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Enabling the Energy Union

D7.2 | Working Paper describing the scenarios and the implications of the scenarios for Energy Union

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Authors:	Sachin A. Babbar, Stijn Van Hummelen, Jon Stenning, Jamie Pirie, Pim Vercoulen, Matteo Caspani (CE), Enikő Kácsor, László Szabó, András Mezősi, Adrienn Selei, Péter Kotek (REKK)
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Coordinators:	Silvia Gaggi and Stefano Proietti (ISINNOVA)
E-mail:	sgaggi@isinnova.org sproietti@isinnova.org

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1 Introduction

The focus of this report is to assess the role households can play in meeting the goals of the Energy Union and analyse the wider economic implications in doing so. Through the development of scenarios that explore policy futures targeted at influencing energy-consuming behaviour of households, the aim is to help policy makers understand the consequences of possible transitions and equip them with a level of foresight of potential hurdles.

The Energy Union was created to bring together a range of decarbonisation and energy policies into a coherent framework. Central to the Energy Union objective is to ensure secure, affordable and sustainable energy for all citizens. The framework of the Energy Union is comprised of five pillars:

1. Energy security, solidarity and trust
2. A fully integrated internal energy market
3. Energy efficiency contributing to moderation of demand
4. Decarbonising the economy
5. Research, innovation and competitiveness

It is within this framework of pillars that specific energy-climate targets and actions for the Energy Union are being defined and revised. In 2014, the European leaders agreed to the 2030 strategy, setting targets around GHG emission reductions (40% compared to 1990 levels), energy efficiency and the share of renewable energy in final energy consumption. The targets for energy efficiency and the share of renewable energy in final energy consumption were revised upwards (i.e. made more ambitious) in 2018 as part of the Clean Energy Package, setting the target to have at least 32% of renewable energy in gross final energy consumption by 2030 and improving energy efficiency by at least 32.5%.

To better understand the policies needed to *enable* households to contribute to the goals and targets of the Energy Union, numerous participatory foresight workshops with households and experts were held as part of the participatory foresight process (WP6) of the ENABLE.EU project. The aim of these workshops was to set out the potential policy landscape required to transform the household sectors from their current status into one that is ready to utilise more clean energy, through behavioural change and the deployment of alternative technologies allowing households to reduce consumption of fossil fuels and increase consumption of clean energy.

Policy recommendations from the participatory foresight workshops (WP6) were generated for three areas of household energy use: 'Prosumption' (i.e. rooftop solar PV), 'Energy Consumption and Saving' (i.e. heating and cooling) and 'Sustainable Mobility'. In general terms, the recommended policy landscape was similar across the areas of household energy use:

- Incentives, such as subsidies, are required to make the desired technology cheaper, either directly (subsidising the purchase) or through encouraging research and development;
- Education and awareness are needed to enable households to make better energy choices and generally be more informed about the market. This is because household awareness of renewable technologies and fuel-efficiency measures is generally lacking, particularly around installing solar PV and the regulatory hurdles potential buyers need to go through.

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- Disincentives are needed to discourage polluting technologies, either through market-based instruments such as higher fuel taxes or outright bans (i.e. phase out of polluting technologies by preventing new sales) and scrappage schemes to encourage the disposal of existing stock;
- Mandating energy efficiency standards in new technologies and solar PV for new houses;
- Supporting the role of communities, i.e. setting up energy communities through information provision and grants.

Furthermore, the participatory foresight process (WP6) also suggested targets for 2050 to help define the long-term vision of the European Union to achieve carbon neutrality by 2050. However, these suggested targets for the ENABLE.EU scenarios only relate to household energy consumption and production, while economy-wide carbon neutrality will inevitably require significant changes to industry. While the latter is not the focus of this report, this report tries to give a better sense of what an ambitious transition in the household sector might look like and require in terms of policy investments.

The scenarios presented in this report are informed by the policy recommendations and suggested targets delivered in the participatory foresight exercises and assessed using quantitative modelling. The scenarios explore the implication of changing energy consuming behaviour in the various areas of household energy use and compare the outcomes with the binding targets of the Energy Union / Clean Energy Package using a combination of bottom up technology diffusion models, a global macroeconomic model and dispatch models. The quantitative modelling was undertaken by Cambridge Econometrics (CE) and the Regional Centre for Energy Policy Research (REKK).

Section 2 of this report presents the modelling framework that was used for the scenario modelling, including a short description the models and how they are linked. Section 3 describes the scenarios that were constructed, based on outputs from the participatory foresight process (WP6). Section 4 presents the results for the different scenarios and assess them against the energy-climate targets of the Energy Union. Section 5 offers concluding remarks and key policy recommendations.

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2 Modelling framework

The modelling framework that has been developed for ENABLE.EU includes 7 different models in order to cover the different energy services and activities being investigated in the project. This entails four technology diffusion models (applied by CE), one macroeconomic model (applied by CE) and two dispatch models (applied by REKK), softly linked to gain the results for the modelled period: 2020 to 2050. When linked together, these models provide a unique modelling framework to assess many of the impacts changing household behaviour can have on the EU's economy and the environment in the future.

The subsections below provide a general overview of the modelling framework and an introduction to the models. More detailed information on the models can be found in 'D7.1 of the ENABLE.EU project ('A working paper detailing the model development')[1].

2.1 Modelling the diffusion of technology in the household sectors

The approach focuses in the first instance on modelling the take up of specific technologies in the various household sectors: mobility, heating & cooling, and prosumption (i.e. solar PV). Diffusion models simulate the decision-making process of investors/consumers wanting to invest in new technology but face a number of different decisions and constraints.

The **FTT:Transport** model, developed by Mercure and Lam (2018), projects future shares of vehicle types, ranging from conventional ICEs to electric vehicles. The model captures the decisions of households, in terms of their choice between an array of available technologies. This is done by making pairwise comparisons of technologies, which is conceptually similar to a binary logit model. Technology comparisons are done on the basis of the Levelised Cost of Transportation[2]. The LCOT of each vehicle type can be influenced by government policy, to aid the penetration of certain vehicles types into the stock, and/or restrict vehicle types from being purchased. FTT:Transport focuses on the private passenger vehicle market only. It includes 25 different vehicle options[3]. The model calculates the market share of each technology and engine size to meet a projection of private LDV passenger-km (i.e. the total demand for passenger car transport) for 61 countries, including all 28 EU Member States, up to 2050. The outputs of the model include the market share of vehicle technology type and engine size, energy demand and the associated tailpipe CO_2 emissions.

The **FTT:Heat** model has a similar decision-making core to that of FTT:Transport. This model projects forward the deployment of an array of heating technologies for dwellings. There are 13 heating technologies, ranging from traditional wood-burning stoves to modern heat

[1] D7.1 of the Enable.EU project ('A working paper detailing the model development') reflects the planned model developments and intended methodology for linking the models. Please note that, due to technical constraints, changes may have been made to the methodology and assumptions throughout the project implementation.

[2] Levelized Cost of Transportation (LCOT) is a similar approach to the existing framework Levelized Cost of Electricity (LCOE) which is used by industry to compare costs between technologies. LCOT captures the capital cost, operating and maintenance cost, fuel cost, carbon costs associated with emissions and a discount rate.

[3] There are seven different technology types for 4-wheelers and two different technology types for 2-wheelers. These are further segmented by engine size: economy, medium and luxury to represent the greater product variation in the private passenger vehicle market.

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pumps, each with individual characteristics in terms of costs, energy consumption, and emissions. Consumer decisions relating to heating technology = purchases depend on the Levelized Cost of Heating (LCOH) and relevant government policy.

The **Residential Prosumer Model**, initially developed by Cambridge Econometrics as part of the *Study on Residential Prosumers in the European Energy Union* (Gfk, 2017), simulates the take up of rooftop solar PV in each Member States in each year to 2050. The take up of solar PV is expressed in solar PV capacity (MW); the equivalent generation is also reported. The model also reports the proportion of technical potential capacity that is taken up and the number of households that are prosumers, as well as the payback period for the mean household, expressed in years.

The decision by households to purchase solar PV is based on the comparison of two groups of factors: monetary and non-monetary. Monetary factors include the potential revenue (feed-in tariffs, net-metering and energy bill savings) from solar PV minus the costs (capital cost, interest rates, installation, and operation and maintenance). Non-monetary factors cover consumers preference for solar PV. When conditions attributed to both of these sets of factors are met, households are assumed to invest in solar PV. In other words, the purchase of solar PV must be cost effective and attractive for the household in order for them to invest. The household would not invest if their preferences mean the investment is unattractive (non-monetary), even if the purchase of solar PV is cost effective (monetary). Over time, costs and consumer preferences shift; and if conditions are favourable there will be a higher diffusion of solar PV.

The **Residential Cooling Model** was newly developed for the ENABLE.EU project to project the energy demand for air conditioning (AC) units. The methodology to determine the energy demand for cooling from AC units is based on a methodology by Isaac and van Vuuren (2009) in their paper *Modelling global residential sector energy demand for heating and air conditioning in the context of climate change*. The diffusion of AC units is based on the income per capita and the demand for energy is based on the number of cooling degree days in a given year. The full methodology, policy levers and the assumptions of the Residential Cooling Model can be found in Annex 7.2. Note that the model only considers one technology: conventional electric air conditioning units, and does not include evaporative air conditioning, fans and use of natural gas.

2.2 Modelling the impacts on the wider economy

The take up of solar PV, renewable heating technologies and electric vehicles by households leads to changes in energy consumption, a reduction in greenhouse gas emissions and changes in consumer spending. Each of the diffusion models produces outputs for these indicators, through which the impacts of changes on the wider economy are analysed for all EU Member States. This is done by linking the results from the technology diffusion models with Cambridge Econometrics' macroeconomic model E3ME.

