

Costs and Benefits to EU Member States of 2030 Climate and Energy Targets



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Acknowledgements

Costs and Benefits to EU Member States of 2030 Climate and Energy Targets is based on analyses using the POLES-Enerdata model and presents an overview of the main European energy and climate policies: reduction of CO₂ emissions, development of renewable energies, and promotion of energy efficiency. The report looks forward to 2030 and beyond to evaluate possible targets and the goal of maintaining global temperature rise to 2°C. This publication was produced by Enerdata's Global Energy Forecasting team, including the modelling and scenario analysis, within the framework of an external service contract to the UK's Department of Energy and Climate Change; the contact person at DECC for this contract was James Foster.

Executive Summary

Delivering both economic growth and GHG emissions reductions is essential to avoiding dangerous climate change, with its associated economic, social and environmental costs. Keeping the global temperature rise below 2°C represents a major challenge, particularly while ensuring decarbonisation is cost-effective and maintaining security of supply and competitiveness. A number of policies have been implemented throughout the EU to reach its 2020 targets; the next challenge is to look ahead to 2030.

To continue the process of transforming to a low carbon economy and set the next waypoint towards the EU's 2050 objective of reducing GHG emissions by 80-95%, the European Commission has released its proposal for an EU 2030 framework for climate and energy policies. Pursuant to this, the UK's Department of Energy and Climate Change commissioned a set of detailed quantified scenarios for GHG emissions and the energy sector, in order to look at the costs and benefits to individual Member States and the EU as a whole from different potential EU policies and objectives for 2030.

Significant potential exists within the EU to reduce GHG emissions at reasonable costs, both in the short and long term. The 20% reduction of emissions by 2020 will likely be overachieved despite the current low ETS price; indeed, even with the existing surplus of EUAs, this will probably be the case without further policy intervention. The Commission's Low Carbon Roadmap suggests that a tighter cap and target would put the EU on a more cost effective pathway to 2050.

About the Analysis

Total costs in this report include abatement cost, permit trading cost, the purchase of international credits, and renewables subsidies (costs from deploying renewable technology specifically). The abatement cost includes the resource costs of consumption, but is based on more than just the cost of technology and change in behaviour needed to drive deployment. Implicit barriers or support included in historical energy consumption data (i.e. differences from what pure technology costs and energy prices would suggest) are also taken into account in abatement costs to reflect the actual energy system choices of Member States.

Costs are given relative to a *Reference case* to indicate the additional effort needed to achieve a set of targets beyond a 'business as usual' case. The *Reference case* modelled in this study includes current European policies up to 2020 (EU and Member States), only EU climate policy beyond (i.e. maintaining the current EU ETS cap trajectory), no Member State level legislation or policies beyond 2020 (i.e. current renewables subsidies are discontinued), and conservative estimates of energy efficiency measures.

Much of this study focuses on the implementation of renewable power sources due to their detailed description in POLES. Some other promising decarbonisation options, such as direct heat use or transportation modal shifts, are represented in POLES at a relatively aggregated level (that is, specific technologies are not modelled explicitly as in the power sector). The extent to which these other technologies could be adopted compared to options such as biomass is therefore uncertain because of the difference in modelling detail. The study also uses historical technology costs, fossil fuel prices, and renewable potentials from established international sources; however, there is considerable uncertainty over the use of these into

the future, and scenarios included in this report may vary from countries' own specific assumptions, or those used in other studies. These factors mean that results, especially at a disaggregated level of detail, will vary from other analyses.

Compared to POLES, the model used for this analysis, the PRIMES model (used by the European Commission) includes more 'bottom-up' detail of energy consuming and supplying technologies. PRIMES details many individual energy technologies, for example in terms of useful energy, industrial processes and capital vintages, both due to data availability and in order to have a strong focus on the EU energy system. POLES represents many sectors, aside from the power sector where technologies are explicitly modelled, through reduced-form energy demand and supply equations that relate explanatory variables (such as prices, GDP, etc.); this ensures a consistent framework is used in all world regions, for which many are often lacking available detailed energy data. Compared to PRIMES, POLES also models endogenous technology costs (i.e. the costs vary between scenarios and depend on deployment), with these depending on both worldwide and country specific deployment. POLES also directly models international fossil fuel prices, which depend on the global situation in each scenario.

Costs and benefits of GHG targets

The overall EU results are shown in the table below. Key results from this modelling are:

- A GHG target of 40% domestic reduction by 2030 costs the EU 0.2% of GDP in 2030 compared to the *Reference case* (current EU policy only) equivalent to a reduction in the average annual growth rate from 2014-2030 of 0.01 pp (from 1.59 to 1.58%). As the GHG target in 2030 increases, costs rise but remain below 0.6% of GDP for a 50% target. A 50% target with the use of 5% credits costs less than 0.5% of GDP, equivalent to a reduction of 0.03pp in the average annual growth rate. (see Abatement costs)
- Cumulative total costs to 2050 to achieve an 80% target are approximately 0.5% of cumulative GDP from 2020-2050. Costs include the abatement of emissions and credits purchased. Taking early action and achieving a 50% target in 2030 will reduce the cost by 0.03% of cumulative GDP. Improving energy efficiency is central to a cost-effective approach to achieving any GHG target; energy demand in 2030 falls from 21% below the 2030 EU baseline (the same projection used for the 2020 Energy Efficiency target) under the Reference case, to 27% under a 40% GHG target. (see Additional and alternative targets)
- Implementing a GHG emissions reduction target will reduce dependence on imported energy sources. Overall, the EU could reduce its energy import bill for fossil fuels in 2030 by over 0.4% of GDP (while the abatement of fossil fuels is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost). Reductions in oil imports make up 63% of this difference, and reduced gas imports 32%. (see Energy security)
- Overall, reduced reliance on fossil fuel electricity generation could reduce EU health costs due to respiratory illness by an average of 0.1% of GDP in 2030 under the mean value of health impacts (these benefits are not captured in the total cost figures)

above). Although the uncertainty in health impacts is large, this illustrates the potential for benefits. These are primarily concentrated in Member States that currently generate a high proportion of their power from coal, and that also have a strong forecasted growth in electricity demand. These are primarily Central and Eastern European countries, such as Estonia, Poland, and Bulgaria; however, most countries will experience a net health benefit from the shift away from fossil fuel generation. (see Health cost benefits)

- The power sector provides some of the most easily available sources of mitigation options and will likely provide the majority of reductions to 2030. Decarbonising the electricity supply could help provide important momentum on a low- or zero-carbon path. Power sector emissions are almost 27% lower in 2030 in the *40% Scenario* compared to the *Reference case*.
- To reach the 40% target, the main reduction option pursued is to reduce GHG emissions from the power sector, representing almost half of the renewables consumed. This is mainly achieved through increases to power capacity in wind (onshore +46%, offshore +140%) and solar (+75%). Overall, renewable electricity generation capacity grows to 48% of all power capacity. (see Renewables)
- Earlier access to CCS technology on a commercial scale, driven either through advancements in technology or reduced investment costs could promote an extra 34 GW of CCS electricity generation capacity across the EU by 2030. In this scenario, the share of renewable technologies is lower, while fossil fuel use and import bills are reduced by less than in the *40% Scenario*. (see Abatement costs)
- By 2030, to meet all of the GHG target scenarios, this modelling suggest biomass will need to provide a large share of the consumption in the final demand sectors (industry, buildings and transportation). In the *40% Scenario*, nearly 33% of fuel used in industry and heat for buildings will be provided by biomass, while biofuels will make up 20% of total liquid fuels consumed in light and heavy duty vehicles.
- The numbers above are based on a particular set of assumptions on future technology costs which are uncertain. Changes to those assumptions could have an important impact on the results. For example, uncertainty in investment costs is partly related to how much costs come down as deployment increases. If this “learning by doing” cannot be sustained in the long term, it will lead to higher than expected investment costs, though consumption of renewable energy falls by less than 0.1%. If investment costs do not decrease as fast as expected from fewer benefits due to slower learning, total EU costs in 2030 could be 0.03% of GDP, higher than in the *40% Scenario*.

Costs and benefits of renewables targets

- A GHG target of 40% domestically would drive levels of renewables in the EU close to 30% by itself: the share of coal in primary consumption falls from 14% to 8%, with two-thirds of this share going to renewables and the remainder to nuclear.
- However, the cost of a 40% domestic GHG target with a 30% renewables target is estimated to be 36% greater than a GHG target alone, equalling 0.1% of GDP, with this cost driven largely by burden sharing. This cost is largely caused by a mismatch of

renewable potentials and Member State targets under a scenario that extends the 2020 climate package burden sharing approach to 2030. Different burden share methodologies could reduce these costs by bringing MS targets more in line with the cost-effective distribution of effort, but do not mitigate the impacts of uncertainty.

- The costs for some countries of the RES and GHG target combined are lower than for the GHG target alone because they face two specific circumstances. First, their required level of RES under the burden share is already met under the GHG target alone, and so there are no additional RES costs. Second, as the RES target lowers the EU-wide price of EU ETS allowances, net purchasers of EU ETS allowances face cheaper purchase costs. In practice, the extent to which this would happen, and to which countries, under a RES target scenario would depend on the exact RES target and burden share applied, the cost effective level of RES, and the actual net trading position of each country in the EU ETS and EUA price (which will both also depend on relative targets and technology costs).

Additional and alternative targets

- An alternative burden share for sectors outside the EU ETS (the non-traded Sector, NTS) that assigns more effort to Member States with higher GDP per capita, but keeps the same overall NTS target of a 30% reduction, will not change the total cost at the EU level compared to the *40% Scenario* (since cost efficiency is assumed within the Non-ETS sectors through trading, which will still provide the same lowest overall cost). However, the level of trade between Member States changes. The countries most affected by the change in burden share all see a decrease in their net cost: Bulgaria (+0.24 pp share of GDP), Lithuania (+0.16 pp) and Romania (+0.15 pp).
- In a 40% GHG target scenario, having an additional energy efficiency target in excess of the level implied by meeting the GHG target alone imposes additional costs on the energy system. Meeting a 30% energy efficiency target decreases energy demand and so the shadow carbon price necessary to achieve the emission reduction target is reduced by more than half. However, the resulting total cost is more than three times larger than the 40% Scenario at 0.6% GDP or equivalent to a reduction of 0.04 pp/year in the GDP growth rate. This large increase in cost is due to the different effects of a carbon price versus an energy consumption tax (i.e. an efficient approach to reducing energy consumption). While both measures reduce energy consumption through higher fuel prices, a carbon tax specifically decreases fossil fuel use to reduce GHG emissions (increasing the share of non-emitting sources in the power mix), whereas an energy consumption tax reduces all energy use equally, affecting renewables and nuclear power, as well as fossil fuels. Bottom-up modelling that examines the impact of removing behavioural barriers to energy efficiency could indicate different impacts, for example lower costs and action in different sectors.

In a 40% GHG target scenario, a 30% RES target using the same burden shares by Member State as the 2020 targets, and a 30% energy efficiency target results in a total cost in 2030 of 0.8% GDP or an equivalent reduction in growth of 0.05 pp/year between 2014 and 2030. Compared to the 40% Scenario, total cost increases by 0.6% GDP or an equivalent reduction in growth of 0.04 pp/year. Two-thirds of the additional total cost comes from the energy efficiency target, while about a quarter is due to meeting the RES burden sharing.

Table: Cost of energy policies by scenario

| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG | % GDP | 50% GHG (10% credits) | % GDP |
|---|--------------|---------|-------|-------------------|-------|---------|-------|-----------------------|-------|
| Total cost vs. Ref, €bn | | 30 | 0.2% | 41 | 0.3% | 94 | 0.6% | 67 | 0.4% |
| Average health cost vs. Ref, €bn (not captured in total costs)* | | -18 | 0.1% | -18 | 0.1% | -27 | 0.2% | -19 | 0.1% |
| Energy import bill vs. Ref, €bn (captured in total costs)** | Fossil fuels | -72 | 0.4% | -78 | 0.5% | -111 | 0.7% | -58 | 0.4% |
| | Biomass | 4 | 0.0% | 5 | 0.0% | 6 | 0.0% | 3 | 0.0% |

| In 2030 | | 40% GHG + Alt NTS burden shares | % GDP | 40% GHG + Alt split ETS/NTS | % GDP | 40% GHG + 30% EE | % GDP | 40% GHG + 30% RES + 30% EE | % GDP |
|---|--------------|---------------------------------|-------|-----------------------------|-------|------------------|-------|----------------------------|-------|
| Total cost vs. Ref, €bn | | 30 | 0.2% | 41 | 0.3% | 100 | 0.6% | 121 | 0.8% |
| Average health cost vs. Ref, €bn (not captured in total costs)* | | -18 | 0.1% | -18 | 0.2% | -27 | 0.1% | -24 | 0.1% |
| Energy import bill vs. Ref, €bn (captured in total costs)** | Fossil fuels | -72 | 0.4% | -66 | 0.4% | -101 | 0.6% | -107 | 0.7% |
| | Biomass | 4 | 0.0% | 5 | 0.0% | -1 | 0.0% | 1 | 0.0% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

Introduction

The solidity of the science behind anthropogenic climate change has been strengthened with the 5th Assessment Report of the Intergovernmental Panel on Climate Change released in 2013, which states with 95% certainty that humans are the dominant cause of climate change (IPCC 2013). With the economic slowdown since 2008 mainly impacting Western economies, emissions globally have continued to increase at a significant rate. In 2013, carbon dioxide concentrations in the atmosphere reached 400 ppm; even if stabilised at this level, it is estimated that global average temperatures could still rise by between 2°C and 2.4°C by the end of the current century.

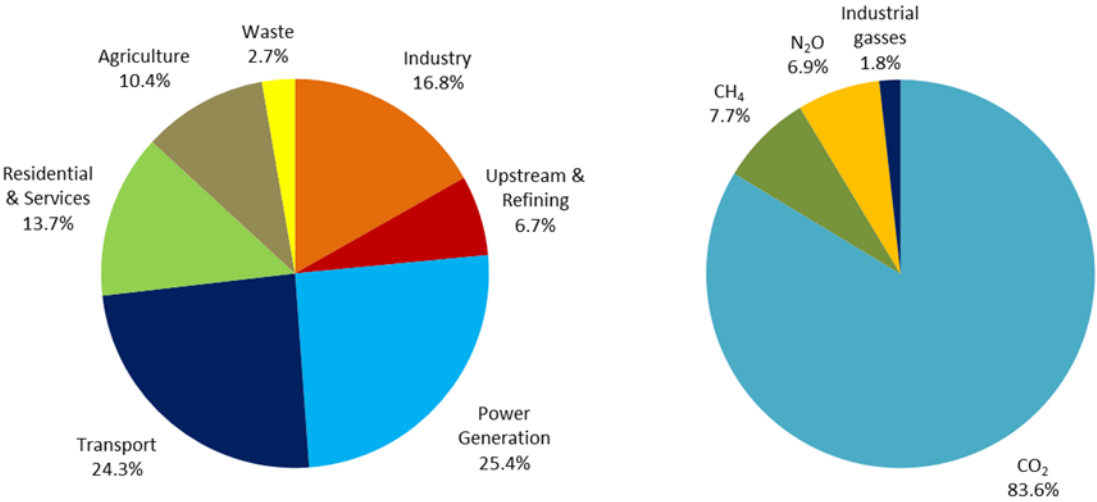


Figure 1: EU28 GHG emission profile (excluding LULUCF) in 2010, by sector and by gas

Although the decoupling of economic growth and emissions growth has been observed in some countries and appears to be increasing globally, economic growth based purely on non-emitting activities has yet to be achieved. This represents a major challenge for the future, but efforts must start now. The European Commission has prepared both a “Roadmap for moving to a competitive low carbon economy by 2050” (2011) and an “Energy Roadmap 2050” (2011) outlining possible scenarios to achieve this goal. The Climate and Energy package adopted in June 2009 finalised many of the measures needed to achieve 2020 targets, stressing the three pillars of the European Union’s energy policy: competitiveness, security of supply and sustainability.

To continue the process of transforming to a low carbon economy and set the next waypoint to 2050, the European Commission has released its proposal for the EU’s 2030 framework for climate and energy policies. Pursuant to this, the UK’s Department of Energy and Climate Change commissioned a set of detailed quantified scenarios for GHG emissions and the energy sector, which involved modelling and analysis, in order to look at the costs and benefits to the EU as a whole and to individual Member States incurred by different EU policies and objectives for 2030.

Policy Context

In 2007, the European Commission designed the Climate and Energy Package which was definitively adopted by the European Parliament in 2009. The final adoption of the package implements the following targets:

- A 20% reduction of GHG emissions by 2020, compared to 1990 levels;
- A 20% share of renewables in the gross final consumption of energy; and
- A 20% reduction of primary energy demand in 2020 compared to the initial projection of 1842 Mtoe from the PRIMES 2007 baseline (final energy demand of 1348 Mtoe).

The package was developed into a series of EU-wide and Member State-level policies:

Renewables

The 2020 renewable energy target was designed to complement the GHG emissions reduction objective, but also to promote the security of energy supply for Europe, to foster technological development and to provide opportunities for employment and regional (intra-EU) growth.

The Renewable Energy Directive (2009/28) defines mandatory national shares of renewables in the gross final consumption of energy for 2020 in order to reach the EU-wide 20% share. The shares apply to the sum of electricity, transport, heating and cooling from renewables (biomass in district heating, biomass and part of waste in building heating, solar heat, and biofuels), and is compared to the gross final consumption (which includes losses in electricity and heat transmission and distribution and excludes electricity produced for pumped storage).

The specific Member State targets for renewables range from 10% in Malta to 49% in Sweden, with a flat rate share for each member state supplemented by an element depending on both past penetration of renewables in each country, and relative GDP per capita between Member States.

Additional to the 20% renewables target, the European Commission set up a specific objective of 10% renewable energy consumption for the transport sector in 2020 (i.e. biofuels).

Greenhouse gas emissions

The EU Emissions Trading System currently includes 31 countries, the 28 EU Member States and the 3 EFTA countries (Iceland, Liechtenstein, and Norway).

The third phase of the EU ETS began in January 2013 and implements major changes compared with previous phases:

- An EU-wide cap on emissions, instead of individual national caps;
- Progressive phase-in of auctioning of emission allowances, rather than free allocation based on historical emissions; and
- Additional sectors covered by the trading system, notably aviation (which first began in 2012) and production of certain chemicals.

The EU ETS is expected to play a major role in achieving the 2020 emissions target and is supported by the Effort Sharing Decision which sets binding national targets on emissions for sectors not covered by this trading scheme. The overall 20% effort (compared to 1990) for the 2020 target is shared as follows:

- A 21% decrease in ETS sectors' emissions compared to 2005; and
- A 10% decrease in non-ETS sectors' emissions (i.e. mainly road transport, residential and tertiary) compared to 2005.

The 20% emissions reduction target was set prior to the economic crisis of 2008 and largely did not anticipate current economic difficulties and public budgetary constraints. Indeed, the economic slowdown of recent years will actually be a contributor to achieving the 2020 target, as evidenced by the recent low prices for EUAs and sharp falls in emissions.

In the European Commission's Low Carbon Roadmap, the GHG reduction target under the 2020 Climate and Energy package is extended to 2050 by looking ahead to the 80-95% reduction in GHG emissions agreed by the EU.

