enabling cost-effectives self-consumption (in line with the Energy Union's objective of empowering consumers) could be assessed in the revision of the legislative framework for post-2020.

- *Guarantees of origin (GO)*: The regulatory framework in the RES Directive has not provided sufficient clarity and suitable provisions for the creation of a comprehensive, liquid and harmonised GO system for all energy sources throughout the EU. It enables the provision of "green" supply contracts which are dissociated from the physical delivery of renewable electricity. The revision of this provision in the context of the legislative work for the post-2020 energy framework could look at improving the consistency in the application of the system by Member States as well as extending their use.

- *Bioenergy sustainability*: Indirect land use effects were not included from the very beginning in the EU mandatory sustainability criteria for biofuels and bioliquids. The related policy debate and regulatory amendments have created investors uncertainty and, in turn, a serious slowdown in investments, including in advanced biofuels. Different national implementation modes of the EU sustainability criteria, including a lack of mutual recognition of national

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accompanying the proposal for the RES Directive considered a reinforced "national action" approach without specific EU guidance as the most appropriate way forward. However, the REFIT evaluation concluded that even the reinforced provisions of Article 13(1) of the RES Directive have not substantially improved the situation and the public consultation for the present Impact Assessment demonstrated clear support for a more stringent approach and harmonised EU minimum rules in the post-2020 period.

certification schemes, have led to some market fragmentation. The lack of EU sustainability framework for biomass and biogas used in heating/cooling and electricity has also resulted in a growing debate, which in turn has prompt the introduction of national scheme, with possible market distortion.

In a post-2020 scenario consideration should be given to the opportunity of extending the sustainability criteria to account, not only for biofuels and bioliquids as it is already the case, but also for solid and gaseous biomass, in a cost-efficient way. Furthermore, the future framework should give consideration to effective and pragmatic ways to enhance renewables deployment, notably advanced biofuels, in the transport sector. This should build on the experience gained by many Member States with the implementation of national incorporation mandates for biofuels/renewable energy. Improved information and tracking systems are also needed to prevent fraud and abuse.