E3ME is a global, macro-econometric model with a high level of disaggregation, enabling detailed analysis of sectoral and country-level effects from a wide range of scenarios. E3ME is defined at Member State level and incorporates two-way linkages between the economy, wider society and the environment (energy consumption, emissions and material consumption). This means that the model is well suited to address national and EU-wide economy and economy-environmental policy challenges (Cambridge Econometrics, 2019).

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Developed and expanded over the last 25 years, it is one of the most advanced models of its type today. Its main strengths are:

- A high level of disaggregation, enabling detailed analysis of sectoral and country-level effects from a wide range of scenarios.
- An econometric specification that addresses concerns about conventional macroeconomic models and provides a strong empirical basis for analysis.
- Integrated treatment of the world's economies, energy systems, emissions and material demand. This enables E3ME to capture two-way linkages and feedbacks between each of these components.

E3ME extends economic analysis to include physical environmental impacts (energy consumption, emissions and material consumption). The current version of the model has the following dimensions:

- 61 regions – all major world economies (i.e. G20), the EU28 and candidate countries plus other countries' economies grouped
- 70/43 industry sectors, based on standard international classifications
- 28 categories of household expenditure
- 22 different users of 12 different fuel types
- 14 types of airborne emissions (where data are available) including the six greenhouse gases monitored under the Kyoto protocol66

The structure of E3ME is based on the system of national accounts, with further two-way linkages to energy demand and environmental emissions. The labour market is also covered in detail, including both voluntary and involuntary unemployment. In total there are 33 sets of econometrically estimated equations, also including the components of GDP (consumption, investment, international trade), prices, energy demand and materials demand. Each equation set is disaggregated by country and by sector. E3ME's historical database covers the period 1970-2016 and the model projects forward annually to 2050. The main data sources are Eurostat, the OECD (both the National Accounts section and STAN), World Bank, UN, IMF and ILO, supplemented by data from national sources. Energy and emissions data are sourced from the IEA and EDGAR. Gaps in the data are estimated using customised software algorithms.

E3ME can produce endogenous projections for a range of economic, energy and environment indicators. The following list provides a summary of the most common model outputs:

- GDP and its aggregate components (household expenditure, investment, government expenditure and international trade)
- Sectoral output and Gross Value Added (GVA), prices, trade and competitiveness effects
- International trade (imports and exports) by sector, origin and destination
- Consumer prices and expenditures
- Sectoral employment, unemployment, sectoral wage rates and labour supply
- Energy demand, by sector and by fuel, energy prices
- CO_2 emissions by sector and by fuel
- Other air-borne emissions
- Material demands

For a model detail explanation of the E3ME model please see the full model manual available online from www.e3me.com.

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2.3 Modelling the impact on the power and gas markets

The changes in energy consumption resulting from the diffusion of advanced technologies and their associated economic impacts also affect the energy system and the power sector in particular. The impact on the EU's electricity and gas markets are modelled using REKK's dispatch models - the European Electricity Market Model (EEMM) and European Gas Market Model (EEGM), covering the impact on prices, quantities, and emissions. Both the change in the quantity of consumption and the pattern of consumption can have significant impacts on system operation and performance. Changes can take place in many directions: while energy-savings would reduce the overall energy consumption, electric mobility on the other hand would increase electricity consumption, with the possibility of even higher volatility in hourly consumption patterns.

The **European Gas Market Model (EEGM)** is a dynamic partial equilibrium model of the European gas sector. The model assumes perfect competition constrained by long-term supply contracts. The model covers the EU28, the EnC contracting parties, Turkey and the Caucasus. The global market is represented by a simplified LNG market module. Input data for the model are the country-level demand, production, capacities of the natural gas infrastructure (interconnectors, storage facilities and LNG terminals), as well as long-term contracts. Given the input data, the model calculates a dynamic competitive market equilibrium and returns the market clearing prices, along with the production, consumption and trading quantities, storage utilization decisions and long-term contract deliveries.

Model calculations refer to 12 consecutive months. Dynamic connections between months are introduced by the operation of gas storages ("you can only withdraw what you have injected previously") and TOP constraints (minimum and maximum deliveries are calculated over the entire 12-month period, enabling contractual "make-up" within the year). Consumers are represented with a downward sloping demand curve, unique for each country. Monthly distribution of the consumption is based on historical natural gas use of the respective country. Producers located in the modelled countries are considered to be the cheapest source of supply. Supply makes up an ascending stepwise supply function.

Pipeline interconnectors are directional, but physical reverse flow can be allowed for by adding a parallel connection that "points" in the other direction. Each linkage has a minimum and a maximum monthly transmission capacity, as well as a proportional transmission fee. Virtual reverse flow ("backhaul") on unidirectional pipelines or LNG routes can also be allowed. Storage is capable of storing natural gas from one period to another, arbitraging away large market price differences across periods. LNG infrastructure consist of LNG liquefaction plants of exporting countries, LNG regasification plants of importing countries and the "virtual pipelines" connecting them, which are needed to define for each possible transport route a specific transport price.

Spot trade serves to arbitrage price differences across markets that are connected with a pipeline or an LNG route. Spot trading continues until either (1) the price difference drops to the level of the transmission fee, or (2) the physical capacity of the connection is reached. LTC contracts have monthly and yearly minimum and maximum quantities, a delivery price, a point of delivery and a monthly proportional TOP-violation penalty. The delivery routes (the set of pipelines from source to destination) must be specified as input data for each contract.

The optimisation algorithm reads the input data and searches for the simultaneous supply-

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demand equilibrium (including storage stock changes and net imports) of all local markets in all months, respecting all the constraints detailed above. In short, the equilibrium state (the "result") of the model can be described by a simple no-arbitrage condition across space and time[4]. However, it is instructive to spell out this condition in terms of the behaviour of market participants: consumers, producers and traders.[5]

The **European Electricity Market Model (EEMM)** is a partial equilibrium microeconomic model of the EU electricity sector, assuming perfect competition in all modelled electricity markets. In the model, electricity generation as well as cross-border capacities are allocated on a market basis; no gaming or capacity withholding is assumed. This means that the cheapest available generation unit is used, and if imports are cheaper than producing electricity domestically, demand is satisfied from imports. Both production and trade are constrained by the available installed capacity and net transfer capacity (NTC) of cross-border transmission networks respectively. Due to these capacity constraints, prices across borders are not always equalised. Three types of market participants are included in the model: producers, consumers, and traders. In line with the assumption of perfect competition all behave in a price-taking manner: they take the prevailing market price as given and assume that their actions have a negligible effect on this price.

There are 38 countries (41 markets) modelled in EEMM: in these countries, prices are derived from the demand-supply balance, while in external markets (e.g. Russia, Belarus) exogenous prices are assumed. The EEMM models 3400 power plant units operated with 12 different fuels: natural gas, coal, lignite, heavy fuel oil (HFO), light fuel oil (LFO), nuclear, biomass, geothermal, hydro, wind, solar and tide and wave. Each plant has a specific marginal cost of production, which is constant at the unit level. In addition, generation capacity is constrained at the level of available capacity. Power flow is ensured by 104 interconnectors between the countries. Each country is treated as a single node; thus no domestic power system constraint is assumed. NTC values are used to indicate trading possibilities, seasonal differences are included in the modelling based on historical data from ENTSO-E Transparency Platform. Future investments are assumed based on data from ENTSO-E's latest Ten-Year Network Development Plan (TYNDP).

Consumers are represented in the model in an aggregated way: one downward sloping linear demand curve is assumed for each modelled market. Traders connect the production and consumption sides of a market, through exporting electricity to more expensive countries from cheaper ones. The EEMM models hourly markets; 90 representative hours are modelled for each year, independently. These hours cover yearly and daily variations in electricity demand and in renewable generation. This way the impact of volatility in the generation of intermittent RES technologies on wholesale price levels are captured by the model, despite the fact that no stochastic approach is used. The model is conservative with respect to technological developments, and thus no significant technological breakthrough is assumed (e.g. battery storage, fusion, etc.), however, demand side management (DSM) and carbon capture and storage (CCS) is included.

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[4] There is one rather subtle type of arbitrage which is treated as an externality, and hence not eliminated in the model. We assume that whenever long-term TOP contracts are (fully or partially) linked to an internal market price (such as the spot price in the Netherlands), the actors influencing that spot price have no regard to the effect of their behaviour on the pricing of the TOP contract. In particular, reference market prices are not distorted downwards in order to cut the cost of long-term gas supplies from outside countries.

[5] We leave out transmission system operators and storage operators, since tariffs are set exogenously, and the usage of infrastructure is set by traders.

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Taking into account the short-term marginal cost for all available power plant units merit order curves are calculated for each market. With the demand curve and the constraints on international trade all input parameters are set. After that, the model maximises the European welfare (sum of producer and consumer surpluses). The model provides the equilibrium (wholesale) electricity prices for each market, the trade on each interconnector and the production of each power plant unit as output.

The following outputs from E3ME are used by EGMM and EEMM models: natural gas consumption (by year and by country, aggregated), year on year electricity consumption growth (by country) and year on year changes in installed capacities of renewable electricity generation units (by country and by technology). From the received yearly aggregated natural gas consumption data monthly levels are generated in EGMM, using assumptions based on historical data on the yearly distribution of consumption in each modelled country. This is used to gain the results on wholesale gas prices and total consumer expenditure on natural gas. Changes on import dependency are also calculated from the results of EGMM.

The modelled natural gas wholesale prices, differentiated by country and by year are then fed into EEMM, together with the above-mentioned outputs from E3ME (electricity consumption growth and data on renewable penetration). EEMM then calculates the optimal block level production for all units included in the model and the equilibrium wholesale electricity prices in all modelled countries up to 2050. From this, several additional indicators can be calculated, such as CO_2 intensity of electricity generation, total natural gas consumption of the power sector or RES-E share in the EU and in the different regions.