Energy efficiency

The energy efficiency objective of the Climate and Energy Package states that the EU reduces its primary consumption (excluding non-energy uses) by 20% in 2020 compared to the baseline scenario modelled with the PRIMES model and published in 2007; a 2012 update gives this value in terms of final consumption (target of 1078 Mtoe). This objective is defined at the EU-level, and is not provided by Member State or by sector.

Under the Energy Savings Directive (2006/32), each Member State had to submit a National Energy Efficiency Action Plan (NEEAP) describing its efforts to 2016 for savings in final energy demand (excluding ETS sectors). The NEEAPs use a bottom-up analysis and provide energy reductions calculated by sector.

The EU Energy Efficiency Directive (2012/27/EU) established a common framework of measures to promote energy efficiency across different sectors of the economy.

The Directive introduced two new targets for Member States:

- A non-binding national energy efficiency target for 2020, to be set by Member States taking into account the EU's overarching non-binding 2020 energy efficiency target (Article 3); and
- A legally binding target to save 1.5% of final energy annual, year on year, between January 2014 and December 2020 (Article 7).

Scope

This project looks ahead to 2030. To do this, scenarios were developed using the POLES-Enerdata model, a world energy-economy model that fully describes the energy system and associated GHG emissions. This report analyses the costs and benefits to all EU Member States under different scenarios of the level and type of EU targets defined within a 2030 climate and energy framework. Scenarios include progressively more stringent GHG targets in 2030 (40%, 50%, and 60% reductions compared to 1990), alternative assumptions on

access to international credits (0%, 5% and 10% of 1990 emissions), the addition of RES burden shares by Member State, accelerated CCS commercial availability and reduced renewables learning rates. These are the sensitivities commissioned as part of this report; however, they are not a comprehensive range covering all possible outcomes that could arise in reality.

What are the costs and benefits to Member States under different scenarios of the level and type of EU targets? The analysis assesses the benefits of different scenarios to improved air quality and health, diversity of energy supply, and reduced costs of meeting longer term emission reduction targets (notably the EU's commitment to reduce emissions by 80-95% by 2050).

Relying on more low-carbon, domestic, or diversified sources of energy can bring significant benefits not only for the environment, competitiveness and security of energy supply, but also in terms of economic growth, employment, regional development and innovation. This study quantifies some of these impacts on the energy system from changes induced via carbon pricing, and other measures, to reach different emissions reduction objectives.

Methodology

For this project, scenarios were developed using the POLES-Enerdata model, a world energy-economy model that fully describes the energy system and associated emissions. Results are provided for all EU Member States and at the EU-28 level. Different scenarios and target objectives were developed to 2030; the quantified modelling was extended to 2050 in order to address the impacts on meeting the EU's long-term targets.

All prices and costs in this report are given in 2010 euros (€), unless stated otherwise.

Main assumptions

The starting point of all scenarios in the POLES-Enerdata model is up-to-date databases, including a complete data set for economic growth, energy demand (and associated emissions), energy prices, power production and power capacities for all world regions up to and including 2011, in many cases up to 2012. Details can be found in the box below.

CO₂ and other GHG emissions from POLES are based on historical data compiled by Enerdata, with a methodology similar to that of the IEA (i.e. sectoral approach based on fuel combustion); as for the IEA, differences may exist between Enerdata data and UNFCCC submission data due to differences with national GHG estimation methodologies, however for Member State countries these differences are relatively small and acceptable for this analysis.

Since POLES is primarily an energy-economy model focused on the production and consumption of energy, there is no direct coverage of land use, land use change and forestry emissions (LULUCF) or non-CO₂ emissions from agriculture. Approximations for emissions from these sources and reductions to meet the overall GHG reductions consistent with a 2°C scenario have been accounted for when determining the necessary reductions from energy related emissions.¹

A *Reference case* was first developed to 2020 to meet the EU Climate and Energy Package objectives, and then extended to 2030 (see Scenarios description below). All variant scenarios follow the same development as the *Reference case* up to 2020; then differ depending on the scenario definition of a 2030 climate and energy framework.

¹ Total GHG emissions from UNEP 2013 Gap report, medium chance scenario (Table 3.1). Agriculture non-CO₂ emissions from EC Low Carbon Roadmap 2050 (EU27 – Table 17; world – Fig. 14). LULUCF emissions from EC Low Carbon Roadmap 2050 (EU27 – Fig. 34) and OECD Environmental Outlook to 2050 published in 2012 (world – Fig. 3.8).

Main assumptions in the Reference case and Scenarios

Population: National growth rates for EU Member States were provided by DECC (European Commission from 2030 Impact Assessment); while growth rates for non-EU countries are taken from the United Nations Population Division's medium fertility scenario (2012 revision).

GDP growth rates:

EU28

- 2000-2012 – World Bank
- 2013-2017 – International Monetary Fund (April 2013 update)²
- 2018-2030 – European Commission (from upcoming 2030 IA)
- 2031-2050 – Centre for Prospective Studies and International Information (June 2013 update)³

Non-EU28

- 2000-2012 – World Bank
- 2013-2017 – International Monetary Fund (April 2013)
- 2018-2050 –CEPII (June 2013)

Technology costs and details: Relative cost of technologies drive the competition for several aspects of POLES: power generation and installed capacities, penetration of new vehicle technologies and shift to low energy consumption buildings. Costs and details of technologies, including lifetime, learning rate, efficiency and capacity factor, are initially exogenous in the POLES model; technologies are then assumed to develop over time and follow endogenous learning curves based on global installed capacity and R&D efforts. Technology costs in 2012 for this project have been sourced and applied to the POLES model from the IEA's World Energy Outlook 2012⁴.

Policies: EU ETS directive; Effort Sharing Decision (non-ETS sectors); RES directive (20% target) and National Renewable Energy Action Plans; National energy consumption objectives (August 2013) to 2020. Note that policies related to local air pollutants like SO₂ and NO_x or specific emissions sources (for example, the EU Large Combustion Plant Directive which applies emission limits to large combustion sources) are not directly represented in POLES since modelling does not include individual combustion sources, power plant vintages, or local air dynamics.

² EC forecasts were produced in 2011 and do not take into account the economic development in European Member States between 2010 and 2012, which was very low. As a result, the EC economic growth forecast for the period 2010-2015 now looks unlikely to be achieved, and we have chosen to substitute the more recently produced IMF forecast for this period.

³ French research institute (Centre d'études prospectives et d'informations internationales) providing long-term GDP forecasts based on the MaGE model.

⁴ <http://www.worldenergyoutlook.org/weomodel/investmentcosts/>

Key methodological points in forecasts

The model simulates the annual development of energy supply and demand within a global context, using historical values as a starting point. Endogenous international fuel prices (driven by supply and demand relationships) influence regional and domestic import prices; these in turn, drive substitution between fuels, market shares for more competitive energy options, and ultimately learning rates for new technologies.

POLES simulates the evolution of energy consumption and GHG emissions within the EU and the rest of the world. Compared to the *Reference case*, the only additional policy implemented for non-EU countries is the addition of a carbon price necessary to meet the long-term goals of keeping global temperature increases below 2°C (see Scenarios description)⁵.

Marginal abatement cost curves (MACCs) are produced from the POLES model and are based on a full technological description and load curve simulation for the power sector, and on econometric demand functions (including short and long-term price elasticities) for final demand sectors. The introduction of a carbon price adds a premium to fossil fuel prices perceived by consumers based on a fuel's carbon content. This affects the competitiveness of different fuels in the energy system, and as a consequence, less carbon intensive fuels are consumed as the carbon price increases.

Future carbon markets are simulated through the equalisation of marginal abatement costs of GHG emissions from combustion & industrial processes between individual sectors and countries participating to the permit trading market. The behaviour of each actor on a market (long or short) depends on its marginal cost (i.e. their response profile between cost and demand).

Until 2030, only Least Developed Countries are able to provide credits to the EU ETS and non-ETS sectors under scenarios that consider international credits, as specified in the current ETS legislation. After 2030, we assume that all Developing Countries will be able to provide credits given that the total potential for emissions reductions in LDCs is limited relative to the demand for credits within the EU.

Because POLES is not an optimisation model and cannot look forward over time periods to find the most efficient method of using credits (i.e. banking or borrowing), either for profit generation or emissions reductions, a more stylised approach has been adopted. We assume that the current surplus of 1.7 GtCO₂ credits from the ETS Phase 2 will largely be preserved in the short to medium term before being surrendered in future periods when the carbon price increases. However, some amount of credits will normally be surrendered, even in the short term, by more risk averse permit holders or to meet urgent needs. Accordingly, the total volume of surplus EUAs is distributed as a wedge of emissions allowances above the ETS cap over the period 2014-2050 (i.e. rising from 0 MtCO₂ in 2013 to 88 MtCO₂ in 2050). The current unused credit allowances (424 MtCO₂) are distributed evenly throughout Phase

⁵ The scenarios include feedbacks between developments in the EU and elsewhere, such as the impact of EU demand on international fossil fuel prices and the demand for credits in the EU. Thus the international context is largely, but not exactly, the same between scenarios.

3, including a short ramp-up to 2015 due to the very low EUA price in 2013 and consequent low demand for credits.

The shares of the EU ETS cap to be auctioned and freely allocated to Member States were estimated based on current splits under the 2020 package and were provided by DECC. Between 2021 and 2030, the shift from freely allocating permits to auctioning is assumed to increase gradually in line with current trends. The share of the non-traded Sector cap is also based on the current methodology under the 2020 package (See Annex 2 for NTS burden shares by Member State).

The method for quantifying the benefits of reducing health impacts associated with PM_{2.5} and PM_{2.5} precursors, NO_x and SO₂, is based on a study conducted by the European Environmental Agency (2008).⁶ Here, we use the EEA study's minimum and maximum values for the economic value of health impacts from local air pollution associated to fossil fuel electricity production, and calculate a mean value based on the min and max provided. The uncertainty between the max and min values from the EEA study is quite large, reflecting the range of values appearing in the literature and the difficulty to directly attribute reductions in particulate emissions to health costs. These impact values (given on a kilowatt hour basis) are used to illustrate the potential for net benefits between the Scenarios and the *Reference case*. Similar to fossil fuel combustion plants, biomass combustion facilities also emit fine particles. We include the health costs associated to biomass combustion (excluding biomass gasification) using the assumption that biomass combustion emits approximately two-thirds of the emissions from coal combustion plants on a kilowatt hour basis.⁷

Modelling features and limitations

As a modelling framework, POLES offers a relatively detailed view on most aspects of the energy system; however, at a fundamental level, the model assumes the same behaviour of actors and energy supply-demand systems. A shift to a substantially decarbonised economy will likely disrupt many of the traditional energy systems used throughout world economies, which are often heavily based on fossil fuels. This type of paradigm shift is not easily represented within POLES, especially in an endogenous fashion. It is difficult to model breakthrough technologies that substantially disrupt traditional systems. These problems are not limited to POLES, and apply to all energy-economy (and macroeconomic) models to some degree. Because of this issue, we have chosen an 80% reduction below the 1990 GHG emission level as the maximum reduction targeted in 2050 for the scenarios in this study. This level has been chosen partly for its significance in global climate discussions, but also because many of the energy consumption and transformation systems represented in POLES can achieve this level of reduction at reasonable costs. Beyond this level, mitigation costs rise rapidly and the necessity for an alternative organisation of urban, transportation, and

⁶ European Environmental Agency (2008), *EN35 External costs of electricity production*, <http://www.eea.europa.eu/data-and-maps/indicators/en35-external-costs-of-electricity-production-1>

⁷ Nussbaumer, T., Czasch, C., Klippel, N., Johansson, L. and C. Tullin (2008), *Particulate emissions from biomass combustion in IEA countries*, ISBN 3-908705-18-5

energy systems becomes apparent, and the role for as yet unknown and un-modelled technologies becomes stronger.

Much of this study focuses on the implementation of intermittent renewable power sources due to their detailed description in POLES. Limits for the addition of intermittent renewables are included based on minimum existing backup capacities (gas turbines and hydro). Alternative methods of integrating intermittent renewables into network electricity power have not yet been integrated into the POLES model; for example, smoothing of load curves through time of use pricing, smart grids and technologies, and large-scale power storage.

Some other promising decarbonisation options, such as direct heat use or transportation modal shifts, are represented in POLES at a relatively aggregated level (that is, specific technologies are not modelled explicitly as in the power sector). The extent to which these other technologies could be adopted compared to options such as biomass is therefore uncertain because of the difference in modelling detail.

The study also uses historical technology costs, fossil fuel prices, and renewable potentials from established international sources; however, there is considerable uncertainty over these into the future, and scenarios included in this report may vary from countries' own specific assumptions, or those used in other studies. These factors mean that results, especially at a disaggregated level of detail, will vary from other analyses.

Compared to POLES, the PRIMES model (used by the European Commission) includes more 'bottom-up' detail of energy consuming and supplying technologies. PRIMES details many individual energy technologies, for example in terms of useful energy, industrial processes and capital vintages, both due to data availability and in order to have a strong focus on the EU energy system. POLES represents many sectors, aside from the power sector where technologies are explicitly modelled, through reduced-form energy demand and supply equations that relate explanatory variables (such as prices, GDP, etc.); this ensures a consistent framework is used in all world regions, for which many are often lacking available detailed energy data. Compared to PRIMES, POLES also models endogenous technology costs (i.e. the costs vary between scenarios and depend on deployment), with these depending on both worldwide and country specific deployment. POLES also directly models international fossil fuel prices, which depend on the global situation in each scenario.

Scenarios description

Descriptions of the scenarios included within the scope of this study are included below.

Reference case

In the *Reference case*, the 2020 Climate and Energy Package targets for renewables and GHGs are achieved, but there is no assumption of additional climate or energy policies.

- Policies necessary to meet the 2020 Climate and Energy package targets (including current policies and any additional mechanisms necessary to achieve the objectives, such as FiTs, energy efficiency trends or ETS carbon price);
- EU ETS cap follows its declining trajectory (38.3 Mt/year starting from 2013);
- Effort Sharing Decision target for non-ETS sectors emissions remains at its 2020 level (i.e. no objective more ambitious than the 10% reduction compared to 2005).

The current surplus of emission allowances is distributed in a growing wedge to 2050 as described in the methodology.

Between 2021 and 2030, international credit access is assumed to be in line with current access under the Climate and Energy Package. Credits are available annually to the ETS sectors at 53 MtCO₂ (2.3% of 2005 emissions) and to non-ETS sectors at 50 MtCO₂ (2.2% of 2005 emissions). After 2030, access to credits diminishes linearly to zero in 2050.

The *Reference case* assumes there will be no additional policy support after achieving the Climate and Energy Package targets. The annual reduction of the ETS emissions cap is the only policy instrument still operating beyond 2020; individual Member State policies are discontinued after 2020. Total GHG emissions in 2050 decline to 53% below 1990 levels, and do not meet the EU's long-term goal of reducing emissions by 80-95%.

Outside of the EU28, countries are assumed to meet their Copenhagen pledges as provided under the United Nations Convention on Climate Change (UNFCCC). Beyond 2020, the national carbon prices and emission reduction efforts are assumed to remain constant.

Scenarios

All of the Scenarios share the same parameters to 2020 and diverge in their respective hypotheses after that time. Unlike the *Reference case*, the Scenarios assume that all sectors can be included together within an economy-wide ETS after 2030.

The aviation sector is treated somewhat independently under the current ETS definition with a separate cap and allowance for credits. Accordingly, we have not included changes to the aviation sector in the scenarios except for its participation to meeting the overall emissions reduction targets (i.e. the aviation cap and credits allowance remains the same for all scenarios).

Compared to the *Reference case*, all of the scenarios assume a level of global action necessary to limit long-term global warming to 2°C. A global carbon price outside of the EU is adopted to meet this goal; with the price being the same between scenarios. Resulting emissions are in line with the “medium chance” case in the UNEP 2013 Gap report, which is in line with the Representative Concentration Pathway RCP4.5 from the Working Group 1 report of the IPCC 5th Assessment Report (2013).

1) 40% domestic GHG emissions target

In 2030, the total GHG emissions from the EU28 countries are reduced by 40% relative to the total 1990 emissions level. Non-ETS sectors achieve emissions reductions in 2030 equal to 30% below 2005 emissions in line with the EU Low carbon Roadmap; ETS sectors achieve reductions necessary to meet the overall target (around 45% below 2005 including International Aviation). Annual emissions reductions continue after 2030 at a constant rate necessary to have an 80% reduction of emissions by 2050.

There is no access to credits after 2020 (except for the aviation sector).

2) 40% domestic GHG emissions target + 30% RES

Emissions reductions and international credit access are the same as Scenario 1.

The share of energy from renewables in gross final consumption already reaches close to 30% at the EU28 level in Scenario 1. This scenario therefore mainly reflects the impacts of each Member State meeting their burden share. These shares are by assumption calculated using the same methodology as used for the 2020 Climate and Energy Package, but extended to 2030. See Annex 1 for burden shares by Member State. This is not intended to be a view of what burden shares should be, as these will be determined through future EU negotiations on the 2030 package; however, it gives an illustrative scenario based on the previously used methodology.

3) 50% domestic GHG emissions target

In 2030, the total GHG emissions from the EU28 countries are reduced by 50% relative to the total 1990 emissions level. Non-ETS sectors achieve emissions reductions in 2030 equal to 40% below 2005 emissions; ETS sectors achieve reductions necessary to meet the overall target (around 56% below 2005, including International Aviation). Annual emissions reductions continue after 2030 at a constant rate necessary to have an 80% reduction of emissions by 2050.

There is no access to credits after 2020 (except for the aviation sector).

4) 50% GHG emissions, including 5% credits

Same definition for emissions reductions as Scenario 3.

Between 2021 and 2030, credits are available annually to the ETS sectors at 144 MtCO₂ and to non-ETS sectors at 138 MtCO₂, based on the current split between sectors. After 2030, access to credits diminishes linearly to zero in 2050.

5) 50% GHG emissions, including 10% credits

Emissions reductions are the same as Scenario 3.

Between 2021 and 2030, credits are available annually to the ETS sectors at 288 MtCO₂ (and to non-ETS sectors at 276 MtCO₂). After 2030, access to credits diminishes linearly to zero in 2050.

6) 60% GHG emissions, including 5% credits

In 2030, the total GHG emissions from the EU28 countries are reduced by 60% relative to the total 1990 emissions level. Non-ETS sectors achieve emissions reductions in 2030 equal to 50% below the 2005 emissions; ETS sectors achieve reductions necessary to meet the overall target (around 67% below 2005, including International Aviation). Annual emissions reductions continue after 2030 at a constant rate necessary to have an 80% reduction of emissions by 2050.

Between 2021 and 2030, credits are available annually to the ETS sectors at 144 MtCO₂ and to non-ETS sectors at 138 MtCO₂. After 2030, access to credits diminishes linearly to zero in 2050.

7) 40% domestic GHG emissions target + early CCS

Emissions reductions and international credit access are the same as Scenario 1.

This scenario evaluates the costs and benefits associated with faster commercial availability of carbon capture and storage in the power sector, driven either through advancements in technology or reduced investment costs, possibly due to increased policy support. Installed CCS capacity is accelerated to be in line with the 2030 estimate from the IEA Technology Roadmap on CCS (2013), approximately 38 GW installed in the EU.

8) 40% domestic GHG emissions target + reduced renewables learning rates

Emissions reductions and international credit access are the same as Scenario 1.

Renewable technology investment costs have decreased considerably in recent years, but future estimates of the rate in cost reductions may be overly optimistic. In this scenario, investment costs for wind, solar and biomass technologies do not decrease as fast as expected due to fewer benefits from slower learning.

9) 40% domestic GHG emissions target + alternate NTS burden shares

Emissions reductions and international credit access are the same as Scenario 1.

The allocation of NTS burden share targets uses a similar methodology as Scenario 1, but places more effort on Member States with higher GDP per capita. This is not intended to be a view of what burden shares should be, as these will be determined through future EU negotiations on the 2030 package; however, it gives an illustrative alternative scenario based around the previously used methodology.

10) 40% domestic GHG emissions target + alternate ETS/NTS split

Emissions reductions and international credit access are the same as Scenario 1.

To evaluate the cost and benefits associated to a stronger effort from ETS sectors 5 percentage points of effort are removed from the NTS target (target reduced to -25% vs. 2005).

11) 40% domestic GHG emissions target + 30% energy efficiency target

Emissions reductions and international credit access are the same as Scenario 1.

This scenario reflects the impacts of the EU cost effectively across Member States meeting a 2030 energy efficiency target calculated using the same methodology as the 2020 Climate and Energy Package (that is, relative to the PRIMES 2007 Reference scenario). This is not intended to be a view of what an energy efficiency target should be, as this will be determined through future EU negotiations on the 2030 package; however, it gives an illustrative scenario based around the previously used methodology.

12) 40% domestic GHG emissions target + 30% RES + 30% energy efficiency

Emissions reductions and international credit access are the same as Scenario 1.

RES burden shares are the same as Scenario 4.

Energy efficiency burden shares are set cost effectively as in Scenario 11.

Costs

Total costs in this report include abatement cost, permit trading cost, the purchase of international credits, and renewables subsidies.

- Abatement costs are those driven by the carbon price;
- Trading costs include buying emission permits from other sectors;
- International credits are purchased from countries and sectors not included in the EU ETS (for this study these include Least Developed Countries until 2020, and then all Developing Countries thereafter); and
- In the RES scenarios, renewables subsidies are the additional cost to meet the RES burden share (note that this cost decreases the necessary abatement cost).

Energy import bills are calculated as the regional or international market prices multiplied by the net imports of fuels (i.e. oil, gas, coal, and biomass).

Avoided health costs are calculated as above in the methodology description, using the respective costs by fuel given in Annex 3 multiplied by the difference in power produced by fuel between the *Reference case* and a scenario. For example, decreased power generated from coal combustion under a carbon price will result in a reduced health cost equal to the health savings (€/kWh) multiplied by the decreased power measured in kWh.

Costs are given relative to a *Reference case* to indicate the additional effort needed to achieve a set of targets beyond a 'business as usual' case. The *Reference case* modelled in this study includes current European policies up to 2020 (EU and Member States), only EU climate policy beyond (i.e. maintaining the current EU ETS cap trajectory), no Member State level legislation or policies beyond 2020 (i.e. current renewables subsidies are discontinued), and conservative estimates of energy efficiency measures.

Europe (EU-28) Results

Significant potential exists within Europe to reduce GHG emissions at reasonable costs, both in the short and long term. The reduction of GHG emissions by 20% below 1990 by 2020 will likely be overachieved with little increase to the current low ETS price; indeed, even with the existing surplus of EUAs, this will probably be the case without further policy intervention. This study’s *Reference case* follows this storyline forward to find that meeting the 2020 Climate and Energy package will put the EU on a path to reach an emissions reduction of 27% by 2030 (even without further policy effort beyond the ETS cap reduction of 38 Mt/year).

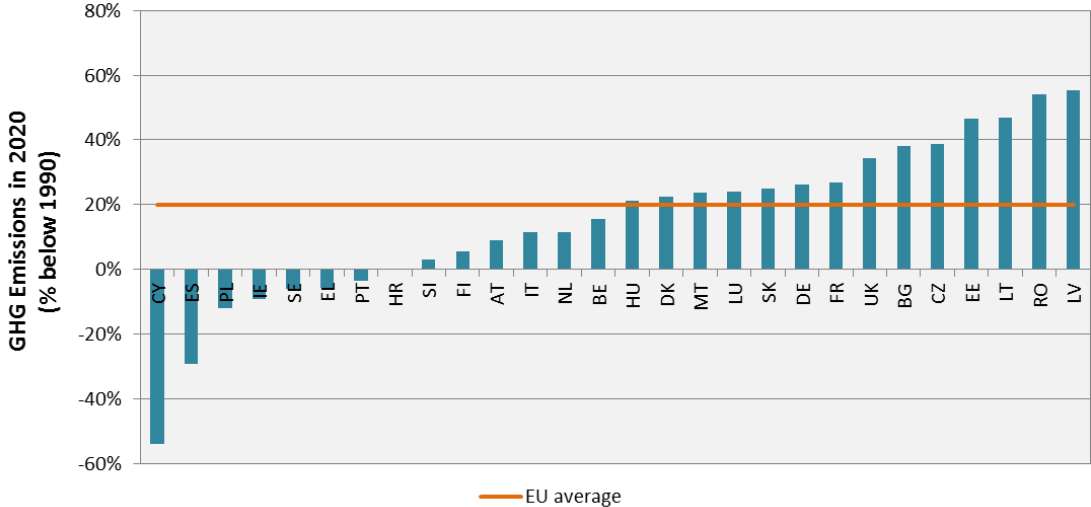
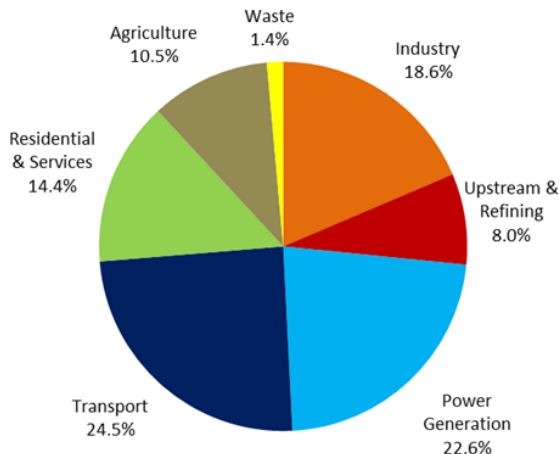


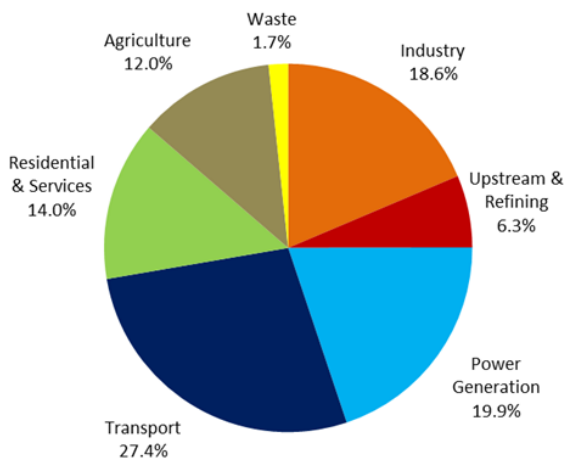
Figure 2: GHG emission reductions 2020 vs. 1990, by Member State in Reference Scenario

The proportion of emissions by sector remains fairly stable over the next two decades in the *Reference case*. Low ETS prices mean that there is not much pressure to reduce emissions from large stationary emitters, such as power plants and industrial installations; although reductions still occur with the shift to more renewable power generation.

Reference case



40% Scenario



50% Scenario

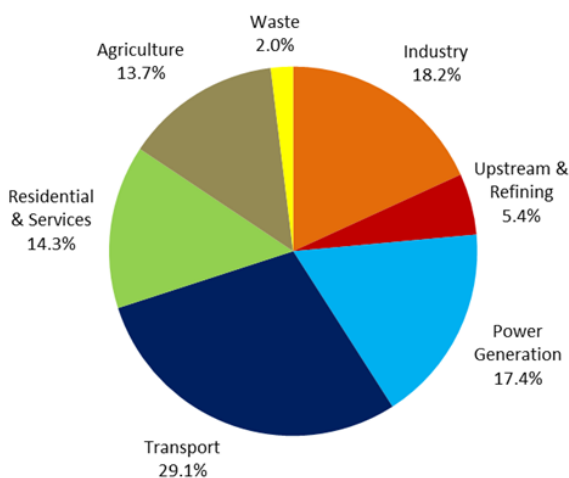


Figure 3: EU28 GHG emission profile (excluding LULUCF) in 2030, by scenario

Emissions from the power sector decrease rapidly with the switch to more renewables (primarily wind and solar PV), despite the growing electrification and increased demand from other sectors in the economy. Power sector emissions are almost 27% lower in 2030 in the *40% Scenario* than in the *Reference case*, 684 MtCO_{2e} and 932 MtCO_{2e}, respectively. The power sector provides some of the most easily available sources of mitigation options and will likely include the majority of reductions to 2030. Decarbonising the electricity supply could help provide important momentum on a low- or zero-carbon path.

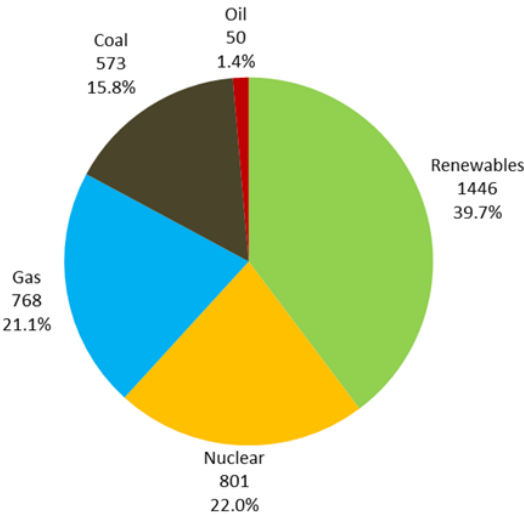
Transport sector emissions for road and aviation decrease with stronger targets, but their share in total emissions rises. When meeting the total economy targets in the scenarios, efforts in sectors included in the ETS trading system are consistently about 15% stronger by 2030 than in sectors left to mitigate emissions primarily through non-pricing mechanisms.

Moving to stronger GHG targets, but not changing the coverage of the ETS to include additional sectors, will result in the main emission sources becoming more distributed non-ETS sectors like small industrial facilities, and mobile vehicles. Under the *40% Scenario*, by 2030 distributed sources (including aviation) could represent almost 59% of total EU emissions (1770 MtCO_{2e}), compared to 49% today.

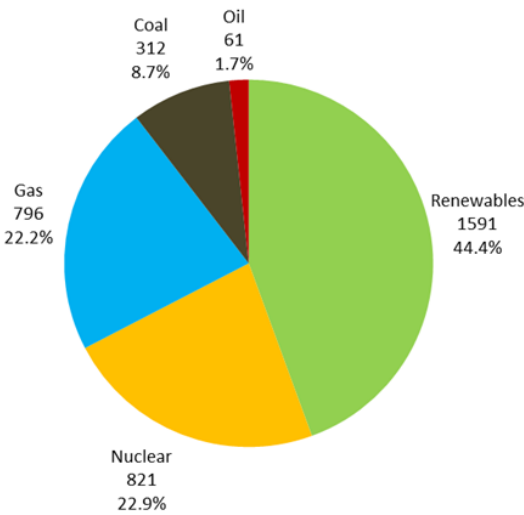
Achieving an 80% reduction of GHG emissions in 2050 requires much more effort than in the *Reference case* where long term emissions only reach a 53% reduction. While total EU emissions are 18% lower in 2030 in the *40% Scenario* compared to the *Reference case*, emissions will need to be 58% lower by 2050.

The contribution of each Member State to the total effort of reaching an 80% reduction in GHG emissions by 2050 depends on their respective remaining potential for mitigation actions. Some Member States, especially those in Central and Eastern Europe where there is a more recent history of coal power utilisation, will have larger potentials to reduce their emissions in the power sector. Since changes to electricity generation are often both efficient and effective to reduce emissions, these Member States can provide a large number of credits under the ETS. Overall, the EU benefits from the ETS mechanism providing opportunities to those states, where incremental change to power systems is easier, to sell EUAs to states where changes to power generation could be more costly.

Reference case



40% Scenario



50% Scenario

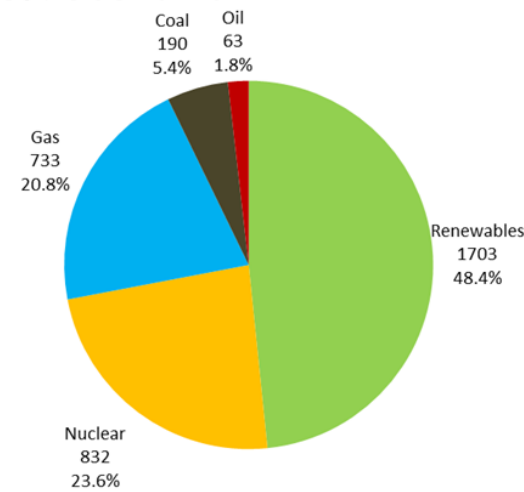


Figure 4: EU28 Power mix in 2030, by scenario (fuel; TWh; share)

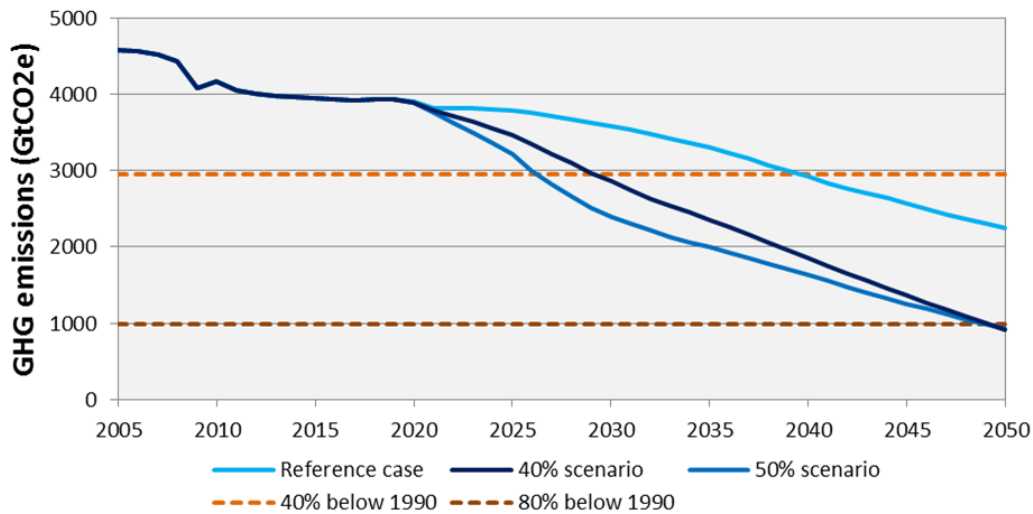


Figure 5: Total EU28 emissions (2005-2050)

While the GHG target of the 2020 Climate Package will likely be over achieved with little additional policy effort, the 20% renewables goal will need a strong increase in renewables spending and policy support. Stable funding mechanisms, such as feed-in tariffs/premiums or investment grants, will need to remain in place or be increased to provide investors and developers with incentives to continue the rapid build-up of renewables capacity.

The *Reference case* includes the 20% penetration of renewables in gross final energy consumption at the EU level. By Member State, the national objectives detailed in the NREAP targets are implemented, by renewable energy source in the power sector, as well as in transport and heating and cooling of buildings.

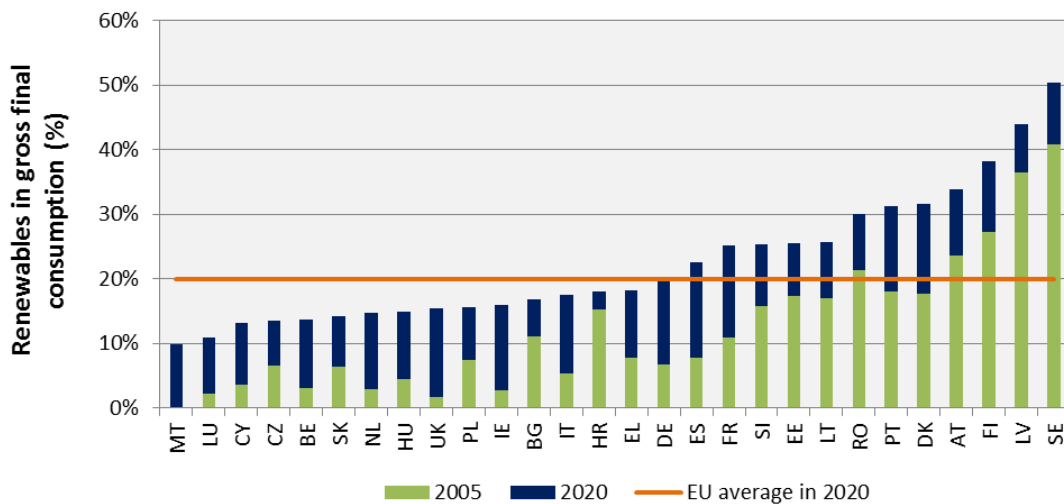


Figure 6: Share of renewables in gross final consumption in 2020, by Member State

Abatement costs

GHG emissions reduction potential is reflected in the abatement costs of each Member State, with marginal costs rising as the potential for further reduction diminishes. Meeting the 40% target requires an abatement cost of €30bn in 2030 relative to the *Reference case* – this is the average cost of all measures, not just those in the traded sector, and so would not translate into a carbon price in the model. This cost also depends on what policy is already assumed in the *Reference case*, with greater assumed policy typically resulting in lower average energy costs. As set out, the *Reference case* makes few assumptions about EU policy post 2020.

The relationship between abatement costs and GHG targets is non-linear; moving to the 50% domestic target will triple the abatement cost compared to a 40% domestic target (€95bn), while stricter targets will entail much higher costs. Allowing international credits can help to reduce the cost burden; however if in the first years following 2020 the access to credits is relatively large (e.g. in the *50% target, including 10% credits Scenario*), little domestic action will be taken and the carbon price will remain low. This could lead to a situation where emission reductions will need to be accelerated in later years to meet the long-term 2050 GHG target and actually require a larger domestic cumulative abatement cost over the period 2021-2050. The large access to credits effectively delays action to reach the target, similar to the situation described in the box below, *Early vs. Delayed Action*.

The power sector is the main source of abatement potential in the EU and accounts for 85% of all EUA permits sold into the EU ETS market. While the power sector represents about half of all emissions in the ETS (at EU level), the potential for reductions is substantial; there are many zero- and low-emission options that can replace high emitting alternatives like coal power, such as adopting renewables (mainly wind and solar), nuclear, fossil fuel switching, and implementing CCS and efficiency measures (retrofits or more efficient technologies).