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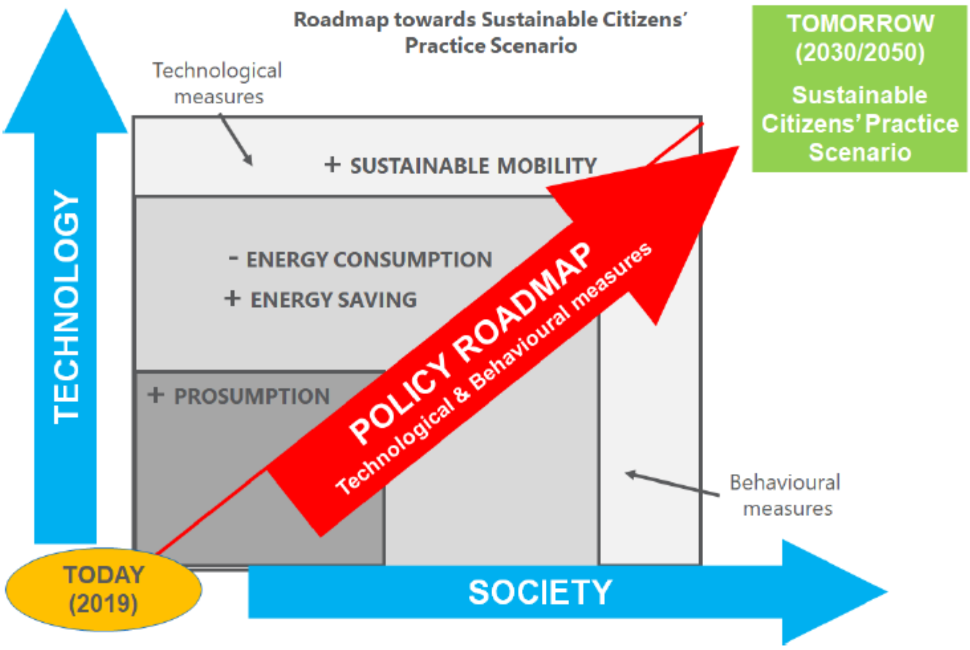
3 Scenarios

This section sets out the narratives and targets (where applicable) of the scenarios that have been assessed for ENABLE.EU. A set of scenarios has been created to project a world where ambitious policies enable the different aspects of household energy use (mobility, energy consumption, and energy production) to transition towards technologies and practices which reduce the consumption of fossil fuels by households and reduce the impact on climate change. More specifically, to assess the energy and emissions savings that can be generated at home, and what the potential economic impact could be.

Each of the scenarios contains a package of ambitious policy measures intended to influence household behaviour, involving carbon pricing, subsidies, feed-in tariffs, energy efficiency improvements and direct regulation. The policies are introduced to influence household decisions around energy use and production. The policy packages have been informed by the outcomes from the participatory foresight process (WP6), which collated the views of experts and households to understand what regulatory framework should be in place to enable an ambitious citizens' driven transition.

Figure 3.1: The ENABLE.EU roadmap to the Sustainable Citizens Practice Scenario (SCP)



Source: Proietti S. et. al. (2019) 'Transition Practice Framework Workshop Report', Enable.EU

In the Roadmap towards the Sustainable Citizens Practice (SCP) Scenario envisaged by the participatory foresight process (WP6) (Figure 3.1), policy measures are split into two distinct categories which can help the Energy Union goals to be achieved: technology measures, such as investing in an electric vehicle, and behavioural measures, such as influencing how often you use a vehicle, if at all. The policy roadmap envisaged by the participatory foresight process (WP6) is a combination of these measures.

The policy measures retained in the policy packages of the scenarios are a selection of the measures put forward by the participatory foresight process (WP6), made by the modelling team on the basis of the following criteria;

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- Technical feasibility: whether a policy measure can be translated into model inputs and thus assessed within the modelling framework that has been developed for ENABLE.EU. It is not technically feasible to implement all the recommended policies in the models.
- Importance: those measures identified in 'D6.3 Transition Practice Workshop Report' (Annex II in particular)[6] as important drivers of changing household behaviour were prioritised.

A detailed overview of the policy packages is provided in Annex 1. Most of the policies are introduced as percentage changes, and thus reflect the different starting points that exist in different Member States, but it was not within scope to tailor the policy packages to the political context or assess the political feasibility of the policy package in each Member State. Rather, the scenarios are designed to kick-start and realise an ambitious transition in the household sector that is technically and economically feasible, while not making any judgement about the political feasibility of the policy packages in a given country. In other words, the scenarios are designed to meet a certain target and the policies determined in function of that, rather than to assess how far a politically feasible policy package would get towards the Energy Union goals.

Policies are introduced from 2020 onwards. Policy packages are specific to the household sector and do not introduce economy-wide measures nor measures targeted at other sectors (i.e. the power sector and other industries). The scenarios should thus be seen as possible future developments for household energy use (mobility, heating & cooling, prosumers) while mostly ignoring possible future developments in other sectors of the economy.

The modelling is developed through four policy-based scenarios. In the first instance, the policy packages are introduced to i) road transport/mobility, ii) heating & cooling and iii) household solar PV separately and in isolation. Finally, the policy packages are brought together in a combined scenario in order to assess the changes for the household sector overall, i.e. the extent to which these policies move Europe onto a pathway consistent with the EU targets. Scenario results are presented for the combined EU28 in this report.

All scenarios assume that there is no change in government balances in the scenario as compared to the baseline; this means that any change to government tax take in the scenario (e.g. higher income tax receipts from higher wages) are balanced through a change in tax rates across the whole economy (e.g. a reduction in the income tax rates). This ensures that there is no more or less government borrowing in any of the scenarios compared to the baseline, and is achieved through adjusting a combination of sales taxes, income taxes and social contributions.

3.1 The Baseline for the analysis

The baseline can broadly be considered as a continuation of current trends for key demographic, economic and energy indicators. Policies implemented by a specific date remain in place and have some lagged effects that continue into the projection period, but there are no policy changes. The baseline is a 'business as usual' (BAU) case and represents what would happen without further policy intervention.

[6] Annex II of 'D6.3 Transition Practice Workshop Report' presents the results of an online survey asking participants to categorise policy measures according to importance.

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Alternative scenarios are designed as policy packages that are added to the baseline in order to demonstrate the potential impact of these policies in terms of demographic, economic and environmental indicators. In other words, the differences in results between the scenarios and the baseline are attributed to the policies being assessed.

Depending on the type of analysis that is performed and the type of model that is used, baseline projections can either be fully endogenous or made consistent with existing projections. In the former case, a projection for a given indicator is explained by the model equations, either stochastic equations or identities, and produced by the model as it solves. In the latter case, projections for a given indicator are produced by another model and taken as inputs. The model is set up to produce projections for other indicators that are consistent.

The modelling framework used for ENABLE.EU is made up of several models and the models are linked together to provide a full evaluation of policy impacts. For example, E3ME is a macro-econometric model and its baseline includes demographic indicators (population growth) and economic indicators (e.g. GDP growth), while the baseline for the FTT:Power model includes projections for energy balances. More detail is provided below.

The baseline scenario does not incorporate the 2030 Energy and Climate policy framework (since these are broad policy goals rather than substantive policies), nor is any new policy introduced after the starting year of the baseline projections unless these policies are represented in exogenous projections used as inputs. This means that the baseline is a projection of trends as if the Clean Energy for All Package is not implemented.

For most indicators included in the baseline for ENABLE.EU, the starting point for projections is 2016 (the last year of history in most available datasets). In the baseline, low-carbon technologies continue to diffuse after the last year of history (due to the nature of the technology diffusion models, and in a way that they would not in many economic models) based upon prevailing market conditions. Nonetheless, the starting point for baseline projections may vary slightly between countries and indicators, depending on the sources of information used.

3.1.1 Demographics

The E3ME baseline projections for demographic indicators are made consistent with the Ageing Report (European Commission, 2018) and Eurostat Europop population projections for EU regions[7]. For regions outside of the EU, the UN population projection from the "World Population Prospects: The 2017 Revision" (United Nations, 2017) report is used. As in the Eurostat report, demographic features of population ageing, fertility and life expectancy are accounted for.

A more detailed description of the historical data, key assumptions and mechanics of the E3ME model can be found in deliverable D7.1 for the ENABLE.EU project (Cambridge Econometrics , 2018) or on the E3ME website[8].

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7 https://ec.europa.eu/eurostat/web/population-demography-migration-projections/population-projections-data

8 https://www.e3me.com/

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3.1.2 GDP and labour markets

For EU regions, GDP projections are consistent with the AMECO 2017 release[9] in the short-term and with the EU Reference Scenario 2016 (European Commission, 2016) in the long term. Gross value added (GVA) is disaggregated by sector to be in line with the EU Reference Scenario assumptions. For non-EU regions GDP assumptions from the IEA World Energy Outlook 2016 (International Energy Agency, 2016) have been used.

EU sectoral employment projections are consistent with CEDEFOP's latest projections created by Cambridge Econometrics (projection reference E3ME 6.1 C174 from January 2018) under the framework contract 201 6-FWC4/AO/DSLJVKVET/skills forecasts/00 1/16.

A more detailed description of the historical data, key assumptions and mechanics of the E3ME model can be found in deliverable D7.1 for the ENABLE.EU project (Cambridge Econometrics , 2018) or on the E3ME website[10].

3.1.3 Energy

Baseline projections for the power sector are generated endogenously with the FTT:Power model. FTT:Power models the complex dynamics of investor decisions within the power sector, using a novel framework for the dynamic selection and diffusion of energy technologies. FTT:Power determines the share of technologies in each country for a given scenario depending on implemented policies.

The baseline is a projection without any introduced policy. FTT:Power projects forward from 2012, but to reflect the most recent trends in generation capacities for the different technologies, the baseline was calibrated to 2012-2016 data on generation capacities from Eurostat.

Changes in the power technology mix result in changes of production costs, reflected in the price of electricity. In line with the projected mix of technologies, FTT:Power produces aggregate outputs such as power generation investment, fiscal adjustment for subsidies, demand for other fuels and power generation CO_2 emissions.

Baseline projections for the prices of fossil fuels (coal, oil and gas) are based on the IEA World Energy Outlook 2016 (International Energy Agency, 2016) Current Policies Scenario.

Baseline carbon prices are based on the EU Reference Scenario 2016 (European Commission, 2016) .

3.1.4 Emissions

Historical GHG emissions data is taken from the EDGAR – Emissions Database for Global Atmospheric Research[11]. The EDGAR emissions data are calculated based on the energy balance statistics of IEA (2010)[12].

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9 https://ec.europa.eu/info/business-economy-euro/indicators-statistics/economic-databases/macro-economic-database-ameco_en

10 https://www.e3me.com/

11 https://edgar.jrc.ec.europa.eu/

12 http://www.oecd-ilibrary.org/energy/co2-emissions-from-fuel-combustion-2010_9789264096134-en

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In the baseline and other scenarios, GHG emissions are projected forward using the disaggregation of E3ME and based on emissions coefficients for each fuel and fuel user derived from historical data and fuel demand for each fuel and fuel user.

3.1.5 Household solar PV

The baseline projection for installed capacity of household solar PV without further policy intervention is produced by the Residential Prosumer Model.

There are a series of input projections used in the model; population, the number of households per country and electricity prices. Baseline population levels and the number of households for the EU28 are made consistent with Eurostat Europop 2017 population projections[13]. Electricity prices in each country are set to grow in line with projections from the EU Reference Scenario 2016 (European Commission, 2016).

Historical data for key variables (i.e. the cumulative solar PV installed capacity, the electricity prices for median households, borrowing costs, solar PV load factors, current residential solar PV installed capacity and CAPEX costs) are used up to 2018, using a combination of EU data sources (e.g. Eurostat) and national data sources. Historic data on public policies to foster the take-up of solar PV in the residential sector are updated to 2018 for all modelled countries.

Load factors are estimated using the latest Eurostat data (2016) on solar PV installed capacity and generation, and then kept constant over the projection period. Where data was not available for a specific country, the load factor for a country at the same latitude was used as a proxy.

A more detailed description of the historical and projected data used for the Residential Prosumer Model can be found in Annex 7.3. A more detailed description of the mechanics of the model are described in deliverable D7.1 for the ENABLE.EU project (Cambridge Econometrics , 2018).

3.1.6 Road transport

The baseline projections for the deployment of passenger vehicles without further policy intervention is produced endogenously by the FTT:Transport model. In the baseline scenario, exogenous data for future demand for vehicle transportation (Mveh-km) and future sales is used as an input into the model and sourced from Euromonitor International (2012) and MarkLines global sales data (2014) respectively. This, along with the assumption on the survival rate[14], are used to derive the fleet size.

A more detailed description of the historical data, key assumptions and mechanics of the

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

[14] Vehicles from the fleet are scrapped according to a survival function which are first sourced from the literature, and if not available, they are constructed by determining a survival function for the UK (using data obtained from DVLA (2012b) and then adjusting it with country specific data of total sales and stocks (from Euromonitor International, 2012). For more details on the survival function please see Mercure & Lam (2018).

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FTT:Transport model can be found in in deliverable D7.1 for the ENABLE.EU project (Cambridge Econometrics , 2018).

3.1.7 Heating and cooling

The baseline projection for the deployment of heating technologies without further policy intervention is produced endogenously by the FTT:Heat model[15]. This is calculated from a starting point of useful energy demand for heat, whichis an exogenous input to the FTT:Heat model. For ENABLE.EU, the projection for heating demand was based on IMAGE-REMG[16] projections (employed by the Netherlands Environmental Assessment Agency) (Daioglou, 2012), which was used for scenario c of Knobloch et al. (2019). The scenario covers three elements: 1) Heat degree day projections under a 1.5 °C scenario; 2) Assumptions on improved insulation (see mitigation scenario SSP2-1.9 of Riahi et al. (2017)); 3) Rapid retrofitting of the existing building stock, expressed as a rapid convergence of the heating intensity to 45 $kJ_{UE}/m^2/HDD$ in 2050. Currently, the heating intensity ranges between 50 to 150 $kJ_{UE}/m^2/HDD$. Compared to scenario a of Kobloch et al. (2019) (which only covers aspect 1 of scenario c), the heat demand in 2050 for Western Europe decreases by approximately 29%. For Central and Eastern Europe, the heat demand decreases by approximately 14% overall.

A more detailed description of the historical data, key assumptions and mechanics of the FTT:Heat model can be found in in deliverable D7.1 for the ENABLE.EU project (Cambridge Econometrics , 2018).

There is no separate treatment to determine the level of cooling demand directly in FTT:Heat. Instead, baseline demand for cooling is produced endogenously by the E3ME model as part of the calculation of total household energy demand. Total household energy consumption is a function of consumers' expenditure – higher expenditure results in greater household energy consumption, within limits[17]. In order to include efficiency improvements for cooling, a separate model was developed to project energy savings, which were exogenously added in to E3ME. A more detailed description of the Residential Cooling Model can be found in Annex 7.2of this report.

3.2 Prosumption Scenario

The target set forth by the participatory foresight process (WP6) is to achieve an ambitious democratisation of electricity production for household consumption, driven primarily by an ambitious deployment of rooftop solar PV across the EU. In the prosumption scenario, solar PV is deployed across the EU at levels close to its full technical potential (see Annex 7.3.3 for more detail). This means that – where possible – solar panels have to be installed by households. However, a mixture of policies is used to encourage such behaviour – not simply regulation. The decision of households to invest in solar PV is driven by a number of factors, and the scenario introduces a policy package that addresses these, consisting of:

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[16] IMAGE-REMG projects both water and space heating. The former is a function of income and converges to a maximum saturation value, which is a function of climate change expressed in the form of heating degree days. Space heating is a function of population, floor area per person, heating degree days, and the useful energy heating intensity (in $kJ_{UE}/m^2/HDD$). The heating intensity converges to a certain level, depending on the assumptions made.

[17] An upper limit is imposed to stop household energy consumption reaching unusually high levels (Cambridge Econometrics, E3ME Technical Manual v6.1, 2019).

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- Feed-in-Tariff
- Green loans
- Subsidies
- Greater provision of information - reduce regulatory barriers to investment
- Improve batteries technology and performance
- Mandatory installation of solar PV in all new buildings

The policies are introduced from 2020 onwards and adjusted for each country depending on the level of policy required to achieve a deployment of solar PV close to full technical potential. Economic incentives such as feed-in-tariffs, green loans and subsidies were introduced into the model to help achieve a higher take up of solar PV. Without these, most households do not find it sufficiently attractive to invest in solar PV. Feed-in-tariffs are assumed in all countries, ranging from €0.05/kWh to €0.75/kWh. Green loans are applied in several countries to reduce the borrowing costs for solar PV installations: a reduction of 1 percentage point was applied to the baseline rate. Subsidies were also applied in some countries: the subsidy was 40%[18] of the CAPEX cost of solar PV.

One of the recommendations made in the participatory foresight process (WP6) is the provision of correct information and assistance from energy advisors to citizens in order to remove any information asymmetry which might exist and prevent the take up of solar PV. It has been discussed in earlier work packages that this information asymmetry may be a potential factor in reducing the take up of solar PV. To reflect an increase in the provision of information the assumptions around the regulatory framework of solar PV have been relaxed. In the model there are three barriers which affect the attractiveness of investment; administrative barriers, permitting requirements, and rules to access the grid[19]. By relaxing these assumptions, we reflect the fact that the households have greater information or sufficient support from energy advisors and will therefore find investing in and using such technology more straightforward.

Improvement in battery technology is an important technological development, as it increases the household's ability to retain its generated electricity rather than feed it back into the grid. Such a household becomes less reliant on the grid and external power generation, as they can store their own electricity and utilise it at a later date. To reflect an improvement in battery technology the rate at which solar PV generated energy is exported to the grid gradually reduces to 5% by 2050.

The last policy included in the prosumption scenario is that the government mandate the deployment of solar PV in all new homes from 2020 onward. House builders and planners are forced to consider the geography (e.g. south facing) so that solar PV can be utilised.

[18] Average of the current available subsidies in EU Member States.

[19] Each policy barrier is assigned either 1,0 or -1 to indicate whether the barrier is high, medium or low, respectively. This is then used to adjust the required rate of return for each country. The required rate of return (measured as a percentage of the total system cost) is the amount the household would need to receive from the solar PV for the investment to be attractive. By relaxing the assumptions around the barriers to enter (i.e. assigning a value of-1), the required rate of return is reduced, which means households require lower returns from the investment and will therefore be more likely to invest.