Improving energy efficiency is central to a cost-effective approach to achieving any GHG target; energy demand in 2030 falls from 21% below the 2030 EU baseline (the same projection used for the 2020 Energy Efficiency target) under the Reference case, to 27% under a 40% GHG target. (see Additional and alternative targets)

Early vs. Delayed Action

The cumulative cost to achieve an 80% reduction in GHG emissions depends very strongly on the path followed; that is early or delayed action to meet the overall goal. Over the long term, the early action pursued in the *50% Scenario* (compared to a 40% target) will result in lower cumulative (undiscounted) abatement costs in 2050; approximately 6% lower for a cost saving of €170bn. However, earlier climate action results in larger up-front costs, with lower annual costs and overall cumulative savings deferred into the future. Depending on society's needs and willingness to postpone these benefits (social discount rate), the cost associated to stronger efforts in the short term could be well worth the advantages in the future of a stronger position on clean technology deployment, reduced energy import dependence and smaller health costs from coal power plant emissions.

Unsurprisingly, shorter-term cumulative abatement costs between 2020-2030 are more than three times higher in the *50% Scenario* due to the additional domestic effort, resulting in a cumulative cost difference of €241bn at the EU level relative to the *40% Scenario* over this period. Access to international credits can help to reduce this cost burden by promoting lower marginal cost actions outside of the EU. However, credit access should be prevented from being so large that domestic action is prevented from occurring because most of the reduction demand can be satisfied by lower cost actions outside of the EU (as happens in the *50% target, including 10% credits Scenario*). This could lead to delayed domestic action that is not sufficient to meet the longer-term Low Carbon Roadmap targets and creates higher cumulative costs for the EU.

The countries with the lowest increase in their abatement costs compared to the *Reference case* have high proportions of power generated from coal combined with at least moderate possibilities for renewables installation (e.g. Denmark, Hungary, and Czech Republic). These countries possess easier reduction options; that is, existing high emission sources that can be converted to zero-emission alternatives. Member States which could experience higher than average increases in abatement costs generally lack one of these conditions. If coal power doesn't currently play a large role in electricity generation (e.g. France, Latvia, and Croatia), a carbon price will be less effective in shifting relative costs to increase the competitiveness of renewables and other low carbon technologies. Alternatively, less physical renewables potential (e.g. Italy) or a small need for additional capacities beyond the existing stock due to slow growth in electricity demand (e.g. Cyprus and Luxembourg) reduce the potential for switching to renewables.

Table 1: Cost of energy policies per scenario

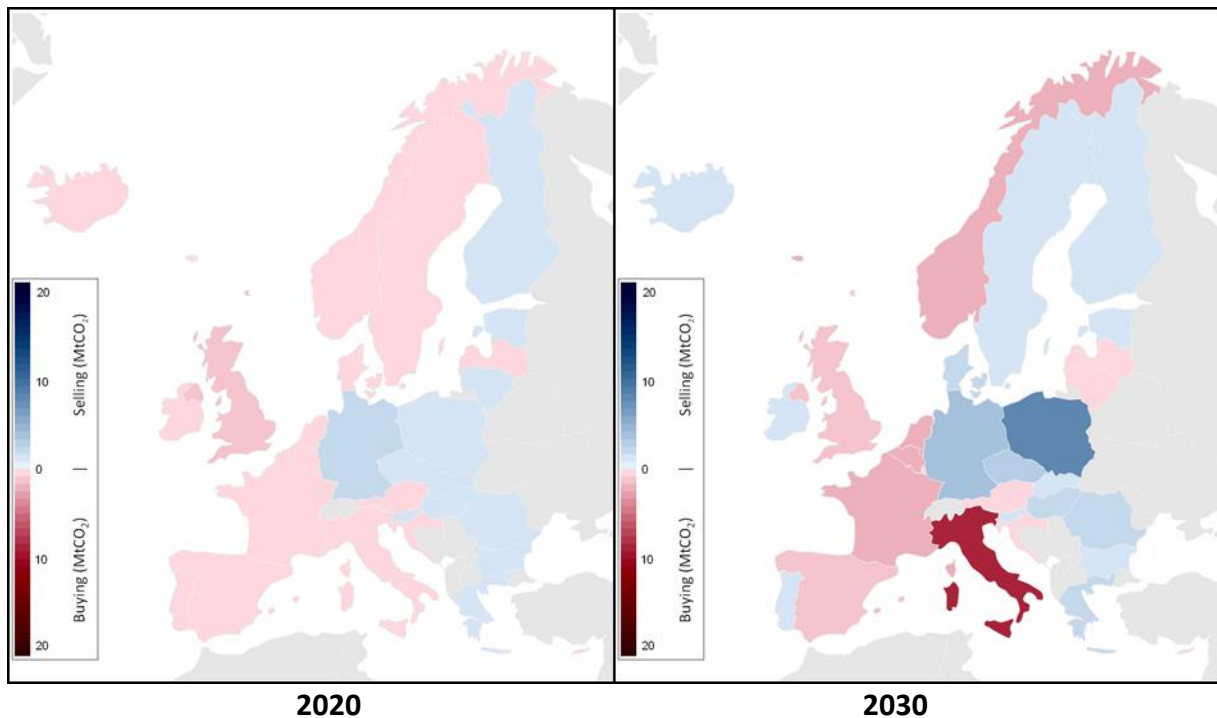
| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG | % GDP | 50% GHG (10% credits) | % GDP |
|---|--------------|---------|-------|-------------------|-------|---------|-------|-----------------------|-------|
| Total cost vs. Ref, €bn | | 30 | 0.2% | 41 | 0.3% | 94 | 0.6% | 67 | 0.4% |
| Average health cost vs. Ref, €bn (not captured in total costs)* | | -18 | 0.1% | -18 | 0.1% | -27 | 0.2% | -19 | 0.1% |
| Energy import bill vs. Ref, €bn (captured in total costs)** | Fossil fuels | -72 | 0.4% | -78 | 0.5% | -111 | 0.7% | -58 | 0.4% |
| | Biomass | 4 | 0.0% | 5 | 0.0% | 6 | 0.0% | 3 | 0.0% |

| In 2030 | | 40% GHG + Alt NTS burden shares | % GDP | 40% GHG + Alt split ETS/NTS | % GDP | 40% GHG + 30% EE | % GDP | 40% GHG + 30% RES + 30% EE | % GDP |
|---|--------------|---------------------------------|-------|-----------------------------|-------|------------------|-------|----------------------------|-------|
| Total cost vs. Ref, €bn | | 30 | 0.2% | 41 | 0.3% | 100 | 0.6% | 121 | 0.8% |
| Average health cost vs. Ref, €bn (not captured in total costs)* | | -18 | 0.1% | -18 | 0.2% | -27 | 0.1% | -24 | 0.1% |
| Energy import bill vs. Ref, €bn (captured in total costs)** | Fossil fuels | -72 | 0.4% | -66 | 0.4% | -101 | 0.6% | -107 | 0.7% |
| | Biomass | 4 | 0.0% | 5 | 0.0% | -1 | 0.0% | 1 | 0.0% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

The different levels of abatement costs across Member States mean that there is scope to reduce overall costs at the EU level through emission permits trading. Member States that can achieve reductions more easily will reduce more than needed and sell excess credits on the ETS. Countries that find mitigations are too expensive can purchase credits from the ETS for less than the cost of domestic actions. By 2030, the ETS trading volume in the *40% Scenario* reaches 10% of the total reduction objective. Generally, Member States located in Central and Eastern Europe will be credit providers due to their larger potential to replace older, less efficient power plants, and which also tend to have a higher share of coal generation facilities.



**Figure 7: EU ETS emission permit trade
(40% Scenario)**

International emissions trading

Currently, only Least Developed Countries (LDC) can provide international emission credits to the ETS as described under current EC legislation (2009/29). However, these countries have relatively low abatement potential due to low consumption and generally moderate levels of centralised power generation; relative to EU emission reduction objectives, these countries cannot provide a large percentage of credits. Based on indications from the EC that it would like to see a new mechanism that would help developing countries to scale up their efforts to reduce GHG emissions in the most cost-effective way, an international emissions trading market may emerge after 2020 with developing country markets linked to the EU ETS.

Allowing credit access in the *50% target, including 10% credits Scenario* means that only a 40% reduction needs to be performed domestically within the EU. As expected, total domestic costs (abatement plus international trading) are significantly lower in the *50% target, including 10% credits Scenario* when compared to the scenario without access; costs are reduced by about 20% to meet the lower domestic target. However, by definition, this Scenario is a form of delayed action if the EU intends to meet an 80% domestic reduction in 2050. This delayed action results in cumulative total reduction costs (2020-2050) that are domestically 10% higher when access to international trading is allowed. However, when considered globally, access for the EU to international emissions trading provides an additional 3% world emissions reduction compared to the scenario without access. The additional cost to the EU may be considered acceptable when considering the benefits of technology transfer, economic efficiency and international relations.

Earlier access to CCS technology on a commercial scale, driven either through advancements in technology or reduced investment costs, possibly due to increased policy support, could promote an extra 34 GW of CCS electricity generation capacity by 2030. In this scenario, much of the CCS installed replaces otherwise existing capacity, but due to lower costs for fossil fuels with CCS relative to some more expensive technologies (e.g. offshore wind), there is a net gain of 5 GW of generation capacity. There is an 11 GW net gain in gas capacity (including gas with CCS), with the increased demand for natural gas pushing the European market price up by about €0.18/MMBtu. There is also an increase of 6 GW of coal capacity (including CCS), resulting in a higher European coal market price of €0.41/t. CCS-equipped fossil fuel technologies do not just replace other CO₂-emitting technologies, but also substitute for renewables and non-emitting technologies; renewables capacity is decreased by 10 GW and nuclear by 2 GW. Fossil fuel use and import bills are reduced by less than in the 40% Scenario.

Energy security

Implementing a GHG emissions reduction target will contribute to reducing overall consumption and diversify energy sources, both of which generally promote less dependence on imported energy sources. By increasing the proportion of electricity in final consumption, domestic energy sources such as wind and solar power can reduce dependence on foreign oil and gas used in buildings, industry, and vehicles. Without electrification, biomass provides the only carbon neutral energy source for final consumption; due to the population density of the EU and surfaces available for biomass production, increased use can still create dependence on foreign sources, albeit at a lower level than for fossil fuels.

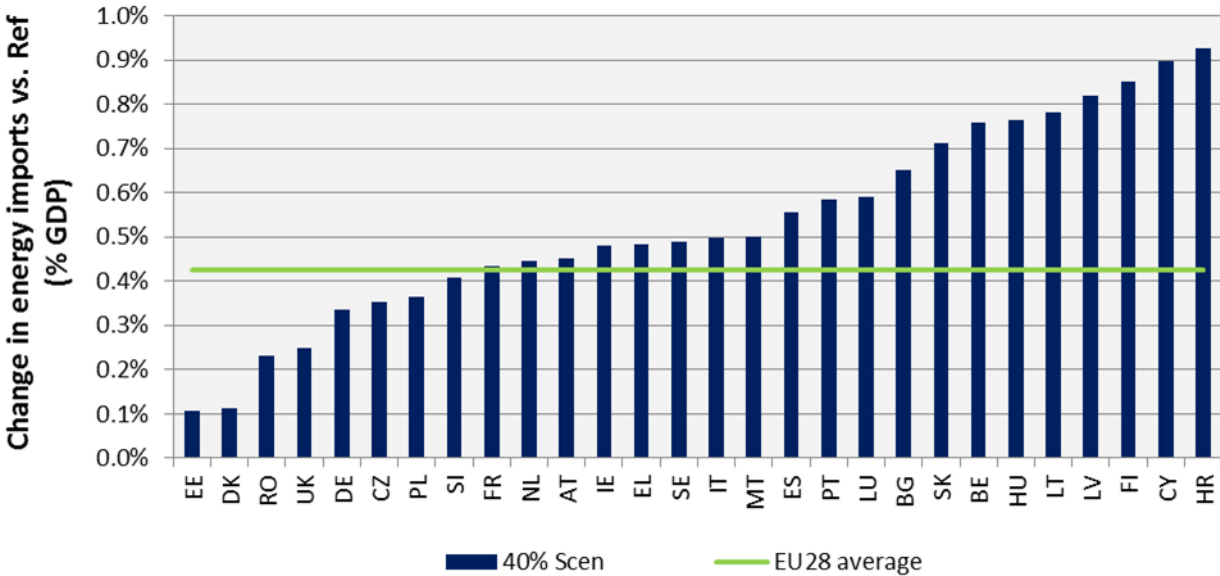


Figure 8: Change in energy import bill (oil, gas, coal and biomass), 2030 (40% Scenario vs. Reference)

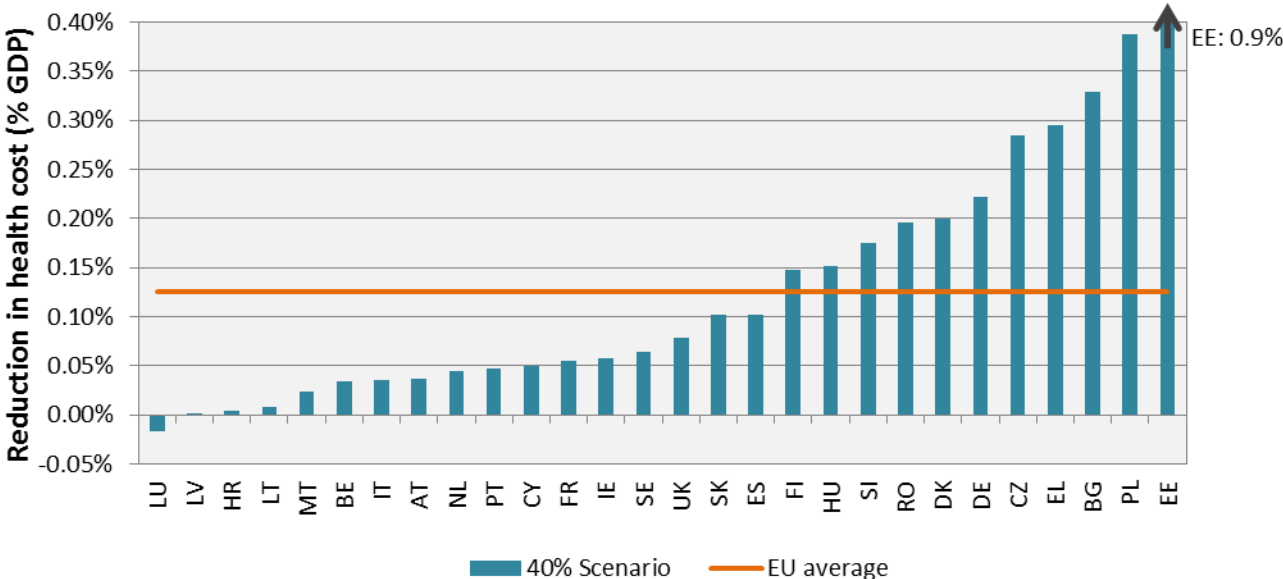
Overall, the EU could reduce its energy import bill for fossil fuels in 2030 by over 0.4% of its GDP (while the abatement of fossil fuels is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost). Reductions in oil imports make up 63% of the difference, and reduced gas imports 32%.

Health cost benefits

Shifting away from coal power will contribute to additional benefits beyond reducing GHG emissions. The decrease of local air pollutants that are produced as a by-product of fuel combustion, primarily from coal power, such as NO_x and SO₂ can help reduce health care costs associated to respiratory diseases. Overall, reduced reliance on fossil fuel electricity generation could reduce EU health costs by an average of €19bn, or 0.1% of GDP, in 2030 (40% Scenario compared to the Reference case). These benefits are not captured in the total cost figures above.

Benefits are primarily concentrated in Member States that currently generate a high proportion of their power from coal, and that also have a strong forecasted growth in electricity demand. These are primarily Central and Eastern European countries, such as Estonia, Poland, and Bulgaria; however, most countries will experience a net benefit from the shift away from fossil fuel generation. A very few countries have a net negative impact, mostly due to increased generation from biomass, which emits local air pollutants at approximately two-thirds the rate of coal. Benefits from health cost reductions per capita follow a very similar distribution to benefits per GDP.

There is quite a large uncertainty in the health care costs associated to the reduction of local air pollutants from fossil fuel combustion; the maximum health costs on a kilowatt-hour basis from the EEA (2008) are almost three times the minimum costs. At the EU level in the 40% Scenario this cost difference between max and min values amounts to €18bn in 2030.



**Figure 9: Reduction in air pollutant related health costs (2030)
(Average sensitivity; 40% Scenario vs. Reference)**

Renewables

Reaching GHG emissions reduction targets will entail a strong penetration of renewable technologies in the power sector, as well as in heat production and as a fuel for industry and transportation. Total renewables consumed in the EU as a share of gross final consumption reaches 25% in 2030 in the *Reference case*. The power sector accounts for 68% of the penetration of renewables in gross final energy consumption, transport for 17% and heating for 15%.

The total share of renewables in gross final consumption reaches 29% under the *40% Scenario*, with a shift in the shares of primary fuels away from fossil fuels towards non-emitting sources. Notably, coal’s share of primary consumption falls from 14% to 8%, with two-thirds of this share going to renewables and the remainder to nuclear.

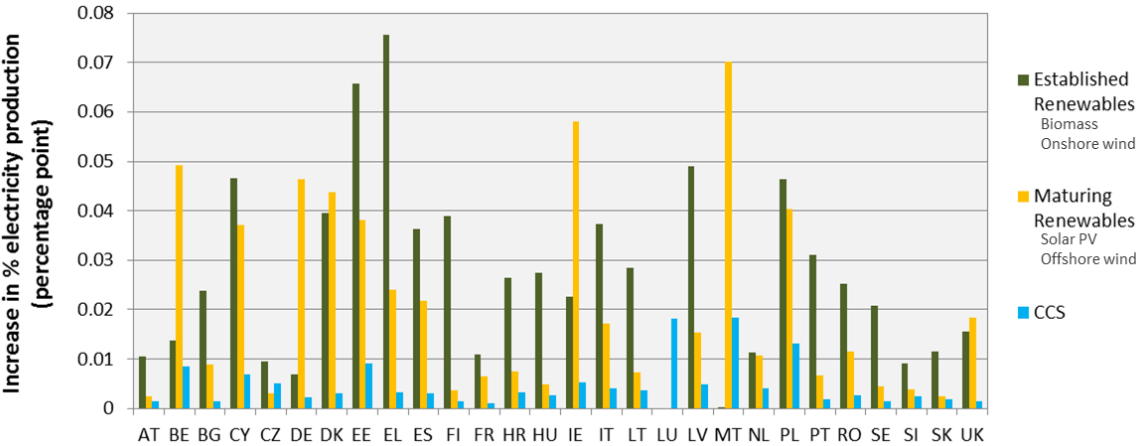


Figure 10: Increase in renewables and CCS electricity production (2030) (40% Scenario vs. Reference)

Beyond simply reducing the share of coal consumed in general, a particularly important effect of using a carbon price to reduce emissions is its impact on the construction of new coal power plants. Since a carbon price acts as a proportional tax on CO₂ emissions, combustion of coal-based energy sources are strongly disadvantaged relative to other energies. By moving from the *Reference case* to a 40% reduction target, the cumulative total of new coal power plants built without carbon capture and storage (CCS) technology is reduced by almost 1.8 GW, or 60%, between 2021 and 2030. Without a carbon price advanced coal power stations make up the majority of new builds due to their greater efficiencies versus older technologies. Under a carbon price, much less unabated coal is installed: coal dependent Member States build advanced coal, while other Member States don’t build any, or else very little, advanced-technology unabated coal.