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3.3 Energy Consumption and Saving Scenario

The target set forth by the participatory foresight process (WP6) for the Energy Consumption and Saving Scenario is that by 2050 there are zero emissions from heating and cooling. This requires a complete switch to renewable forms of heating and more efficient cooling technologies. To achieve this, a number of policies are introduced, informed by the outputs of the participatory foresight process (WP6);

- Subsidies
- Taxes on residential fuel use
- Ban on the use of fossil fuels for heating from 2025
- Government incentives for energy efficiency technologies to reflect investment in education and awareness programmes
- More ambitious efficiency mandates for cooling technologies
- Government mandates for the scrappage of inefficient/fossil fuel boilers
- Public procurement (government installs new technology in the publicly owned housing stock)

Subsidies were recognised as a useful measure in making renewable heating systems more accessible to the population in the participatory workshops as they help reduce the purchase cost of heating systems. The subsidy is assumed to be 50% of the total costs and is introduced in 2020 with a gradual phase out between 2030 and 2050. Disincentive policies are also used to discourage the take up of fossil fuel technologies. Taxes are imposed on each tonne of CO_2 emitted to internalise the negative externalities of pollution; this is to curb the use of energy as well as discourage individuals from investing in new fossil fuel heating system in the future. Further down the line in 2025, more restrictive measures (a ban on new sales of fossil fuel units) are taken to ensure that no new fossil fuel heating units are sold.

As well as economic incentives, the participatory workshops focused on the need for energy awareness and education. To enable take up of energy efficient technologies (e.g. LED lights) more education and awareness is needed. A lack of understanding surrounding these technologies means beneficial investments are likely not to take place. Efforts can be made by government to induce this behaviour such as awareness programs, courses and training. Although it is difficult to model education directly, an increase in educational opportunities is proxied by assuming a level of investment in this technology (paid for by government) and an associated level of energy savings. The values are based on data from the IEA 450 scenario (International Energy Agency, 2015) of investment in energy efficient technology (e.g. more efficient cooking appliances, lighting etc.), albeit with an increase in ambition of 25%.

Policy makers are also assumed to mandate cooling technologies with higher standards of efficiency. This ensures that consumers are purchasing the best available technologies, which will help reduce household energy demand. In the Energy Consumption scenario, the average efficiency of cooling units is increased to match those from the Efficient Cooling Scenario from the Future of Cooling report (International Energy Agency, 2018).

Public procurement measures are assumed in some countries to prompt renewable heating technologies and kick-start their take up over the projected period. In some countries there is no take up of the renewable heating technologies in the historical data, reflecting a situation in which renewable heating technologies are not yet available in the

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marketplace. In these countries, public procurement measures are introduced to facilitate the take up of renewable heating technologies. A small share of 1% of renewable technologies are assumed for those countries without any renewable technology in the recent history to reflect this public procurement. It is assumed that these increases in renewable heating technologies occur in the public housing stock.

A scrappage rate was set to ensure that all existing fossil fuel heating units were removed by 2050.

3.4 Sustainable Mobility Scenario

The target for mobility in the participatory foresight process (WP6) is to reduce tailpipe CO_2 emissions by 80% by 2050 compared to 1990 levels. To meet this an ambitious policy package was designed with specific recommendations from the participatory foresight process (WP6). The recommendations from the participatory foresight process (WP6) included: changing mind-sets, sustainable planning of cities and the provision and enforcement of alternatives to private vehicles. This led to a number of policies which are summarised in the list below:

- Higher taxes on more polluting fuels and vehicles (including aviation)
- Phase out of petrol and diesel ICEs across the EU
- Subsidies for the purchase of electric vehicles
- Public procurement for electric vehicles
- Higher rates of car sharing
- Urban planning to promote cycling and car free zones in cities
- No-emission zones in urban areas
- Subsidies for the use of public transportation

A change in mind-sets is defined as a movement away from traditional vehicles to new technologies – electric vehicles. Whilst it is not possible to directly model a change of mind-sets in the model, it is possible to influence the household's decisions through incentives and a change of regulatory framework. However, currently the total cost of ownership of electric vehicles is comparatively higher compared to the traditional vehicles. Therefore, policy is needed to aid the transition: by making traditional vehicles more costly to purchase and operate, through carbon registration taxes (starting at €90/gCO_2/km in 2020 rising to €135/gCO_2/km) and fuel taxes (starting at €0.1/L in 2020 rising to €1/L in 2050) respectively. These policy inputs were based on previous work by Mercure J-F et al. (2018) to measure the impacts of road transportation to meet climate targets well below 2°C. Making electric vehicles more accessible by introducing subsidies was also included in this scenario package (using a maximum available grant of €3500, broadly based on subsidies currently available in the UK (gov.uk, 2019)). Already, such subsidies are being provided in several countries of the EU (e.g. UK, Belgium) and are having an impact on the total cost of ownership and ultimately take-up rates. In those countries with very low numbers of electric vehicles, the scenario introduces public procurement by governments to kick start the transition to electric vehicles, i.e. the government invests in charging infrastructure and electric vehicles instead of ICE vehicles[20]. A complete ban on sales of petrol and diesel ICEs was introduced in all countries from 2030 in the model onward to support the transition.

[20] From a modelling perspective public procurement is an important measure, because without any shares in the history or first year of the model solution the model will not predict any take up in the future. This reflects the real-world situation that you can only buy goods which are available in the marketplace, it is not possible to buy something which no-one else has/not offered by the market.

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Hybrid vehicles continue to be sold.

Better sustainable planning of cities as a policy measure to reduce the environmental impact of mobility was also recognised as an important measure during workshops carried out in the participatory foresight process (WP6). This is in line with the views of the European Commission who support such measures (European Comission, 2013). The communication by the Commission highlights the need to promote cleaner ways of travelling in cities by switching to low car mobility such as walking or cycling and reducing the use of conventional vehicles. To achieve this, three different measures are considered: car sharing initiatives, car free zones, and no-emission zones.

Car sharing has the potential to help meet the goals of this scenario by reducing the demand for the purchase of vehicles and private passenger transportation demand. For each car sharing vehicle, research suggests that between 5 and 10 vehicles are displaced (Harrison P., 2017), either by selling the vehicle or deferring purchase. Furthermore, since users do not have a vehicle at their convenience constantly, they are forced to become more aware regarding the need for specific trips, and on average reduce their consumption of travel demand (person-km) by such vehicles (Trinomics, 2017), instead opting for other means of transportation, e.g. cycling, public transport. A reduction in the travel demand leads to lower fuel demanded and consequently a reduction in emissions. The impact of car sharing is difficult to estimate, with a great deal of uncertainty. This scenario has been designed based upon previous work for the European Commission *Environmental potential of the collaborative economy* (Trinomics, 2017). In 2030 it is assumed 29 million car sharing users exist across the EU, which equates to reduction in sales of around 7 million (see 7.1.1 for more details) and a reduction in expenditure on the purchase of vehicles of 3%.

Car free zones are another policy measure used in this scenario package which contributes to the sustainable planning of cities. They help to reduce the amount of private passenger travel demand in city centres, reducing emissions and increasing the air quality of densely populated areas. Banning the use of private passenger travel in city centres forces individuals to meet their needs through alternative forms of mobility. In Amsterdam, cycling accounted for 55%[21] of all vehicle trips in 2000. The Dutch capital has introduced policies which have banned the use of vehicles from their city centre and encouraged cycling through funding important infrastructure (e.g. bike lanes and parking facilities) (Buehler R., 2010). This success story is used as a guide for the impacts of this policy measure - to ban vehicles from city centres. It is assumed that 55% of all private passenger urban travel demand goes to cycling and walking in 2050, gradually increasing from 5% in 2020 – reflecting the adoption of policies in smaller cities first. Funds to support the required infrastructure are redirected from funds otherwise used for roads.

Some form of mobility is still required outside of city centres, where typical trip distances are longer, and cycling is less attractive. Therefore, an additional policy is introduced – No-emission zones. No-emission zones are introduced which ban the use of conventional fuelled vehicles in urban areas but allow electric vehicles. This zone is a more ambitious form of the Ultra-Low Emission Zones (ULEZ) operating in London whereby vehicles must meet a certain Euro Standard if they are to enter.

It is important to note that the rise of car free zones reduces the use of car sharing schemes.

[21] This represents the historic city centre, moving out of the inner city, the rates of cycling decline to about 21% in suburban districts.

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Car sharing schemes are most widely used in urban areas, and a ban on vehicle usage in such areas will limit the potential usage of car sharing. The scenario takes this into account and limits the spread of car sharing beyond 2030 – when car free zones begin to take off.

To address the issue of car use outside of urban areas, greater enforcement of alternatives is needed. Rail transportation is highlighted in the participatory foresight process (WP6) as a key service that can reduce such car use, but in order to shift individuals away from road transportation towards rail transportation more investment is needed. The participatory foresight process (WP6) makes explicit references to the need to increase the quality of service through train reliability and comfort. Whilst these measures are important it is not possible to model the change in these soft factors directly. Therefore, in the scenario this has been proxied by introducing a government subsidy to reduce the price of train services, informed by the reduction in prices the Spanish government used to encourage greater usage of the Spanish High Speed Rail (HSR) (Hortelano A-O., 2016). A reduction of 11% in the ticket price is assumed, triggering a rise in demand for rail services consistent with the price elasticity of demand (PED) observed in Spain. This rise in demand is assumed to be substituted away from private travel demand causing a reduction in fuel use and emissions.

Finally, there was also strong feedback from the participants in the participatory foresight process (WP6) that aviation should be better regulated. The scenario imposes a fuel tax on all flights (domestic and international) from 2020 onwards at a rate equal to the current minimum level set out in Energy Tax Directive (2003/96/EC)[22] of €330/m^3. This will help reduce emissions away from aviation as individuals find other forms of transportation, such as rail.

3.5 ENABLE.EU: Sustainable Citizens Practice Scenario

This scenario combines the Prosumption Scenario, Energy Consumption and Savings Scenario and the Sustainable Mobility Scenario into one overarching scenario that reflects the contribution that households can make to the goals of the Energy Union.

The interaction of the different scenarios in one package will have both reinforcing and contrasting effects. The switch to electric mobility and electric heating units will increase the demand for electricity from the grid, while energy efficiency measures in the energy consumption scenario and take up of solar PV from the energy production scenario will reduce the demand for electricity from the grid. In financial terms, the transition within the household sectors will require considerable investments from households and government, but also generate savings in the long term.

The results for the ENABLE.EU scenario - meaning the net impacts on energy consumption and the economy when all the reinforcing and contrasting effects are taken into account – are presented in section 4.2 of this report.

[22] Currently the Energy Directive states that aircraft fuel is exempt from taxation but can be implemented at the discretion of the Member States on domestic and intra-EU flights.

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4 Results

4.1 Sector-specific results

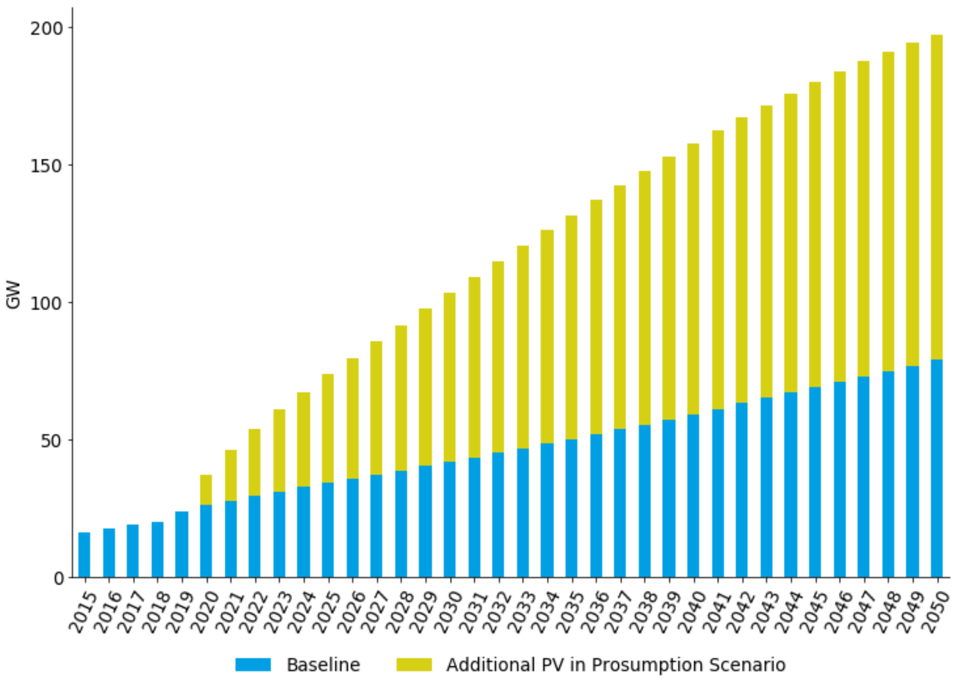
4.1.1 Prosumption Scenario

The Prosumption Scenario creates favourable conditions to aid the take up of solar PV amongst households so that they can produce electricity in addition to demanding it, and thereby alleviate pressures from the grid. This also helps individuals to become increasingly aware of electricity; most electricity is an 'invisible good' which escapes the conscious of individuals (Lindén A., 2006), potentially leading to excess consumption. Through prosumption, households increase their engagement with electricity and thus its 'visibility' increases, which leads to positive change in energy practices (Bergman N., 2011).

The policy package in the Prosumption Scenario makes solar PV investment more attractive, both in terms of cost and non-cost factors (e.g. relaxation in regulation). As well as new builds, which are mandated to include solar PV installations, the policy package enables a substantial rollout of solar PV, reaching of the total technical potential for the EU28 in 2050. This translates to almost 200 GW of total installed capacity. Figure 4.1 shows the profile of additional cumulative capacity of solar PV in the Prosumption Scenario.

The yellow bars in Figure 4.1 below represent the additional cumulative capacity in the Prosumption Scenario in addition to that present in the baseline. For example, in 2030 the total cumulative capacity in the Prosumption Scenario will reach 103 GW – an additional 60 GW from policies in addition to the baseline.

Figure 4.1: Cumulative installed solar PV capacity - EU28:



Alongside this, battery storage technology is projected to improve and the take up of

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batteries in households increases in line with solar PV deployment[23]. This leads to an important trend whereby greater amounts of self-generated electricity are retained and consumed by the households rather than sent back to the grid. This can be seen in Figure 4.2, which shows higher consumption of electricity produced by household from solar PV in total electricity consumption. In the Prosumption Scenario, 18% of electricity consumed by households in 2050 is electricity produced by household from solar PV and 82% is electricity coming from the grid. In the Baseline Scenario, electricity produced by households from solar PV is only 4%.

Figure 4.2: Households' electricity demand, split by source – EU28

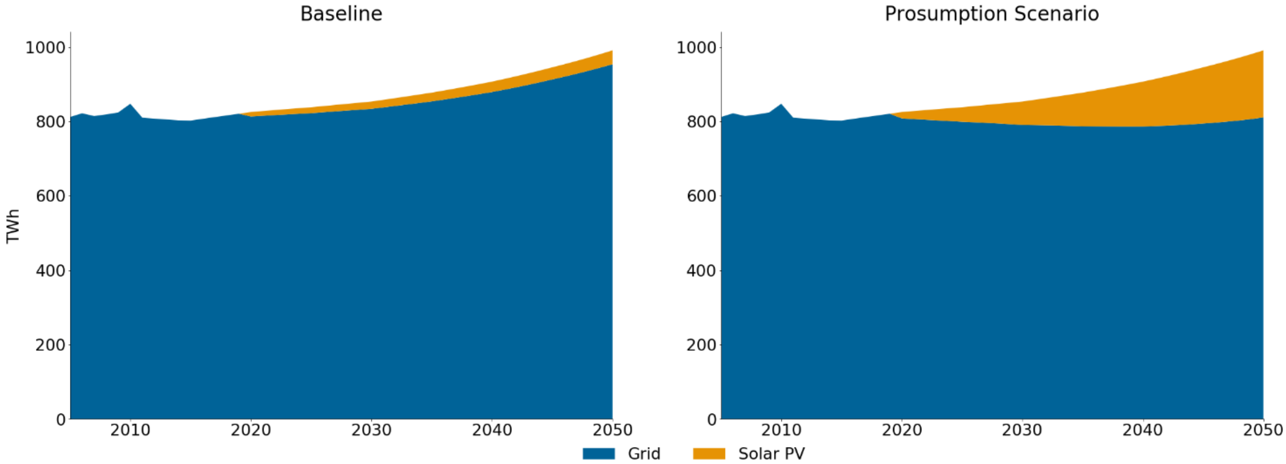

Figure 4.2 shows that the deployment of household solar PV is insufficient to meet all household electricity consumption. Nonetheless, it is sufficient to meet the additional electricity demand from 2020 to 2050. This has substantial implications for the power sector; a reduction in household demand for electricity from the grid would mean that less generation capacity is needed, and investment in the power sector can be reduced.

To meet total household electricity demand just with solar PV, a further 811 TWh is still needed in 2050, which is equivalent to 771 GW[24] of additional solar PV capacity. The current level of solar PV investment modelled in the Prosumption Scenario already covers the majority of roof space, making it hard to meet this target. A larger share of total household electricity demand could only be self-generated if efforts are made to help communities invest in solar PV farms as well as micro grids so that they can produce more electricity and trade it between one another.

It should also be noted that this scenario does not assume an increase in household electricity consumption from take up of electric mobility and electric heating units. This would make it more difficult to achieve the original target, as overall demand for electricity would be increased, meaning that more solar PV would need to be deployed to achieve the same level of self-generation as a share of total household electricity demand. Solar PV potential varies by region, and should only be considered one part of the solution for decarbonising power generation in the EU; other zero carbon technologies, including renewables such as wind and geothermal (and potentially nuclear) should be considered in addition, to help meet the additional requirements arising from increased electrification of household energy demand.

[23] We do not explicitly model the recycling of old EV batteries but model the coevolution of battery technology (greater EV take up at the same time as battery technology penetration in solar PV).
[24] With an assumed load factor equal to the EU28 average – 12%

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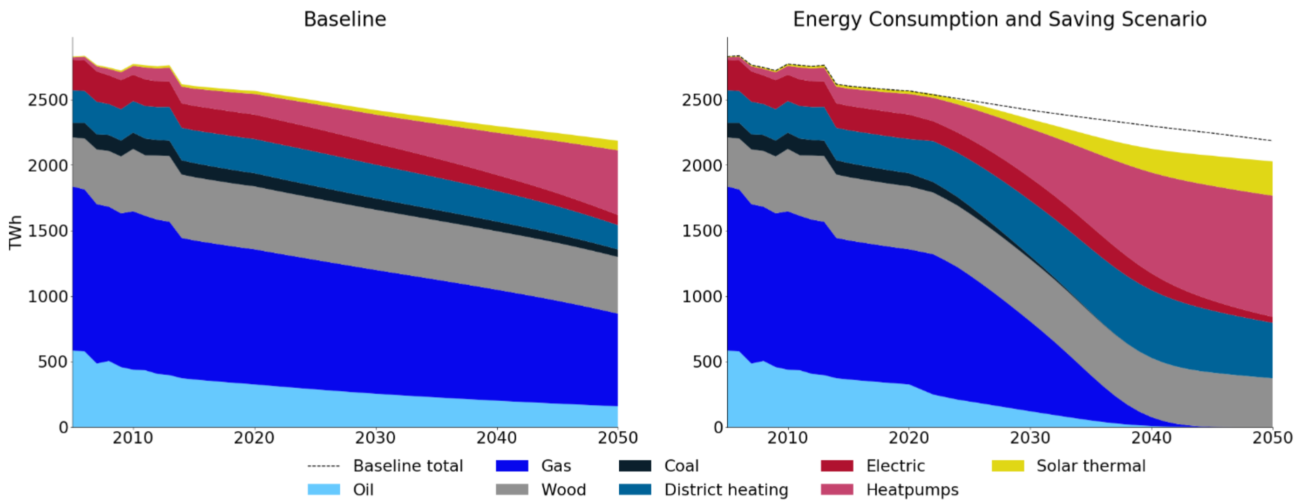
4.1.2 Energy Consumption and Saving Scenario

The target for the Energy Consumption and Saving Scenario is to achieve net-zero emissions from heating and cooling by 2050. The biggest contribution to this transition will have to occur within the heating sector. Active cooling is already powered by electricity, so the role of policy is only to mandate increasing efficiency standards in order to reduce electricity demand, which is included in the scenario. Some improved energy efficiency of household appliances is also included in this scenario (by exogenous assumption rather than endogenously determined within the scenario). As such, modelling of households' decisions to purchase renewable heating units as opposed to fossil fuel units in response to policy stimulus is the main focus of this scenario. The following figures focus on the results of this aspect of the modelling only.