Overall net coal power is not reduced very much though, since CCS-equipped advanced coal power stations could allow coal power to continue to be used. Coal is currently very attractive as a generation technology due to the relatively cheap fuel and familiarity for many power utilities. If CCS can be demonstrated to work at commercial scales and made profitable, which would be helped significantly under a stronger carbon price, the net effect

would be a small reduction in total new coal power builds, as well as a strong reduction in local air pollutants associated to coal combustion.⁸

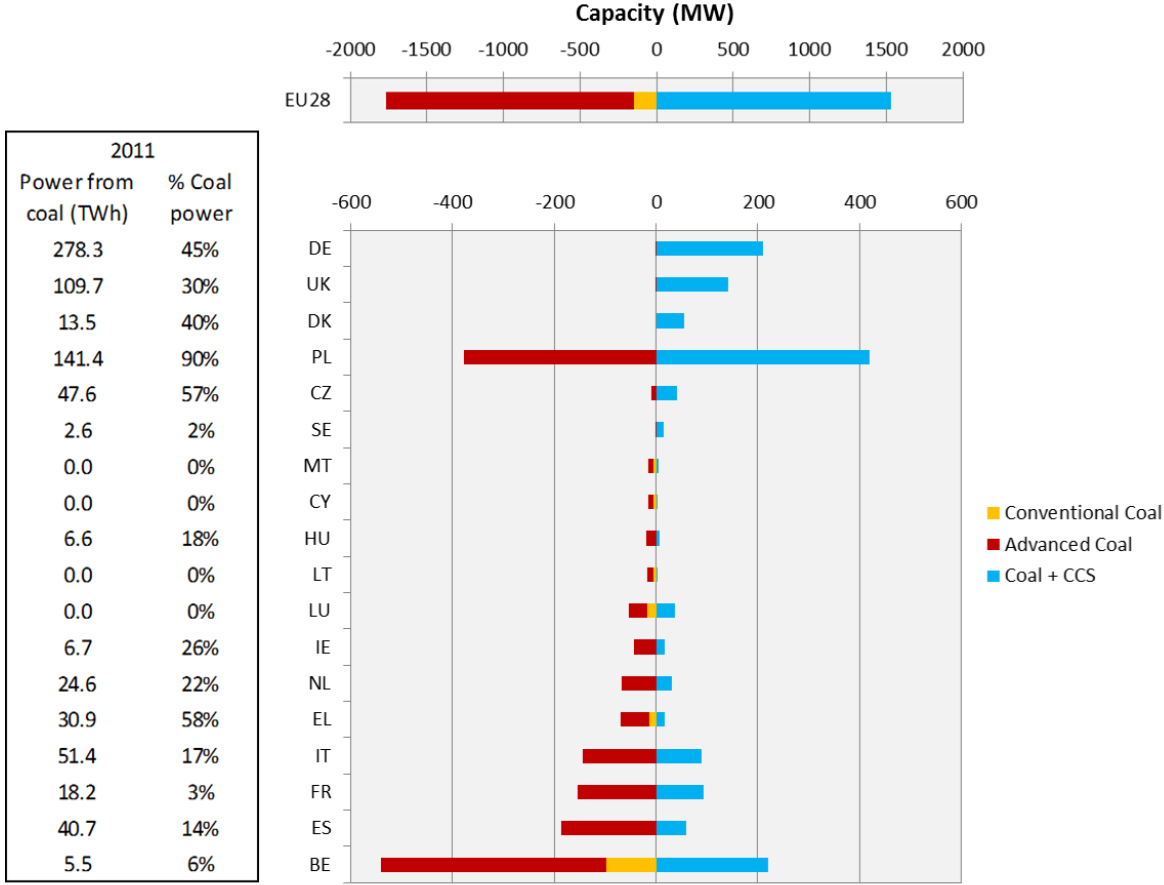


Figure 11: Cumulative change in new coal power plants (2021-2030) (40% Scenario vs. Reference; net difference >10 MW shown)⁹

The growth in total renewables consumption over 2020-2030 in the 40% scenario is in line with growth in renewables between 2013 and 2020 foreseen in the Climate and Energy package; however, the distribution of efforts by Member State is not the same. The growth in renewables included in the 40% Scenario indicates the most efficient distribution of efforts given by the equalisation effect of an ETS-wide carbon price. If the same distribution of efforts to implement renewables that was negotiated under the Climate and Energy Package for 2020 was extended to 2030 there would be additional costs for many Member States. The renewables subsidy bill in 2030 to meet these burden shares would total €23bn,

⁸ During the scrubbing process to remove CO₂ from flue gas, carbon capture and storage technology is assumed to remove most local air pollutants, such as NO_x, SO₂ and PM_{2.5} (for example, see Impact of flue gas impurities on amine – based PCC plants – Final Report, CSIRO, Australia, 2013).

⁹ Note that in this scenarios both gas and coal CCS are included within the modelling and are deployed.

with a total cost 36% greater than a GHG target alone (€12bn or 0.1% of GDP). Different burden share methodologies could reduce these costs by bringing Member State targets more in line with renewable potentials and the cost-effective distribution of effort, but would not mitigate the impacts of uncertainty.

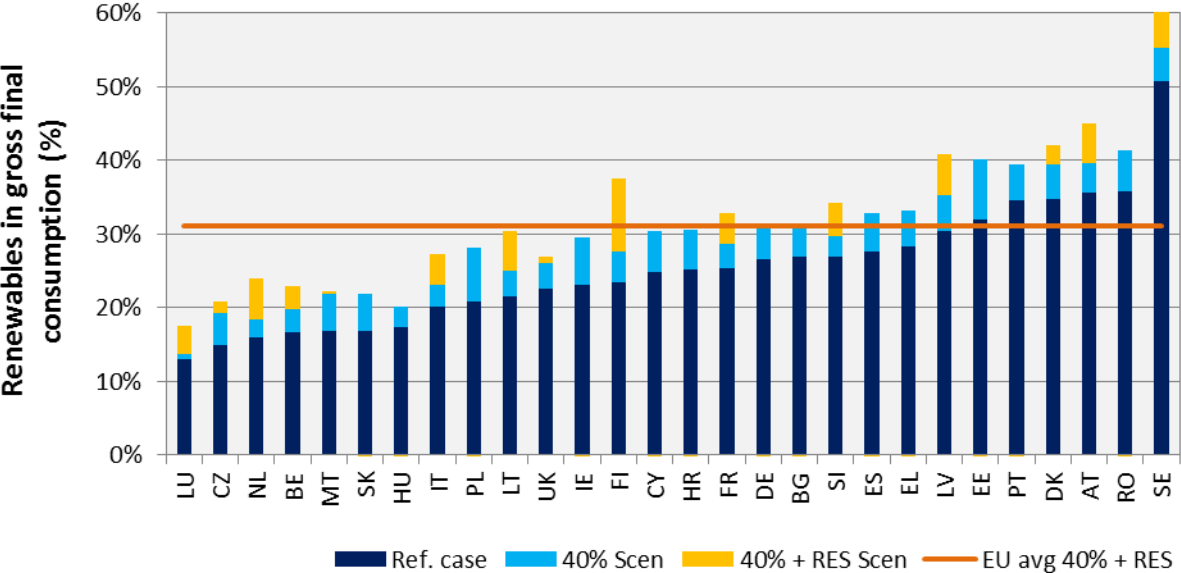


Figure 12: Share of renewables in gross final consumption (2030)
(Reference, 40% and 40% + RES)

Additional costs range anywhere from Austria, which spends 0.7% of its GDP to meet its burden share of renewables in final gross consumption to Spain and Portugal, where costs are minimal at less than 0.15% GDP. Twelve Member States already exceed their renewables burden share under the *40% Scenario* and do not need subsidies to meet their targets.

Three Member States, Finland, Latvia and Luxembourg do not reach their renewables burden share even with significant subsidies. The inability to meet the RES targets is linked to several factors that prevent greater amounts of renewables being consumed. In Finland, a very large portion of new renewables consumption comes from biomass use since this is more cost competitive than other renewables sources; however, biomass is consumed to such a degree that it is questionable if it can all be supplied from sustainable sources. In Latvia, renewables used in building heating make up a large share of overall renewables consumption. Between 2020-2030, more efficient heating processes and a switch to electric heating mean there is less biomass demand in buildings; this structural decrease to biomass use is offset by renewables in the increased electricity demand, but the shift makes it very difficult to meet Latvia’s target. Last, in Luxembourg, there is insufficient final demand to support additional renewables consumption. Without increased demand to provide the need for additional electricity capacity, or early retirements of fossil fuel plants to artificially create capacity turnover, the existing installed generation capacity provides sufficient power to meet the forecasted demand and there is no room to increase renewables. As a result, for these countries we have chosen to cap the renewables subsidies at 1% of their respective cumulative 2021-2030 GDP so as to not distort the overall modelling results.

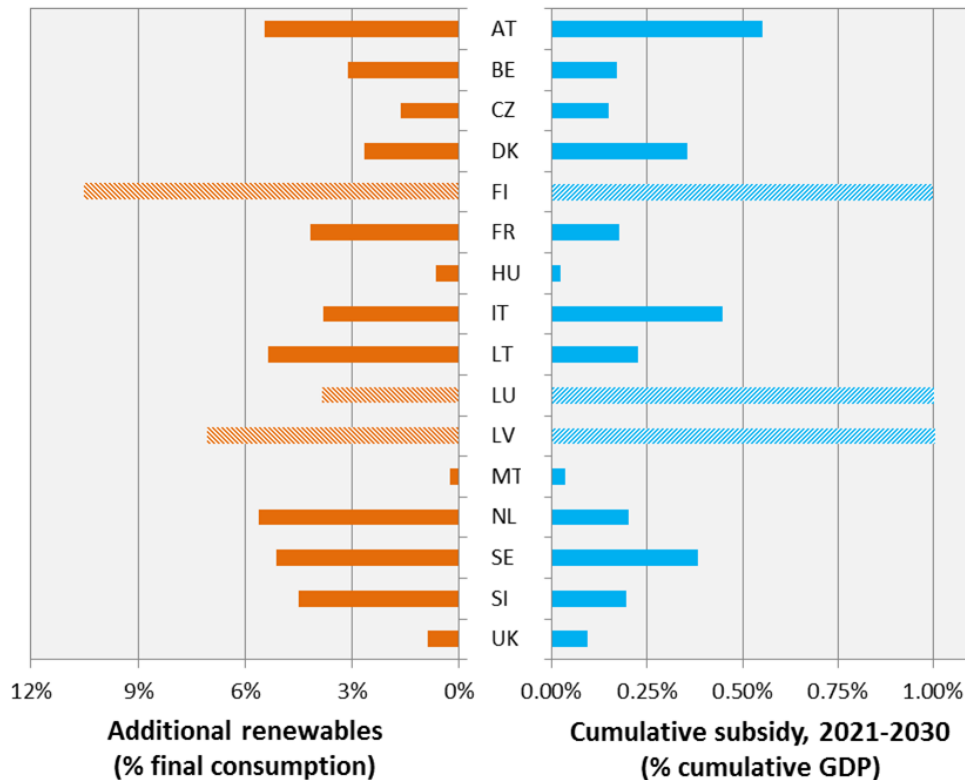


Figure 13: Additional renewables and subsidies to meet RES burden shares (between 40% + RES Scenario and 40% Scenario)¹⁰

The costs for some countries of the RES and GHG target combined are lower than for the GHG target alone because they face two specific circumstances. First, their required level of RES under the burden share is already met under the GHG target alone, and so there are no additional RES costs. Second, as the RES target lowers the EU-wide price of EU ETS allowances, net purchasers of EU ETS allowances face cheaper purchase costs. In practice, the extent to which this would happen, and to which countries, under a RES target scenario would depend on the exact RES target and burden share applied, the cost effective level of RES, and the actual net trading position of each country in the EU ETS and EUA price (which will both also depend on relative targets and technology costs).

Uncertainty in investment costs is partly related to how much costs come down as deployment increases. If this “learning by doing” cannot be sustained in the long term, it will lead to higher than expected investment costs, though consumption of renewable energy falls by less than 0.1%. If investment costs do not decrease as fast as expected from fewer benefits due to slower learning, total EU costs in 2030 could be €5.5bn, or 0.03% of GDP, higher than in the *40% Scenario*.

¹⁰ The additional renewables shown for Finland, Luxembourg and Latvia are the increased final consumption of renewables as a result of the subsidies applied. The burden shares indicate further effort beyond that shown: Finland – 11%, Luxembourg – 5.5%, and Latvia – 9%.

Additional and alternative targets

An alternative NTS burden share that assigns more effort to Member States with higher GDP per capita, but keeps the same overall NTS target of a 30% reduction, will not change the total cost at the EU level compared to the *40% Scenario* (since cost efficiency is assumed within the Non-ETS sectors through trading, which will still provide the same lowest overall cost). However, the level of trade between Member States changes. In general, countries that have an increase in their burden share are also the net buyers of allowances. The countries most affected by the change in burden share all see a decrease in their net cost: Bulgaria (+0.24 pp share of GDP), Lithuania (+0.16 pp) and Romania (+0.15 pp). Those most affected by an increase in trading costs are Luxembourg (+0.07 pp share of GDP), Netherlands (+0.06 pp), Denmark (+0.06 pp) and Ireland (+0.06 pp).

Emission reduction efforts from sectors included in the ETS sector provide cost-effective reductions due to permit trading between participating sectors; however, the relationship between reduction potential and abatement cost is non-linear. As the reduction target increases, cost per MtCO₂ mitigated rises faster and faster. By shifting 5 percentage points of reduction effort from the NTS sectors to ETS sectors (that is, changing the targets vs. 2005 to 25% NTS and 50% ETS (including International Aviation, to achieve an overall reduction of 40% vs. 1990), overall costs rise fairly significantly. The total cost with the new ETS/NTS effort sharing is €45bn in 2030, approximately 33% higher than in the *40% Scenario*. The new configuration changes average marginal costs in each group of sectors from being more or less equal, i.e. a cost effective split, to about four times higher in the ETS compared to the NTS.

A 30% energy efficiency target in 2030 calculated using the same methodology as the 2020 Climate and Energy Package (that is, relative to the PRIMES 2007 Reference scenario), but burden shared in line with where it is cheapest to save energy raises total cost substantially. This is because it drives additional energy savings beyond those required to meet the 40% GHG target alone. A cost efficient energy consumption tax (white certificate) used to meet the 30% energy efficiency target reduces the final demand in this scenario. Due to the decreased demand, GHG emissions are lower and the carbon price necessary to achieve the emission reduction target is reduced by more than half. However, the resulting total cost is more than three times larger than the *40% Scenario* at 0.6% GDP or equivalent to a reduction of 0.04 pp/year in the GDP growth rate. This large increase in cost is due to the different effects of a carbon price versus an energy consumption tax. While both measures reduce energy consumption through higher fuel prices, a carbon tax specifically decreases fossil fuel use to reduce GHG emissions (increasing the share of non-emitting sources in the power mix), whereas an energy consumption tax reduces all energy use equally, affecting renewables and nuclear power, as well as fossil fuels. Bottom-up modelling that examines the impact of removing behavioural barriers to energy efficiency could indicate different impacts, for example lower costs and action in different sectors.

An illustrative scenario based on the 2020 Climate and Energy Package methodology, with a 40% reduction in GHG emissions relative to 1990, a 30% RES target using the same burden shares by Member State, and a 30% energy efficiency target results in a total cost in 2030 of 0.8% GDP or an equivalent reduction in growth of 0.05 pp/year between 2014 and 2030. As a package, these measures would help to promote energy security within the EU due to reduced consumption and lower reliance on imported energy sources, as well as reduce GHG

emissions on a path to an 80% reduction by 2050. Compared to the *40% Scenario*, total cost increases by 0.6% GDP or an equivalent reduction in growth of 0.04 pp/year. Two-thirds of the additional total cost comes from the energy efficiency target, while about a quarter is due to meeting the RES burden sharing.

Member State Results

Austria

Meeting the GHG target in the *40% Scenario* will require moderate total costs in Austria of €570m (0.2% GDP). This cost is equivalent to a reduction in the 2014-2030 GDP growth rate of 0.01 pp/year.

Compared to the *Reference case*, Austria will be able to decrease its reliance on imported sources of energy through a reduction of fossil fuel use. The total cost for importing fossil fuels will decline to €8.1bn in 2030 in the *40% Scenario* (€1.6bn less than the *Reference case*). Biomass import costs remain relatively stable between these scenarios. Under the scenario including a RES target however, biomass import costs could rise by around €0.5bn.

Austria's share of coal power in its electricity generating mix is currently only 10%. While the share of coal power will decrease under a carbon price (falling to less than 3% in 2030), the resulting small improvement in air quality will not provide large savings to health costs. In the *40% Scenario*, avoided health care costs amount to €57-163m, or around 0.03% of GDP.

In the *40% Scenario*, Austria is able to achieve an increase of 11 pp in its share of renewables in final gross consumption, increasing from 29% in 2012 to 40% in 2030. This share places Austria within the top 5 European countries in terms of renewables consumption share. Austria's onshore wind and hydro capacities remain relatively constant between 2020 and 2030; however, the same period brings a large increase in solar PV capacity. Biomass electricity generation capacity and use of biofuels contribute to import needs; with biofuel use in transportation growing by 180% between 2012 and 2030.

With 72% of its energy already coming from renewables, and 79% by 2030 in the *Reference case*, Austria's mix of energy sources will remain fairly stable over the coming decades. Renewables use is slightly greater at 82% in 2030 in the *40% Scenario*, and at 85% in the more constraining *50% Scenario*; with the use of gas, Austria's only other significant energy source two decades from now, decreasing. Almost all of the growth in renewables between 2012 and 2030 comes at the expense of decreased coal power generation, which falls from 10% of the power mix to around 1-2%. Meeting a RES burden share of 45% will require a renewables subsidy between 2020 and 2030 with an annual cost of €2.1bn (0.6% GDP) in 2030.

| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG (10% credits) | % GDP |
|--|--------------|---------|-------|-------------------------|-------|-----------------------------|-------|
| Total cost vs. Ref, €m | | 570 | 0.2% | 2 430 | 0.7% | 1 250 | 0.4% |
| Average health cost vs. Ref, €m (not captured in total costs)* | | -110 | 0.0% | -140 | 0.0% | -150 | 0.0% |
| Energy import bill vs. Ref, €m (captured in total costs)** | Fossil fuels | -1 660 | 0.5% | -2 020 | 0.6% | -2 750 | 0.8% |
| | Biomass | 120 | 0.0% | 560 | 0.2% | 210 | 0.1% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

Belgium

In the *40% Scenario*, total costs in Belgium to reach the GHG target will amount to €1.2bn (0.3% GDP). This cost is equivalent to a reduction in the 2014-2030 GDP growth rate of 0.02 pp/year.

The bulk of Belgium's energy import bill comes from oil, primarily for consumption in the transportation and chemical production sectors. Achieving the 40% emissions reduction target will help to keep Belgium's overall energy import bill stable, as fossil fuel imports decrease and biomass imports increase. However the total energy import bill still represents a significant fraction of 5.0% of the total GDP in 2030, above the EU average.

As with many other Member States that reduce their use of coal power to meet a 40% emissions objective, Belgium will benefit from reduced local air pollution. The reduction of NO_x and SO₂ emissions could cut health care costs by €55m-€160m in 2030. This benefit could offset up to 10% of the total cost of abatement, depending on the sensitivity of health costs to coal power production.