In the Energy Consumption and Saving Scenario, subsidies and fuel taxes are introduced to make renewable heating systems more attractive, initially to only a subset of the population, potentially those who are more environmentally aware. Once these technologies gain a foothold in the market and the costs come down (from economies of scale and learning-by-doing) a tipping point is achieved, after which renewable technologies start to dominate the share of final energy demand (see right-hand graph in Figure 4.3).

Figure 4.3: Final energy demand for heating, split by technology – EU28



Nonetheless, additional policy is needed to completely remove all fossil fuel heating systems by 2050. With an average lifetime of 20 years, most households who invest in fossil fuel technology after 2030 would still have the same unit in 2050. As a result, gas units still make up a large share of household heating demand in 2040 and would continue to remain in the stock unless policy is used to intervene. In the scenario, governments are assumed to introduce early scrappage (starting in 2030) of fossil fuel units, forcing the take up of renewable heating systems, and bringing down local CO_2 emissions from heating in 2050 to zero (see Figure 4.4).

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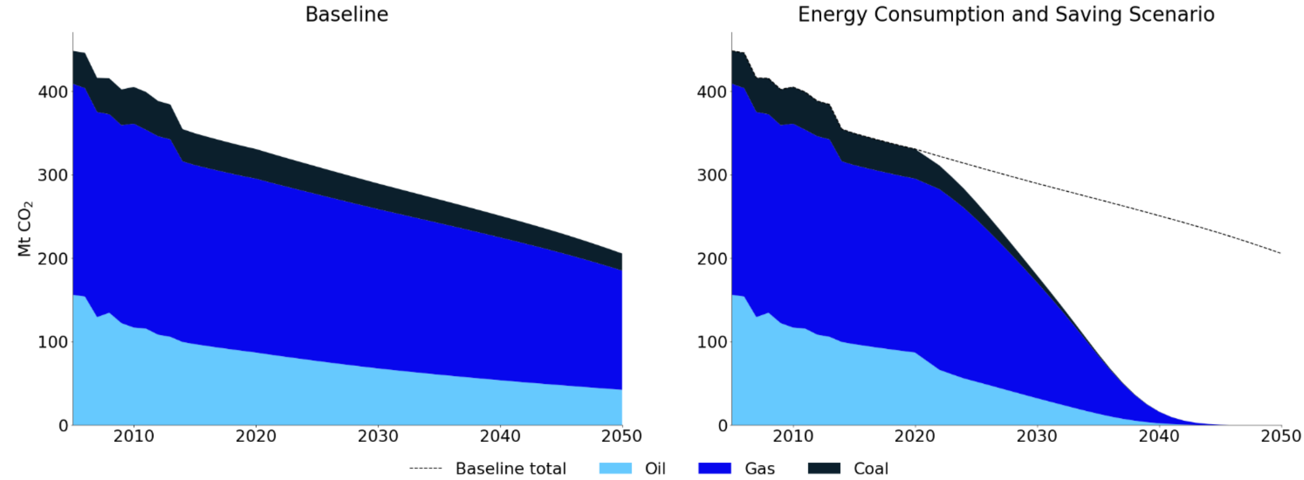
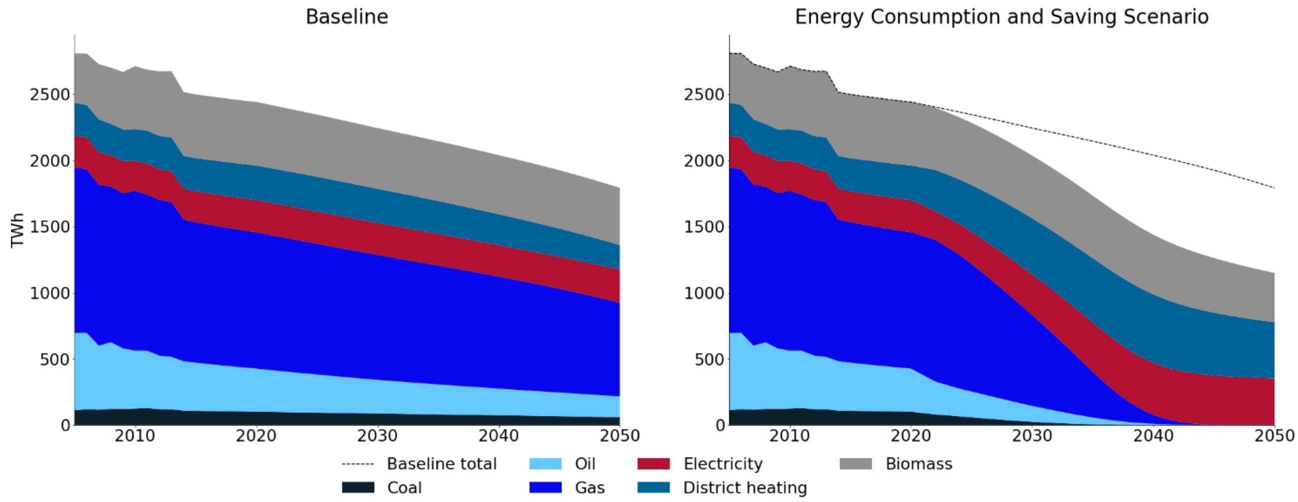
Figure 4.4: Local CO_2 emissions from heating, split by technology – EU28



As shown in Figure 4.5**Errore. L'origine riferimento non è stata trovata.**, moving to zero emissions from household heating by 2050 will increase demand for electricity, biofuels and district heating. Biomass are assumed to be 2nd generation sustainable biomass, and therefore are zero emission. In the case of district heating, households do not create the heat for their homes but instead are supplied with heat which is created elsewhere, such as a runoff from an industrial process coming from a plant close to a residential area. The implied emissions are thus not produced by households directly, but by industry. The scenario also does not assume that electric heating is zero emission; the implied emissions depend on the extent of decarbonisation of the power sector.

Figure 4.5: Fuel demand for heating, split by fuel – EU28



While zero local emissions from heating and cooling are technically possible, it is important that the switch away from technologies with local emissions is accompanied by decarbonisation within agriculture, industry and the power sector. This demonstrates the need to consider decarbonisation across the economy, including (but not limited to) policies to influence household heating decisions.

4.1.3 Sustainable Mobility Scenario

The introduction of policies to achieve a reduction in tailpipe emissions from private

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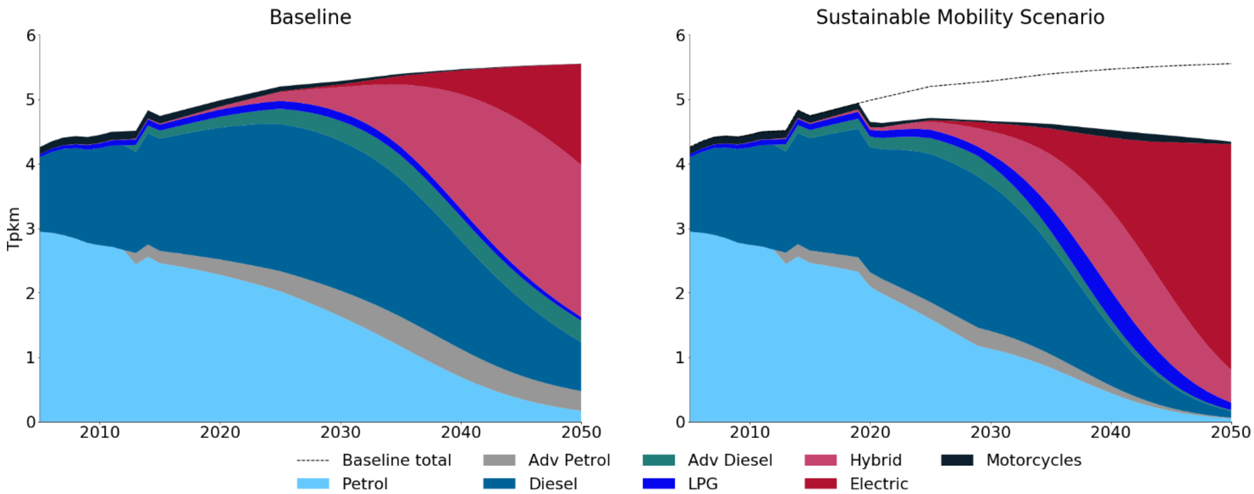
passenger vehicles by at least 80% in 2050 compared to 1990 levels will have profound effects on the road transport sector.