Nuclear power will continue to supply the majority of the baseload needs in Belgium for the coming decades. The share of renewables in 2030 in the power mix increases steadily with the carbon price, from 34% in the *Reference case*, to 40% in the *40% Scenario*, to 46% in the *50% Scenario*. Capacity additions between 2020 and 2030 include a range of renewable power sources: offshore and onshore wind, biomass and solar. Meeting a RES burden share of 23% will require a renewables subsidy between 2020 and 2030 with an annual cost of €0.6bn (0.2% GDP) in 2030.

| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG (10% credits) | % GDP |
|--|--------------|---------|-------|-------------------------|-------|-----------------------------|-------|
| Total cost vs. Ref, €m | | 1 230 | 0.3% | 1 440 | 0.4% | 2 580 | 0.6% |
| Average health cost vs. Ref, €m (not captured in total costs)* | | -110 | 0.0% | -240 | 0.1% | -190 | 0.0% |
| Energy import bill vs. Ref, €m (captured in total costs)** | Fossil fuels | -3 210 | 0.8% | -3 620 | 0.9% | -4 800 | 1.2% |
| | Biomass | 160 | 0.0% | 230 | 0.1% | 170 | 0.0% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

Bulgaria

Meeting the GHG target in the *40% Scenario* will require moderate total costs in Bulgaria of €150m (0.1% GDP). This cost is equivalent to a reduction in the 2014-2030 GDP growth rate of 0.01 pp/year.

Bulgaria remains a net seller overall of EUA permits between 2020 and 2030, due mostly to reductions of fossil fuels in the power sector.

Bulgaria's overall energy import bill declines slowly after 2020, with fossil fuel costs remaining stable between 2020 and 2025 before slightly decreasing to €3.3bn in 2030 (in the *40% Scenario*). The fossil fuel import cost represents 3.2% of the country's total GDP, close to the EU average.

While coal and gas power make up only a small fraction of Bulgaria's electricity mix in 2030, the benefit of avoided health costs from local air pollution due to adopting more nuclear and renewable power could be between €163m-€461m. This avoided cost is large relative to the cost of abating emissions until 2030.

Overall, Bulgaria's share of renewables in gross final energy consumption increases significantly from 15% in 2012 to 31% by 2030 due to the strong penetration of renewables in the power mix over the same period; the largest increase comes from onshore wind.

Power generation in Bulgaria is currently 40% from non-emitting sources (about 25% renewables and 75% nuclear). By 2030, the power system will have a much larger share of non-fossil power capacities accounting for around 85% of total generation compared to the EU average of 75% in the *40% Scenario*. This is mainly due to a significant increase in nuclear power capacities (rising to 50% of total power generation). Meanwhile the share of renewables in power generation increases from 10% to almost 27% over the same period.

| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG (10% credits) | % GDP |
|--|--------------|---------|-------|-------------------------|-------|-----------------------------|-------|
| Total cost vs. Ref, €m | | 150 | 0.1% | 130 | 0.1% | 520 | 0.5% |
| Average health cost vs. Ref, €m (not captured in total costs)* | | -310 | 0.3% | -290 | 0.3% | -490 | 0.5% |
| Energy import bill vs. Ref, €m (captured in total costs)** | Fossil fuels | -630 | 0.6% | -630 | 0.6% | -990 | 1.0% |
| | Biomass | -40 | 0.0% | -40 | 0.0% | -40 | 0.0% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

Croatia

Meeting the GHG target in the *40% Scenario* will require moderate total costs in Croatia of €290m (0.4% GDP). This cost is equivalent to a reduction in the 2014-2030 GDP growth rate of 0.02 pp/year.

Croatia remains a net buyer overall of EUA permits between 2020 and 2030, due mostly to the power sector which represents more than 50% of total purchases.

While Croatia is one of the few European countries to be a net exporter of biomass, which reduces its total energy import bill by €109m, fossil fuel imports are much more significant at almost €3.0bn in 2030. This cost represents 3.6% of GDP (decrease of GDP growth of 0.23 pp/year), above the EU average of 2.8%.

Although the share of coal and gas is relatively high in the power mix, electricity production is relatively low in Croatia representing only 20% of the total final consumption. Because of this, the benefit of avoided health costs from local air pollution due to adopting more renewables in power generation are more limited than in other countries and do not provide significant benefits.

Overall, Croatia's share of renewables in gross final energy consumption increases significantly in the *Reference case* from 14% in 2012 to 29% in 2030; slightly above the EU average on the same period. In 2030, the share of renewables in Croatia's power mix is relatively high at around 57% compared to an average of 44% in the EU in the *40% Scenario*. With no specific plans for nuclear power in the next decades, the remaining power generation will likely come from gas and coal.

| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG (10% credits) | % GDP |
|--|--------------|---------|-------|-------------------------|-------|-----------------------------|-------|
| Total cost vs. Ref, €m | | 290 | 0.3% | 160 | 0.2% | 610 | 0.7% |
| Average health cost vs. Ref, €m (not captured in total costs)* | | 0 | 0.0% | 10 | 0.0% | -30 | 0.0% |
| Energy import bill vs. Ref, €m (captured in total costs)** | Fossil fuels | -720 | 0.9% | -690 | 0.8% | -1 150 | 1.4% |
| | Biomass | -30 | 0.0% | -40 | 0.0% | -20 | 0.0% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

Cyprus

Total costs to reach a 40% GHG target in Cyprus are higher at 0.3% GDP (€70m) than in other Member States. This cost is equivalent to a reduction in the 2014-2030 GDP growth rate of 0.02 pp/year.

Cyprus is a net buyer of EUA permits and its power sector represents almost 100% of the total purchases.

Cyprus' energy import bill reaches €1.2bn in 2030, around 5% of GDP, which is significantly higher than the average in the EU (2.8%). This cost represents an equivalent decrease of GDP growth over 2014-2030 of 0.34 pp/year.

While coal power develops in Cyprus in the *Reference* case, the share does not represent more than a few percent. Accordingly, the lower usage of coal in the *40% Scenario* represents only a minor benefit in terms of avoided health costs associated to lower local air pollution (€5-15m, up to 0.1% GDP).

The share of renewables in gross final energy consumption is relatively low in 2012, but catches up with the 30% average among EU28 countries by 2030. This is mainly due to the penetration of solar and wind in the power mix and biomass in final energy consumption, respectively.

Although in 2012, power was generated by more than 90% by oil-fired power plants, a switch from oil to gas, solar and wind results in a more balanced power mix. In 2030, the share of fossil fuels in the power mix (39% gas and 19% oil) is still relatively high due to the flexibility of oil or gas-fired power plants to meet the specific load curve of an island. However, the share of renewables (mainly wind and solar) is significant with almost 40% of the total power generated in the *40% Scenario*.

| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG (10% credits) | % GDP |
|--|--------------|---------|-------|-------------------------|-------|-----------------------------|-------|
| Total cost vs. Ref, €m | | 70 | 0.3% | 40 | 0.1% | 170 | 0.7% |
| Average health cost vs. Ref, €m (not captured in total costs)* | | -10 | 0.0% | -10 | 0.0% | -20 | 0.1% |
| Energy import bill vs. Ref, €m (captured in total costs)** | Fossil fuels | -220 | 0.9% | -220 | 0.9% | -370 | 1.6% |
| | Biomass | 10 | 0.0% | 10 | 0.0% | 30 | 0.1% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

Czech Republic

Meeting the GHG target in the *40% Scenario* will require total costs in Czech Republic of €300m (0.1% GDP). This cost is equivalent to a reduction in the 2014-2030 GDP growth rate of 0.01 pp/year.

Czech Republic remains a significant net seller of EUA permits between 2020 and 2030, due mostly to the very high abatement potential in the power sector (very high initial share of coal power generation).

Czech Republic's total energy import bill will continue to grow, even under the *40% Scenario*, and reaches €8.1bn by 2030. The fossil fuel portion of this cost represents around 2.5% of the country's total GDP (reduction of GDP growth rate by 0.16 pp/year).

A switch to nuclear power from the large share of coal in the current power mix provides significant benefit of avoided health costs from local air pollution (€413m-€1165m). This avoided cost is substantial relative to the necessary cost to abate emissions until 2030 (depending on the health cost per kWh).

The share of renewables in gross final energy consumption is relatively stable between 2012 and 2030 at around 13% in the *Reference case*. Achieving the *40% Scenario* will help to increase this share to 19%, mostly coming from additional use of low temperature solar heating and cooling in buildings, as well as increased biofuel consumption in transportation.

Czech Republic has a relatively low penetration of 10% renewables in its power mix by 2030, compared to almost 44% in the EU. However, a large share of nuclear power (65%) means that fossil fuel power account for only a limited share of the total power generation (20% coal and 10% gas). Meeting a RES burden share of 21% will require a renewables subsidy between 2020 and 2030 with an annual cost of €0.5bn (0.2% GDP) in 2030.

| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG (10% credits) | % GDP |
|--|--------------|---------|-------|-------------------------|-------|-----------------------------|-------|
| Total cost vs. Ref, €m | | 300 | 0.1% | 700 | 0.2% | 600 | 0.2% |
| Average health cost vs. Ref, €m (not captured in total costs)* | | -790 | 0.3% | -700 | 0.2% | -1 040 | 0.3% |
| Energy import bill vs. Ref, €m (captured in total costs)** | Fossil fuels | -1 180 | 0.4% | -1 270 | 0.4% | -1 940 | 0.6% |
| | Biomass | 120 | 0.0% | 210 | 0.1% | 180 | 0.1% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

Denmark

In the *40% Scenario*, total costs in Denmark to reach the GHG target will amount to €310m (0.2% GDP). This cost is equivalent to a reduction in the 2014-2030 GDP growth rate of 0.01 pp/year.

Denmark remains a net seller of EUA permits between 2020 and 2030, due mostly to the high abatement potential in the power sector (high initial share of coal power generation).

Denmark is one of the few EU countries with a net energy trade surplus, due mostly to fossil fuel export revenues. This revenue stream from oil exports decreases significantly though, from €2.9bn in 2012, to €1.2bn by 2030, mainly due to a decrease in national production. By 2030, revenues from oil exports will still cover the cost of biomass imports; however the net surplus from energy imports will have fallen to €0.4bn.

The currently strong share of coal in the power mix allows a significant benefit of avoided health costs from local air pollution due to the switch to renewables in the power mix (€189m-€532m). This cost represents a savings of €32-€90 per capita, which is well above the EU average of €18-€51 per capita.

Overall, Denmark's share of renewables in gross final energy consumption increases significantly in the *Reference case* from 25% in 2012 to 40% in 2030. It remains well above the EU average on the same period.

The share of renewables in Denmark's power mix is relatively high at 63% (*Reference case*), compared to 39% in the EU. With Denmark choosing not to implement nuclear power, the remaining 37% of generation comes from gas (18%) and coal (18%). In the *40% Scenario*, the structure of the power mix is significantly modified between 2012 and 2030 with an important switch from coal to renewable power generation. Coal falls from 42% to only 6% of generation, while the share of renewables increases from 40% to 71%. Wind and solar PV provide most of the renewables. Meeting the RES burden share of 42% will require a renewables subsidy between 2020 and 2030 with an annual cost of €0.6bn (0.3% GDP) in 2030.

| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG (10% credits) | % GDP |
|--|--------------|---------|-------|-------------------------|-------|-----------------------------|-------|
| Total cost vs. Ref, €m | | 310 | 0.2% | 800 | 0.4% | 630 | 0.3% |
| Average health cost vs. Ref, €m (not captured in total costs)* | | -360 | 0.2% | -520 | 0.3% | -470 | 0.2% |
| Energy import bill vs. Ref, €m (captured in total costs)** | Fossil fuels | -320 | 0.2% | -520 | 0.3% | -660 | 0.3% |
| | Biomass | 100 | 0.0% | 0 | 0.0% | 120 | 0.1% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

Estonia

Meeting the GHG target in the *40% Scenario* will require moderate total costs in Estonia of €40m (0.1% GDP). This cost is equivalent to a reduction in the 2014-2030 GDP growth rate of 0.01 pp/year.

Estonia remains a net seller of EUA permits between 2020 and 2030, due mostly to the high abatement potential in the power sector.

Estonia's fossil fuel import bill increases strongly between 2020 and 2030 to reach €1bn (+100% over this period). This increase is mainly due to a fall in domestic oil production (which could end between 2020 and 2025) resulting in increasing imports.

The currently strong share of coal in the power mix allows significant benefit of avoided health costs from local air pollution due to the switch to renewables in the power mix (€150m-€422m). This avoided cost is significant relative to the necessary cost to abate emissions until 2030.

The share of renewables in the gross final energy consumption increases significantly from 23% in 2012 to 40% in 2030. It remains well above the EU average over the same period due to a significant consumption of biomass in buildings and a rapid growth of renewables in the power mix.

Today, the share of fossil fuels in Estonia's power mix is relatively high, at around 92% from almost entirely coal power. By 2030, that share will have fallen in the *40% Scenario* to 57% (26% for coal, 28% for gas and 3% for oil) compared to 27% in the EU. The structure of the power mix shifts significantly to renewables between 2012 and 2030, with the share of renewables increasing from 8% to 44%.

| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG (10% credits) | % GDP |
|--|--------------|---------|-------|-------------------------|-------|-----------------------------|-------|
| Total cost vs. Ref, €m | | 40 | 0.1% | 30 | 0.1% | 130 | 0.4% |
| Average health cost vs. Ref, €m (not captured in total costs)* | | -290 | 0.9% | -250 | 0.8% | -420 | 1.3% |
| Energy import bill vs. Ref, €m (captured in total costs)** | Fossil fuels | -40 | 0.1% | -50 | 0.2% | -80 | 0.2% |
| | Biomass | 0 | 0.0% | 0 | 0.0% | 10 | 0.0% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

Finland

In the *40% Scenario*, total costs in Finland to reach the GHG target will amount to €360m (0.2% GDP). This cost is equivalent to a reduction in the 2014-2030 GDP growth rate of 0.01 pp/year.

Finland is a net seller of EUA permits in 2030, due mostly to the high abatement potential in the power sector (from a relatively high initial share of coal power generation).

Finland's fossil fuel import bill reaches a maximum in 2025 before decreasing to €6.9bn in 2030 due to the switch to nuclear power and the penetration of biomass in final consumption. Finland is a significant net exporter of biomass with revenues reaching €875m in 2030. The total net import bill is equivalent to 3.6% of the GDP.

The currently strong share of coal in the power mix allows significant benefit of avoided health costs from local air pollution due to the switch to renewables in the power mix (€118m-€334m). This avoided cost is around 25-75% (depending on the health cost per kWh) of the necessary cost to abate emissions until 2030.

Finland's share of renewables in the gross final energy consumption (30%) is already twice the EU average due to the importance of biomass consumption in buildings. Abundant domestic biomass resources allow a strong penetration of renewables, which represent 25% of the final consumption in buildings. In Finland, a very large portion of the new renewables consumption modelled by POLES comes from biomass use since this is more cost competitive than other renewables sources; however, biomass is consumed to such a degree that it is questionable if it can all be supplied from sustainable sources. As a result, we have chosen to cap the renewables subsidies at 1% of the cumulative 2021-2030 GDP (€1.6bn) so as to not distort the overall modelling results; 38% renewables capacity is achieved instead of the 49% burden share.

In 2030, Finland's power mix in the *40% Scenario* is near the EU average with a very similar share of renewables (45%), a higher share of nuclear power (38%) and less fossil fuel power generation (17%).

| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG (10% credits) | % GDP |
|--|--------------|---------|-------|-------------------------|-------|-----------------------------|-------|
| Total cost vs. Ref, €m | | 360 | 0.2% | 1 820 | 1.0% | 990 | 0.5% |
| Average health cost vs. Ref, €m (not captured in total costs)* | | -230 | 0.1% | -200 | 0.1% | -330 | 0.2% |
| Energy import bill vs. Ref, €m (captured in total costs)** | Fossil fuels | -1 610 | 0.9% | -2 040 | 1.1% | -2 630 | 1.4% |
| | Biomass | 0 | 0.0% | 440 | 0.2% | 250 | 0.1% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

France

Meeting the GHG target in the *40% Scenario* will require moderate total costs in France of €2.8bn (0.1% GDP). This cost is equivalent to a reduction in the 2014-2030 GDP growth rate of 0.01 pp/year.

France's large nuclear generating capacity means that there is less potential for emissions reductions in the power sector, which is normally a large contributor to reductions. This translates into less potential for domestic efforts and therefore a higher ratio between EUAs purchased on the ETS market and emissions abated within the country. Most of France's domestic reductions will need to come from heavy industries such as steel and cement production. The bulk of France's energy import bill comes from oil, primarily for consumption in the transportation sector. Achieving the 40% emissions reduction target will help to keep France's overall energy import bill relatively stable; however the total energy import bill still represents a significant fraction of 2.7% of the total GDP in 2030 (about the EU average).

The small amount of fossil fuel generation in the power mix means that there are only minimal benefits for avoided health costs due to reduced air pollution: between €0.6bn and €1.6bn, which are proportionately relatively minor compared to other Member States.

Renewable energy consumption in heating and cooling, electricity generation and transport increases by about 5 pp between 2020 and 2030. Overall, this means that France consumes almost a third of its energy from renewable sources by 2030.

Nuclear power will continue to supply the majority of the baseload power in France for the coming decades. Despite this, the share of renewables in the power mix will grow steadily, with capacity increases of 20-30% coming from most power sources, including solar, onshore wind, and biomass. By 2030, renewables will represent more than 25% of the total power generation (17% in 2012). Meeting a RES burden share of 33% will require a renewables subsidy between 2020 and 2030 with an annual cost of €3.6bn (0.2% GDP) in 2030.

| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG (10% credits) | % GDP |
|--|--------------|---------|-------|-------------------------|-------|-----------------------------|-------|
| Total cost vs. Ref, €m | | 2 820 | 0.1% | 5 840 | 0.3% | 5 970 | 0.3% |
| Average health cost vs. Ref, €m (not captured in total costs)* | | -1 090 | 0.0% | -1 580 | 0.1% | -1 430 | 0.1% |
| Energy import bill vs. Ref, €m (captured in total costs)** | Fossil fuels | -10 100 | 0.5% | -11 460 | 0.5% | -15 110 | 0.7% |
| | Biomass | 420 | 0.0% | 620 | 0.0% | 600 | 0.0% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

Germany

In the *40% Scenario*, total costs in Germany to reach the GHG target will amount to €5.5bn (0.2% GDP). This cost is equivalent to a reduction in the 2014-2030 GDP growth rate of 0.01 pp/year.

The massive restructuring of Germany's power sector already underway with the phase-out of its nuclear reactors and the adoption of wind and solar power will be facilitated under a moderate carbon price necessary to achieve a 40% reduction target, and helped even further under more ambitious scenarios. These changes allow Germany to be a net seller of EUA permits.

Despite the recent increase in coal generated power in Germany, coal capacities will decrease over the coming decades with even a moderate carbon price. This shift away from coal-fired power generation could provide sizeable benefits from reduced health care costs in a country with such a large population. Avoided health costs could be between €3.1bn and €8.7bn (0.1-0.3% GDP).

Power generation will shift from 21% coal in 2030 under the *Reference case* to 12% under a 40% target, and falling to 7% with a stronger 50% goal. A small part of this reduction will go to gas-fired power which increases by 3 pp to provide 18% of total power needs, with little change observed under a more stringent climate scenario. The remaining gap is filled almost entirely by renewables: tripling of offshore wind capacity, and increases to onshore wind and solar.

| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG (10% credits) | % GDP |
|--|--------------|---------|-------|-------------------------|-------|-----------------------------|-------|
| Total cost vs. Ref, €m | | 5 460 | 0.2% | 3 120 | 0.1% | 12 530 | 0.4% |
| Average health cost vs. Ref, €m (not captured in total costs)* | | -5 910 | 0.2% | -5 130 | 0.2% | -8 850 | 0.3% |
| Energy import bill vs. Ref, €m (captured in total costs)** | Fossil fuels | -10 220 | 0.4% | -10 600 | 0.4% | -16 440 | 0.6% |
| | Biomass | 610 | 0.0% | 560 | 0.0% | 880 | 0.0% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

Greece

Meeting the GHG target in the *40% Scenario* will require moderate total costs in Greece of €420m (0.2% GDP). This cost is equivalent to a reduction in the 2014-2030 GDP growth rate of 0.01 pp/year.

Greece remains a net seller of EUA permits between 2020 and 2030, due mostly to the high abatement potential in the power sector (switch from coal to renewables).

Greece's fossil fuel import bill remains stable between 2020 and 2025 at around €10bn before decreasing to €9bn (3.7% GDP) in 2030. Greece is also a net importer of biomass which results in an additional €1.2bn import bill. Together these energy imports amount to an equivalent decrease of GDP growth of 0.27 pp/year between 2014 and 2030.

The currently strong share of coal in the power mix allows significant benefits of avoided health costs from local air pollution due to the switch to renewables in the power mix (€347m-€981m), representing €30-€85 per capita. This avoided cost is large relative to the cost of abating emissions until 2030 (depending on the health cost per kWh), and is well above the EU average (€18-€51 per capita).

Greece's share of renewables in gross final energy consumption increases significantly from close to the EU average (14% in 2012) to slightly above the EU average in the *40% Scenario* (33% in 2030). However, in the power sector, by 2030 the 42% share of fossil fuels (coal and gas) in Greece's power mix is elevated compared to the 33% EU average. As there are no specific plans for nuclear power development, most of the remaining power generation comes entirely from renewables (48%).

| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG (10% credits) | % GDP |
|--|--------------|---------|-------|-------------------------|-------|-----------------------------|-------|
| Total cost vs. Ref, €m | | 420 | 0.2% | 240 | 0.1% | 1 010 | 0.4% |
| Average health cost vs. Ref, €m (not captured in total costs)* | | -660 | 0.3% | -600 | 0.2% | -900 | 0.4% |
| Energy import bill vs. Ref, €m (captured in total costs)** | Fossil fuels | -1 310 | 0.5% | -1 300 | 0.5% | -2 130 | 0.9% |
| | Biomass | 130 | 0.1% | 110 | 0.0% | 130 | 0.1% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

Hungary

In the *40% Scenario*, total costs in Hungary to reach the GHG target will amount to €270m (0.1% GDP). This cost is equivalent to a reduction in the 2014-2030 GDP growth rate of 0.01 pp/year.

Hungary remains a significant net seller of EUA permits between 2020 and 2030, due mostly to the high abatement potential in the power sector.

Hungary's total energy imports stabilise at around €6.8bn between 2020 and 2030, with a slight decrease of the fossil fuel bill offset by an increase in biomass purchases (+€360m). The fossil fuel portion of this cost represents around 3.4% of the country's GDP.

The significant share of coal in the current power mix allows for some avoided health costs from local air pollution (€135m-€383m) due to a switch to renewable power sources.

The share of renewables in gross final energy consumption more than doubles between 2012 and 2030, from 9% to 20% but remains significantly below the EU average (10 pp below). This is mainly due to a relatively low share of renewables in the power mix which is not offset by a very strong penetration of biomass in buildings and transportation. In the *40% Scenario*, renewables account for only 21% of the power mix by 2030, half the EU average. However, a large share of nuclear power (44%) means that fossil fuel power accounts for only a limited share of the total power generation (12% coal and 30% gas). Meeting a RES burden share of 20% will require a renewables subsidy between 2020 and 2030 with an annual cost of €38m in 2030.

| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG (10% credits) | % GDP |
|--|--------------|---------|-------|-------------------------|-------|-----------------------------|-------|
| Total cost vs. Ref, €m | | 270 | 0.1% | 270 | 0.1% | 910 | 0.5% |
| Average health cost vs. Ref, €m (not captured in total costs)* | | -260 | 0.1% | -230 | 0.1% | -330 | 0.2% |
| Energy import bill vs. Ref, €m (captured in total costs)** | Fossil fuels | -1 460 | 0.8% | -1 430 | 0.8% | -2 140 | 1.1% |
| | Biomass | 10 | 0.0% | 10 | 0.0% | -10 | 0.0% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

Ireland

Meeting the GHG target in the *40% Scenario* will require moderate total costs in Ireland of €330m (0.1% GDP). This cost is equivalent to a reduction in the 2014-2030 GDP growth rate of 0.01 pp/year.

Ireland remains a relatively neutral player on the EUA trading market.

Between 2020 and 2030, Ireland's total energy imports stabilise at around €5.9bn, with a slight decrease of the fossil fuel bill offset by an increase in biomass purchases (+€600m). The fossil fuel portion of this cost represents about 2.3% of the country's total GDP.

Reduced use of fossil fuels in power generation will help to reduce health care costs associated with local air pollution from NO_x and SO₂. In 2030, avoided health costs could total between €60m-€170m, representing about €11-€32 per capita, somewhat below the EU average of €18-€51 per capita.

Ireland's share of renewables in gross final energy consumption increases significantly in the *40% Scenario* from only 7% in 2012 (half of the EU average) to 29% in 2030, slightly above the EU average. This increase can be explained by a very strong penetration of renewables in the power mix; however, in 2030 the share of fossil fuels in Ireland's power mix remains relatively high even in the *40% Scenario*. Gas-fired power plants (38%) and coal (7%) still provide much of the electricity generation. The remaining power supply comes from renewables which represent more than half of the total power generated (53%). Between 2012 and 2030, wind power replaces approximately 15% each of gas and coal.

| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG (10% credits) | % GDP |
|--|--------------|---------|-------|-------------------------|-------|-----------------------------|-------|
| Total cost vs. Ref, €m | | 330 | 0.1% | 220 | 0.1% | 800 | 0.3% |
| Average health cost vs. Ref, €m (not captured in total costs)* | | -110 | 0.0% | -90 | 0.0% | -160 | 0.1% |
| Energy import bill vs. Ref, €m (captured in total costs)** | Fossil fuels | -1 190 | 0.5% | -1 170 | 0.5% | -1 780 | 0.8% |
| | Biomass | 80 | 0.0% | 70 | 0.0% | 140 | 0.1% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

Italy

Total costs to reach a 40% GHG target in Italy are higher at 0.3% GDP (€4.9bn) than in other Member States. This cost is equivalent to a reduction in the 2014-2030 GDP growth rate of 0.02 pp/year.

Italy remains a net buyer overall of EUA permits between 2020 and 2030. The significant share of renewables in the current power mix, the relatively low share of coal, and the absence of nuclear power as a future electricity generating option leave abatement options that are generally more expensive than elsewhere in the EU, and so trading plays a key role in reducing costs of meeting the GHG target.

Between 2020 and 2030, Italy's total energy imports stabilise at around €58bn with a slight decrease of the fossil fuel bill offset by an increase in biomass purchases (+€6bn). The fossil fuel portion of this cost represents around 3.1% of the country's total GDP.

Avoided health costs from local air pollution associated to fossil fuel combustion in power plants will only provide minimal benefits in Italy. The total savings of €240m-€685m, represent approximately €4-€11 per capita, well below the EU average (€18-€51 per capita).

Italy's share of renewables in gross final energy consumption increases significantly in the *40% Scenario*, from 13% in 2012 to 23% in 2030, slightly below the EU average. The relatively low consumption of biomass in final sectors is offset by renewables in the power mix.

By 2030, the share of fossil fuels in Italy's power mix remains relatively high in the *40% Scenario*. It is dominated by gas-fired power plants (44%) followed by coal (6%). However, in the absence of nuclear power, the remaining power generation comes from renewables which represent half of the total power generated (46%). Between 2012 and 2030, wind and solar PV gain market shares from coal, while the share of gas power generation remains stable. Meeting a RES burden share of 28% will require a renewables subsidy between 2020 and 2030 with an annual cost of €7.4bn (0.4% GDP) in 2030. Despite high absolute renewables potential, Italy is a densely populated country with a high ratio of electricity demand compared to renewables potential. This means the burden share modelled for a RES target is actually quite expensive to achieve, since Italy uses more of its expensive renewable potential than other countries (i.e. renewables outside of the power sector).

| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG (10% credits) | % GDP |
|--|--------------|---------|-------|-------------------------|-------|-----------------------------|-------|
| Total cost vs. Ref, €m | | 4 900 | 0.3% | 9 980 | 0.6% | 10 940 | 0.6% |
| Average health cost vs. Ref, €m (not captured in total costs)* | | -460 | 0.0% | -1 100 | 0.1% | -640 | 0.0% |
| Energy import bill vs. Ref, €m (captured in total costs)** | Fossil fuels | -9 030 | 0.5% | -10 950 | 0.6% | -13 020 | 0.8% |
| | Biomass | 510 | 0.0% | 630 | 0.0% | 730 | 0.0% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

Latvia

Meeting the GHG target in the *40% Scenario* will require moderate total costs in Latvia of €80m (0.2% GDP). This cost is equivalent to a reduction in the 2014-2030 GDP growth rate of 0.01 pp/year.

Latvia remains a neutral player on the EUA permits market with only 0.1 MtCO₂ of permits sold in 2030.

Between 2020 and 2030, Latvia's total energy imports stabilise at around €1.4bn, which composed almost entirely of fossil fuels, mainly oil and gas. This represents about 3.2% of the country's total GDP, or a reduction in the GDP growth between 2014 and 2030 of 0.21 pp/year.

In the absence of power generation from coal-fired power plants and with relatively stable generation from gas, the avoided health costs of local air pollution are negligible compared to other Member States.

Due to the current very high level of renewables in the power mix, the share of renewables in gross final energy consumption falls slightly from 38% in 2012 to 35% in 2030, although this remains above the EU average. The share of biomass in final consumption (20%) is also significantly higher than elsewhere in the EU (13% average).

In Latvia, renewables used in building heating and cooling make up a large share of overall renewables consumption. Between 2020-2030, more efficient heating processes and a switch to electric heating mean there is consequently less biomass demand in buildings; this structural change makes it very difficult to meet Latvia's target. As a result, we have chosen to cap the renewables subsidies at 1% of the cumulative 2021-2030 GDP (€334m) so as to not distort the overall modelling results; 41% renewables capacity is achieved instead of the 51% burden share.

In 2030, Latvia's power mix is dominated by renewables (74% in the *40% Scenario*), mostly hydro (40%) and wind (27%). Remaining power generation comes mainly from gas-fired power plants (25%). With relatively stable hydro and gas capacities, the only change in the structure of the power mix between 2012 and 2030 comes from the penetration of wind power.

| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG (10% credits) | % GDP |
|--|--------------|---------|-------|-------------------------|-------|-----------------------------|-------|
| Total cost vs. Ref, €m | | 80 | 0.2% | 370 | 0.8% | 180 | 0.4% |
| Average health cost vs. Ref, €m (not captured in total costs)* | | 0 | 0.0% | -10 | 0.0% | 10 | 0.0% |
| Energy import bill vs. Ref, €m (captured in total costs)** | Fossil fuels | -350 | 0.8% | -420 | 0.9% | -570 | 1.3% |
| | Biomass | -10 | 0.0% | 40 | 0.1% | 0 | 0.0% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

Lithuania

In the *40% Scenario*, total costs in Lithuania to reach the GHG target will amount to €190m (0.3% GDP). This cost is equivalent to a reduction in the 2014-2030 GDP growth rate of 0.02 pp/year.

Lithuania is a net buyer of EUA permits in 2030, due mostly to the power and energy transformation sectors, which account for a large share of the purchases. With a relatively carbon free power mix (currently no coal power), the remaining domestic abatement options are relatively more limited and more expensive than for other Member States.

Lithuania's energy import bill remains stable between 2020 and 2030 at around €3.0bn with a slight decrease of the fossil fuel bill offset by an increase in biomass purchases (+€0.1bn). The energy import bill represents around 4.3% of the country's GDP.

The small amount of fossil fuel generation in the power mix means that a switch to renewable power can only provide minimal benefits for avoided health costs due to reduced air pollution.

The share of renewables in Lithuania's final gross energy consumption follows the EU average and increases from 15% in 2012 to 25% in 2030. This increase relates almost entirely to the penetration of wind in the power sector.

In 2030, Lithuania's power mix is marked by a very high share of nuclear power (51%) and an average share of renewables (33%). Power generation from coal-fired power plants is negligible and gas only represents 5% of the total power generation. Between 2012 and 2030, renewables gain significant market shares from nuclear (-15%) and gas (-16%), mostly to the benefit of onshore wind, but also offshore wind and biomass. Meeting a RES burden share of 30% will require a renewables subsidy between 2020 and 2030 with an annual cost of €133m (0.2% GDP) in 2030.

| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG (10% credits) | % GDP |
|--|--------------|---------|-------|-------------------------|-------|-----------------------------|-------|
| Total cost vs. Ref, €m | | 190 | 0.3% | 260 | 0.4% | 390 | 0.6% |
| Average health cost vs. Ref, €m (not captured in total costs)* | | 0 | 0.0% | -30 | 0.0% | 0 | 0.0% |
| Energy import bill vs. Ref, €m (captured in total costs)** | Fossil fuels | -550 | 0.8% | -700 | 1.0% | -820 | 1.2% |
| | Biomass | 10 | 0.0% | 10 | 0.0% | 20 | 0.0% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

Luxembourg

Meeting the GHG target in the *40% Scenario* will require moderate total costs in Luxembourg of €140m (0.3% GDP). This cost is equivalent to a reduction in the 2014-2030 GDP growth rate of 0.02 pp/year.

Luxembourg is a net buyer of EUA permits and its power sector represents most of the total purchases. The bulk of Luxembourg's energy import bill comes from oil, primarily for consumption in the transportation sector. Achieving the 40% emissions reduction target will help to keep the overall energy import bill from rising (as in the *Reference case*), as fossil fuel imports decrease and biomass imports increase. However the total energy import bill still represents a significant fraction of 4.1% of the total GDP in 2030.

There is little change in Luxembourg's power mix, which remains dominated by gas with a smaller portion from renewables (see below). Due to this, there are minimal benefits realised for avoided health costs due to reduced air pollution from less fossil fuel power generation.

In Luxembourg, there is insufficient final demand to support additional renewables consumption. Without increased demand to provide the need for additional electricity capacity, or early retirement of fossil fuels to artificially create the need for capacity, the modelling suggests that it is difficult to augment renewables consumption due to existing installed generation capacity already providing sufficient power. As a result, we have chosen to cap the renewables subsidies at 1% of the cumulative 2021-2030 GDP (€382m) so as to not distort the overall modelling results; 18% renewables capacity is achieved instead of the 23% burden share.

| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG (10% credits) | % GDP |
|--|--------------|---------|-------|-------------------------|-------|-----------------------------|-------|
| Total cost vs. Ref, €m | | 140 | 0.3% | 450 | 1.1% | 300 | 0.7% |
| Average health cost vs. Ref, €m (not captured in total costs)* | | 10 | 0.0% | 0 | 0.0% | 10 | 0.0% |
| Energy import bill vs. Ref, €m (captured in total costs)** | Fossil fuels | -230 | 0.5% | -290 | 0.7% | -370 | 0.9% |
| | Biomass | -20 | 0.0% | 60 | 0.1% | -70 | 0.2% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

Malta

In the *40% Scenario*, total costs in Malta to reach the GHG target will amount to €20m (0.2% GDP). This cost is equivalent to a reduction in the 2014-2030 GDP growth rate of 0.01 pp/year.

Malta is a net buyer of EUA permits and its power sector represents almost 100% of the total purchases.

Malta's energy import bill reaches €360m in 2030, around 3% of GDP, which is close to the average in the EU (2.8%). This cost represents an equivalent decrease of GDP growth over 2014-2030 of 0.2 pp/year.

While coal power develops in Malta in the *Reference* case, the share does not represent more than a few percent. Accordingly, the lower usage of coal in the *40% Scenario* represents only a minor benefit in terms of avoided health costs associated to lower local air pollution.

The share of renewables in the gross final energy consumption is negligible in 2012, but increases to 22% in 2030, slightly below the average among EU28 countries. Most of this increase is due to offshore wind in the power mix and biomass in final energy consumption.

In 2030, the share of fossil fuel in the power mix (43% gas and 24% oil) is relatively high due to the desirable flexibility of oil or gas-fired power plants to meet the specific load curve of a small, isolated island grid. However, the share of renewables (entirely made up of offshore wind) is significant with more than 30% of the total power generated in the *40% Scenario*. These changes help to diversify Malta's power system, which was entirely supplied by expensive oil-fired power plants in 2012. Meeting a RES burden share of 22% will require a renewables subsidy between 2020 and 2030 with an annual cost of €5m in 2030.

| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG (10% credits) | % GDP |
|--|--------------|---------|-------|-------------------------|-------|-----------------------------|-------|
| Total cost vs. Ref, €m | | 20 | 0.2% | 20 | 0.1% | 50 | 0.4% |
| Average health cost vs. Ref, €m (not captured in total costs)* | | 0 | 0.0% | 0 | 0.0% | -10 | 0.1% |
| Energy import bill vs. Ref, €m (captured in total costs)** | Fossil fuels | -60 | 0.5% | -60 | 0.5% | -110 | 1.0% |
| | Biomass | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

Netherlands

Meeting the GHG target in the *40% Scenario* will require moderate total costs in the Netherlands of €1.8bn (0.3% GDP). This cost is equivalent to a reduction in the 2014-2030 GDP growth rate of 0.02 pp/year.

The Netherlands is a significant net buyer of EUA permits in 2030..

The Netherlands' fossil fuel energy imports increase significantly from €15bn in 2020 to €22bn in 2030. This is mainly due to a sharp decline in gas production which falls by 50% over this period. The fossil fuel energy bill represents around 3.3% of the country's GDP.

Much of the displaced coal power generation is replaced with gas, providing fewer avoided health costs from local air pollution (€131m-€373m), compared to a stronger shift to renewables.

The Netherlands' share of renewables in gross final energy consumption increases significantly in the *40% Scenario* from only 4% in 2012 to 18% in 2030, but representing about half the EU average.

In 2030, the share of fossil fuel in the Netherlands' power mix remains relatively high in the *40% Scenario* due to the low share of nuclear power. It is dominated by gas-fired power (36%) followed by coal (10%). However, with only 10% of power generation coming from nuclear, the share of renewables represents a significant fraction of the total power generated (42%, equivalent to the EU average). Between 2012 and 2030, gas and coal lose equivalent market shares of 15% each, re-distributed between nuclear power (+6% of market share) and renewables (+28%). Both offshore and onshore wind, as well as solar PV, capacities are increased. Meeting a RES burden share of 24% will require a renewables subsidy between 2020 and 2030 with an annual cost of €1.4bn (0.2% GDP) in 2030.

| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG (10% credits) | % GDP |
|--|--------------|---------|-------|-------------------------|-------|-----------------------------|-------|
| Total cost vs. Ref, €m | | 1 840 | 0.3% | 2 500 | 0.4% | 4 090 | 0.6% |
| Average health cost vs. Ref, €m (not captured in total costs)* | | -250 | 0.0% | -630 | 0.1% | -490 | 0.1% |
| Energy import bill vs. Ref, €m (captured in total costs)** | Fossil fuels | -3 180 | 0.5% | -4 030 | 0.6% | -4 460 | 0.7% |
| | Biomass | 250 | 0.0% | 450 | 0.1% | 320 | 0.0% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

Poland

Total costs to reach a 40% GHG target in Poland are similar at 0.2% GDP (€1.7bn) to other Member States. This cost is equivalent to a reduction in the 2014-2030 GDP growth rate of 0.01 pp/year.

Poland remains a net seller overall of EUA permits between 2020 and 2030, due mostly to reductions of fossil fuels in the power sector.

Poland's overall energy import bill begins to stabilise after 2025, with oil costs peaking, but gas and biomass costs continuing to increase. Total import costs in 2030 amount to €30.6bn in the *40% Scenario*, representing 3.5% of the country's total GDP; somewhat above the EU average.

A switch to renewables and nuclear power, away from the large share of coal in the current power mix, provides significant benefits from avoided health costs of local air pollution associated to fossil fuel combustion in power plants (€1.7bn-€4.7bn). This avoided cost is large relative to the cost of abating emissions until 2030.

Overall, Poland's share of renewables in gross final energy consumption increases significantly from 11% in 2012 to 28% by 2030 due to the strong penetration of renewables in the power mix over the same period; the largest increases comes from onshore and offshore wind.

There is currently a relatively low penetration of 6% renewables in Poland's power mix, compared to almost 25% average in the EU. The large majority of power is provided via coal power. In 2030, under the *40% Scenario*, the power mix will shift away from coal to include more gas, renewables, and some nuclear.

| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG (10% credits) | % GDP |
|--|--------------|---------|-------|-------------------------|-------|-----------------------------|-------|
| Total cost vs. Ref, €m | | 1 720 | 0.2% | 1 070 | 0.1% | 3 980 | 0.5% |
| Average health cost vs. Ref, €m (not captured in total costs)* | | -3 160 | 0.4% | -2 660 | 0.3% | -4 990 | 0.6% |
| Energy import bill vs. Ref, €m (captured in total costs)** | Fossil fuels | -3 700 | 0.4% | -3 720 | 0.4% | -6 420 | 0.7% |
| | Biomass | 500 | 0.1% | 440 | 0.1% | 840 | 0.1% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

Portugal

Meeting the GHG target in the *40% Scenario* will require moderate total costs in Portugal of €260m (0.1% GDP). This cost is equivalent to a reduction in the 2014-2030 GDP growth rate of 0.01 pp/year.

Portugal will remain a net seller of EUAs to other Member States, mostly due to the transformation of its power sector.

While Portugal's overall energy import bill remains relatively constant at just over €8bn between 2020 and 2030, biomass will make up an increasing portion, rising to 11% by 2030. This increase in biomass imports follows a 5% increase in biomass power generation and 50% increase of biofuel consumption in road transportation.

As with many other Member States that reduce their use of coal power to meet a 40% GHG objective, Portugal will benefit from reduced local air pollution. The reduction of NO_x and SO₂ emissions could cut health care costs by €43m-€122m in 2030.

Power generation in Portugal is currently about 44% from non-emitting renewable sources. By 2030, under all of the scenarios considered, total generation will come from at least 59% renewables, compared to the EU average of 44%. This is mainly due to a significant shift away from coal and gas towards large hydro, solar PV, and biomass electricity generation.

| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG (10% credits) | % GDP |
|--|--------------|---------|-------|-------------------------|-------|-----------------------------|-------|
| Total cost vs. Ref, €m | | 260 | 0.1% | 150 | 0.1% | 720 | 0.3% |
| Average health cost vs. Ref, €m (not captured in total costs)* | | -80 | 0.0% | -70 | 0.0% | -110 | 0.0% |
| Energy import bill vs. Ref, €m (captured in total costs)** | Fossil fuels | -1 500 | 0.6% | -1 440 | 0.6% | -2 260 | 0.9% |
| | Biomass | 70 | 0.0% | 60 | 0.0% | 170 | 0.1% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

Romania

In the *40% Scenario*, total costs in Romania to reach the GHG target will amount to €430m (0.2% GDP). This cost is equivalent to a reduction in the 2014-2030 GDP growth rate of 0.01 pp/year.

Romania will be a net seller of credits under the GHG scenarios considered.

Meeting a 40% GHG target will help to keep Romania's total energy import bill stable, mainly by reducing oil imports, between 2020 and 2030. Total costs in 2030 amount to €2bn (0.7% of GDP).

Due to the significant decrease in electricity generated from coal, there could be large savings in Romania from avoided health care costs due to local air pollution. Coal power production falls significantly in the *40% Scenario*, and this reduction could result in €260m-€733m in benefits. Depending on the health cost per kWh, the benefit from reduced coal power could be substantial relative to the total cost to abate emissions.

After meeting 30% renewables in final gross consumption in 2020, Romania goes further to achieve 41% in final consumption in 2030 (the second highest share of EU28 countries after Sweden). Most of this increase comes from the power sector, but there are also gains of biofuel use in the transportation sector.

Romania currently has a relatively diversified power system with one quarter of electricity produced coming from renewable sources, 19% from nuclear, 36% from coal, and 18% from gas. Coal power decreases significantly, with the difference mainly shifting to renewables; while the shares of nuclear and gas remain constant to 2030 under a 40% GHG target. Major capacity increases come from onshore and offshore wind, large hydro, solar PV and biomass.

| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG (10% credits) | % GDP |
|--|--------------|---------|-------|-------------------------|-------|-----------------------------|-------|
| Total cost vs. Ref, €m | | 430 | 0.2% | 280 | 0.1% | 960 | 0.3% |
| Average health cost vs. Ref, €m (not captured in total costs)* | | -500 | 0.2% | -440 | 0.2% | -650 | 0.2% |
| Energy import bill vs. Ref, €m (captured in total costs)** | Fossil fuels | -620 | 0.2% | -590 | 0.2% | -1 320 | 0.5% |
| | Biomass | -10 | 0.0% | -10 | 0.0% | -50 | 0.0% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

Slovakia

Meeting the GHG target in the *40% Scenario* will require moderate total costs in Slovakia of €270m (0.2% GDP). This cost is equivalent to a reduction in the 2014-2030 GDP growth rate of 0.01 pp/year.

Slovakia will be a net provider of credits under the GHG scenarios considered.

By meeting the 40% GHG target, Slovakia will be able to significantly decrease its energy import bill; reducing its trade bill for oil and gas by 20%. The trade bill of €4.2bn still represents 2.8% GDP, or a reduction of the GDP growth rate by 0.18 pp/year.

Coal power generation in 2030 is divided in half from 8% to 4% between the *Reference case* and the *40% Scenario*. The benefits due to avoided health care costs from local air pollution could amount to €73m-€207m.

The power system in Slovakia is already very reliant on nuclear power to provide almost half of the electricity produced. With a 40% GHG objective, nuclear power production remains constant for the next two decades. Renewable power increases strongly, growing from 19% in 2012 to 27% in 2030.

Almost all of the increase in renewables electricity capacity will come from onshore wind power. While biomass capacity should also increase, biomass as an energy source will be more useful as biofuel in the road transportation sector, growing strongly by 150% between 2012 and 2030.

| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG (10% credits) | % GDP |
|--|--------------|---------|-------|-------------------------|-------|-----------------------------|-------|
| Total cost vs. Ref, €m | | 270 | 0.2% | 150 | 0.1% | 620 | 0.4% |
| Average health cost vs. Ref, €m (not captured in total costs)* | | -140 | 0.1% | -130 | 0.1% | -190 | 0.1% |
| Energy import bill vs. Ref, €m (captured in total costs)** | Fossil fuels | -1 070 | 0.7% | -1 040 | 0.7% | -1 640 | 1.1% |
| | Biomass | -10 | 0.0% | -10 | 0.0% | 20 | 0.0% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

Slovenia

Total costs to reach a 40% GHG target in Slovenia are similar at 0.2% GDP (€90m) to other Member States. This cost is equivalent to a reduction in the 2014-2030 GDP growth rate of 0.01 pp/year.

Slovenia remains a relatively neutral player on the EUA trading

Between 2020 and 2030, Slovenia's total energy imports stabilise at around €1.8bn with a slight decrease of the oil bill offset by an increase in biomass purchases. The fossil fuel portion of this cost represents around 2.8% of the country's total GDP (decrease of 0.18 pp/year in GDP growth).

The benefits of avoided health care costs from reducing local air pollution due to coal power generation could be substantial relative to the costs incurred to abate emissions. Depending on the health cost per kWh of fossil fuel combustion, benefits could be €47m-€133m.

Even under the *Reference case*, the electricity system in 2030 in Slovenia will be relatively low in carbon emissions, with 44% of power coming from renewables and 36% from nuclear. To meet a 40% target in 2030, capacities of both renewables and nuclear increase so that the total non-emitting share is 84%. Meeting a RES burden share of 34% will require a renewables subsidy between 2020 and 2030 with an annual cost of €87m (0.2% GDP) in 2030.

| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG (10% credits) | % GDP |
|--|--------------|---------|-------|-------------------------|-------|-----------------------------|-------|
| Total cost vs. Ref, €m | | 90 | 0.2% | 160 | 0.3% | 210 | 0.4% |
| Average health cost vs. Ref, €m (not captured in total costs)* | | -90 | 0.2% | -100 | 0.2% | -140 | 0.2% |
| Energy import bill vs. Ref, €m (captured in total costs)** | Fossil fuels | -230 | 0.4% | -240 | 0.4% | -340 | 0.6% |
| | Biomass | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

Spain

Meeting the GHG target in the *40% Scenario* will require moderate total costs in Spain of €2.7bn (0.2% GDP). This cost is equivalent to a reduction in the 2014-2030 GDP growth rate of 0.01 pp/year.

Spain is a net buyer of EUA permits in 2030.

While Spain's overall energy import bill remains relatively constant at around €50bn between 2020 and 2030, though biomass will make up an increasing portion, rising to 10% by 2030. This increase in biomass imports follows a 14% increase in biomass power generation and almost 50% increase of direct biomass use in buildings.

As with many other Member States that reduce their use of coal power to meet a 40% GHG objective, Spain will benefit from reduced local air pollution. The reduction of NO_x and SO₂ emissions could cut health care costs by €0.8bn-€2.2bn in 2030.

One third of Spain's total energy consumption could come from renewable sources by 2030; increases would mainly occur through the use of renewables in power generation and biomass for heating and cooling in buildings.

The share of fossil fuels in the power mix falls from over 40% of total production to 32% under the *40% Scenario* (mostly due to reduced coal power production). Wind power capacity could double and solar capacity could increase by almost 50%. Spain could have a very flexible power system with almost 20% of electricity generated from baseload nuclear, around 50% generation from renewables (with the majority from onshore wind and solar), and between 20-25% generated from gas turbines (which could prove very important for regulating the production from intermittent renewables).

| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG (10% credits) | % GDP |
|--|--------------|---------|-------|-------------------------|-------|-----------------------------|-------|
| Total cost vs. Ref, €m | | 2 700 | 0.2% | 1 620 | 0.1% | 6 110 | 0.4% |
| Average health cost vs. Ref, €m (not captured in total costs)* | | -1 470 | 0.1% | -1 300 | 0.1% | -2 100 | 0.1% |
| Energy import bill vs. Ref, €m (captured in total costs)** | Fossil fuels | -8 610 | 0.6% | -8 490 | 0.6% | -12 640 | 0.8% |
| | Biomass | 180 | 0.0% | 190 | 0.0% | 30 | 0.0% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

Sweden

In the *40% Scenario*, total costs in Sweden to reach the GHG target will amount to €530m (0.1% GDP). This cost is equivalent to a reduction in the 2014-2030 GDP growth rate of 0.01 pp/year.

Sweden remains a small net seller of EUA permits between 2020 and 2030, mostly due to power sector abatement.

Sweden's energy import bill gradually declines over the decade from 2020 to 2030, with a limited shift from fossil fuels to biomass. The total import bill represents 2.8% of the country's total GDP (€11.4bn).

While coal power makes up only a small fraction of Sweden's electricity mix in 2030, even in the *Reference case*, the benefits of avoided health costs of local air pollution due to adopting more renewable power could be between €111m-€316m.

With over 60% of its energy already coming from renewables and over 30% from nuclear, Sweden's energy mix will remain almost entirely carbon free for the coming decades. This provides a strong mix of stable baseload power from nuclear and biomass power available for peak load demand.

Sweden's renewable electricity generating capacity remains stable between 2020 and 2030, with the largest increase coming from additional onshore wind, as well as biomass. These additions help Sweden to achieve the highest share (55%) of renewables in final gross consumption of any of the EU28 countries in 2030. Meeting a RES burden share of 60% will require a renewables subsidy between 2020 and 2030 with an annual cost of €1.5bn (0.4% GDP) in 2030.

| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG (10% credits) | % GDP |
|--|--------------|---------|-------|-------------------------|-------|-----------------------------|-------|
| Total cost vs. Ref, €m | | 530 | 0.1% | 1 830 | 0.5% | 1 160 | 0.3% |
| Average health cost vs. Ref, €m (not captured in total costs)* | | -210 | 0.1% | -360 | 0.1% | -320 | 0.1% |
| Energy import bill vs. Ref, €m (captured in total costs)** | Fossil fuels | -1 980 | 0.5% | -2 490 | 0.6% | -3 400 | 0.9% |
| | Biomass | 30 | 0.0% | 40 | 0.0% | 90 | 0.0% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

United Kingdom

Meeting the GHG target in the *40% Scenario* will require moderate total costs in the United Kingdom of €3.9bn (0.2% GDP). This cost is equivalent to a reduction in the 2014-2030 GDP growth rate of 0.01 pp/year.

The UK remains a net buyer of EUA permits between 2020 and 2030.

The UK will remain a net importer of both fossil fuels and biomass under the GHG scenarios considered, with overall shares staying relatively stable at 80% and 20%, respectively. Net imports of fossil fuels reach €27bn in 2030, an increase of almost 40% over 2020. This cost can be cut by €4bn if a stronger emissions target of 50% is adopted, mainly from decreases in oil imports.

A strong climate target also leads to less reliance on coal power to the benefit of renewable sources of electricity. The decrease in coal power generation also contributes to benefits from avoided health costs from improved air quality of €0.9bn-€2.6bn in 2030.

Increases to renewables capacities (solar PV and wind) help with decarbonisation of the power sector. Additional biomass use between 2020 and 2030 will be primarily in the building sector, with little additional biofuel consumption beyond the 2020 level. Meeting a RES burden share of 27% will require a renewables subsidy between 2020 and 2030 with an annual cost of €2.4bn (0.1% GDP) in 2030.

| In 2030 | | 40% GHG | % GDP | 40% GHG + 30% RES | % GDP | 50% GHG (10% credits) | % GDP |
|--|--------------|---------|-------|-------------------------|-------|-----------------------------|-------|
| Total cost vs. Ref, €m | | 3 890 | 0.2% | 5 220 | 0.2% | 8 760 | 0.4% |
| Average health cost vs. Ref, €m (not captured in total costs)* | | -1 760 | 0.1% | -1 200 | 0.0% | -2 560 | 0.1% |
| Energy import bill vs. Ref, €m (captured in total costs)** | Fossil fuels | -6 810 | 0.3% | -6 660 | 0.3% | -10 670 | 0.4% |
| | Biomass | 640 | 0.0% | 820 | 0.0% | 920 | 0.0% |

* Avoided health costs are not accounted for in the total cost, and so provide an offsetting benefit from reduced local air pollutants.

** While reduced fossil fuel use is captured in the total cost, the change in the energy import bill illustrates the potential for wider macroeconomic and energy security benefits not captured in the total cost.

Annex 1 – Illustrative Renewable Energy Burden Shares

| | Country 2030 Renewable Energy Target |
|----------------|---|
| Austria | 45% |
| Belgium | 23% |
| Bulgaria | 23% |
| Croatia | 27% |
| Cyprus | 22% |
| Czech Republic | 21% |
| Denmark | 42% |
| Estonia | 31% |
| Finland | 49% |
| France | 33% |
| Germany | 30% |
| Greece | 28% |
| Hungary | 20% |
| Ireland | 27% |
| Italy | 28% |
| Latvia | 51% |
| Lithuania | 30% |
| Luxembourg | 23% |
| Malta | 22% |
| Netherlands | 24% |
| Poland | 22% |
| Portugal | 39% |
| Romania | 32% |
| Slovakia | 21% |
| Slovenia | 34% |
| Spain | 28% |
| Sweden | 60% |
| UK | 27% |
| EU28 | 30% |

Annex 2 – Non-traded sectors Burden Shares

| | NTS Targets (vs. 2005 GHG emissions) | | | | |
|----------------|--------------------------------------|---------------------------|---------------------------|---------------------------------------|--|
| | 40% GHG target overall | 50% GHG target overall | 60% GHG target overall | 40% target, alternate Burden Share | 40% target, 5 percentage points less effort via the NTS |
| Austria | -38% | -48% | -58% | -42% | -31% |
| Belgium | -36% | -46% | -56% | -39% | -32% |
| Bulgaria | -1% | -11% | -21% | 12% | 9% |
| Croatia | -7% | -17% | -27% | 1% | -1% |
| Cyprus | -23% | -33% | -43% | -19% | -20% |
| Czech Republic | -13% | -23% | -33% | -6% | -7% |
| Denmark | -41% | -51% | -61% | -48% | -31% |
| Estonia | -10% | -20% | -30% | -1% | -3% |
| Finland | -37% | -47% | -57% | -41% | -31% |
| France | -35% | -45% | -55% | -37% | -32% |
| Germany | -36% | -46% | -56% | -40% | -31% |
| Greece | -19% | -29% | -39% | -14% | -15% |
| Hungary | -9% | -19% | -29% | 0% | -2% |
| Ireland | -41% | -51% | -61% | -48% | -31% |
| Italy | -32% | -41% | -51% | -32% | -32% |
| Latvia | -6% | -16% | -26% | 5% | 3% |
| Lithuania | -8% | -18% | -28% | 2% | 0% |
| Luxembourg | -41% | -51% | -61% | -48% | -31% |
| Malta | -17% | -27% | -37% | -10% | -12% |
| Netherlands | -38% | -48% | -58% | -43% | -31% |
| Poland | -9% | -19% | -29% | 1% | -1% |
| Portugal | -18% | -28% | -38% | -12% | -13% |
| Romania | -2% | -12% | -22% | 10% | 8% |
| Slovakia | -10% | -20% | -30% | -1% | -3% |
| Slovenia | -19% | -29% | -39% | -14% | -15% |
| Spain | -28% | -37% | -47% | -26% | -26% |
| Sweden | -40% | -50% | -60% | -46% | -31% |
| UK | -37% | -47% | -57% | -40% | -31% |
| EU28 | -30% | -40% | -50% | -30% | -25% |