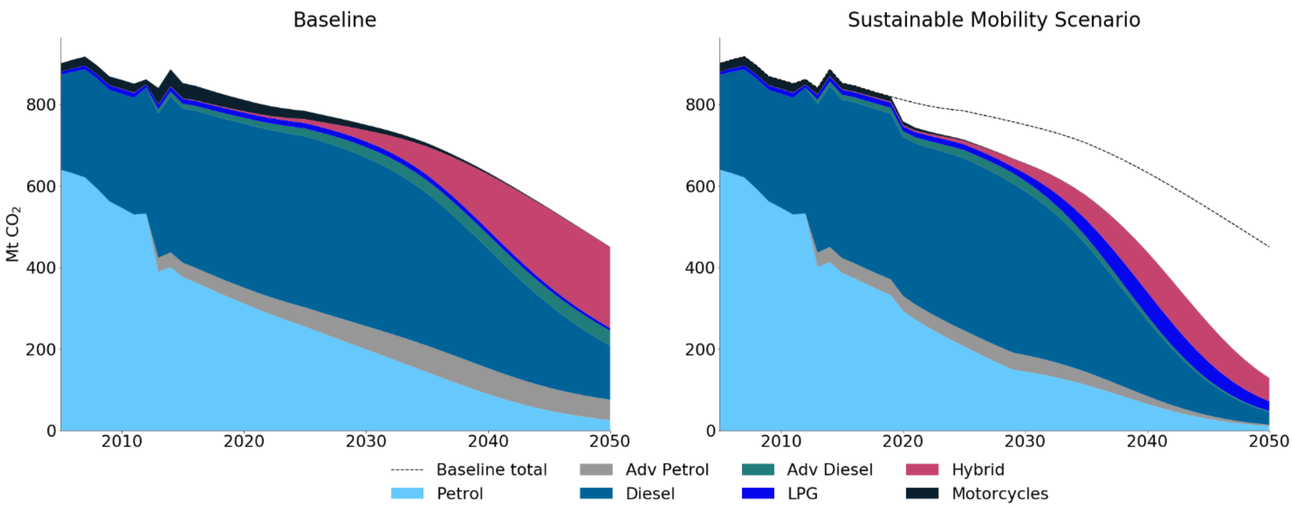
A significant reduction in road transport demand is possible if investments in public transport are made and cars are progressively banned from city centres. In the Sustainable Mobility Scenario, a modal shift arising from rail subsidies and car free zones in European cities causes the demand for private passenger transportation to fall by 12% in 2030 and 22% in 2050 compared to the baseline (see Figure 4.6). This has a number of potential benefits; fewer cars on the roads will reduce congestion, particularly in city centres where car free zones are implemented.

Figure 4.6: Private passengers' travel demand, split by technology – EU28



Nonetheless, in terms of CO_2 emissions from road transport, the reduction in travel demand makes only a small contribution. The biggest reduction in emissions is driven by a shift away from internal combustion engine vehicles (ICE) and towards battery electric vehicles (BEV). In the scenario, by 2050 BEVs will dominate the market for private passenger travel demand, delivering 81% of private passenger travel demand. Such a deployment of BEVs would result in a reduction of CO_2 emissions from road transport by around 82% (in 2050), compared to 1990 levels (see Figure 4.7). In the Baseline, CO_2 emissions from road transport in 2050 are reduced by only 32% compared to 1990 levels.

Figure 4.7: Private passengers' tailpipe CO_2 emissions, split by vehicle types – EU28



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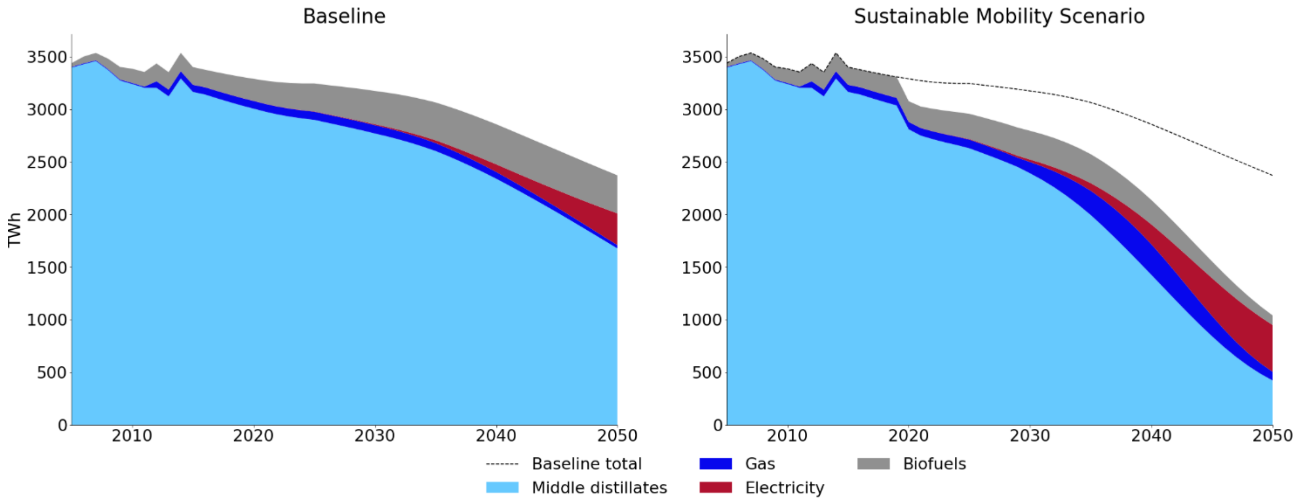
To achieve a transition to sustainable mobility, rapid and ambitious policy action is required, including fuel taxes, subsidies, a phase out of ICE vehicles and public procurement measures. Given that the average lifetimes of passenger vehicles across the EU range from 10 to 20 years across different Member States, and that most policy affects only new sales, it can take 10 years or more for such policy to have a major impact on the stock. Therefore, public procurement programmes and bans on the purchase of ICEs were implemented in the model from 2030 to give time for the impact on purchase decisions to feed through to the stock in time to materially affect the 2050 fleet. This in turn causes the costs of electricity mobility to fall (as a result of economies of scale and learning-by-doing)[25] and therefore it becomes increasingly accessible to the late adopters. Without such ambitious policy action, the take up of electricity mobility would happen at a much slower rate (see Baseline chart in Figure 4.6) and the reduction in CO_2 emissions will not be achieved.

Figure 4.8: Private passenger fuel demand, split by fuel – EU28



As shown in Figure 4.8, the demand for electricity from the road transport sector increases considerably over time, while the demand for petrol and diesel decreases over time. By 2050, total fuel demand (expressed in TWh) in the Sustainable Mobility Scenario will be less than 50% of total fuel demand in the Baseline Scenario, due to the electrification of the European passenger vehicle fleet (due to the fact that BEVs are more energy efficient than ICE vehicles). This also presents an opportunity for policymakers to reduce the implied emissions from road transport through decarbonising the power sector.

4.2 ENABLE.EU: Sustainable Citizens Practice scenario

4.2.1 Energy

4.2.1.1 Total energy demand

A key impact of the Sustainable Citizens Practice (SCP) Scenario is a reduction in total energy demand. The reduction is brought about by households switching to more efficient appliances and engaging in off-grid prosumption, while it is mitigated to some extent by an increasing demand for electricity due to the increased deployment of electric heating and e-Mobility.

[25] While economies of scales and learning effects are assumed, no sudden development in technology (i.e. a technological breakthrough) is assumed

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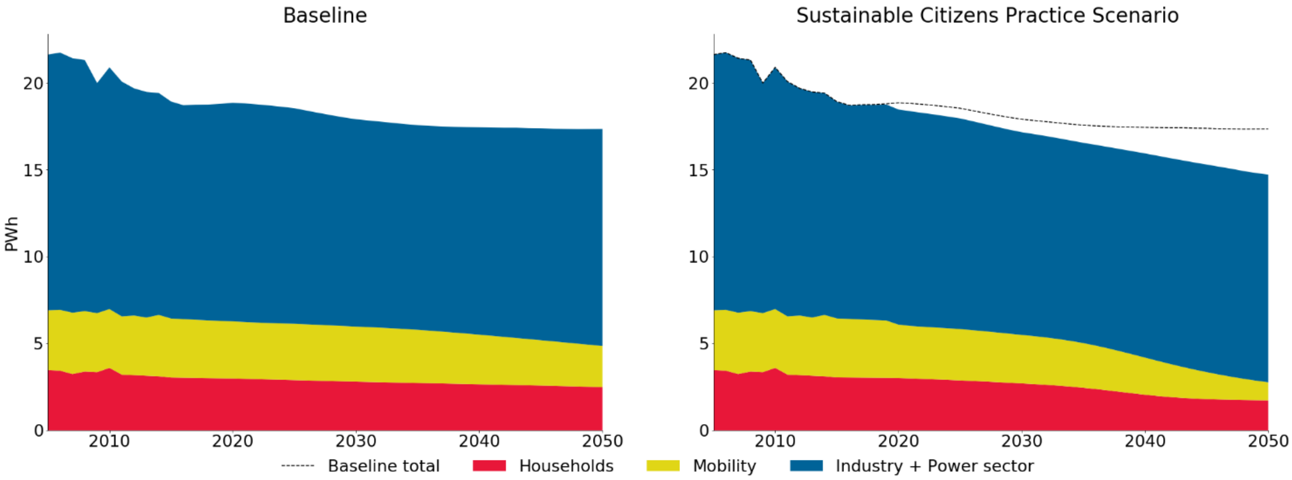
Figure 4.9: Total energy demand for the whole economy, split by sector – EU28



The total fall in energy demand in the SCP scenario (4% compared to the baseline in 2030 and 15% in 2050) is linked entirely to reductions in demand from households. Because energy demand from the rest of the economy stays more or less at the same level, energy demand from households falls as a share of total demand as well as in absolute terms. By 2050, the share of total energy demand for households and their mobility needs is 19%, compared to 28% in the Baseline.

Figure 4.10: Households' (incl. mobility) energy demand, split by fuels – EU28

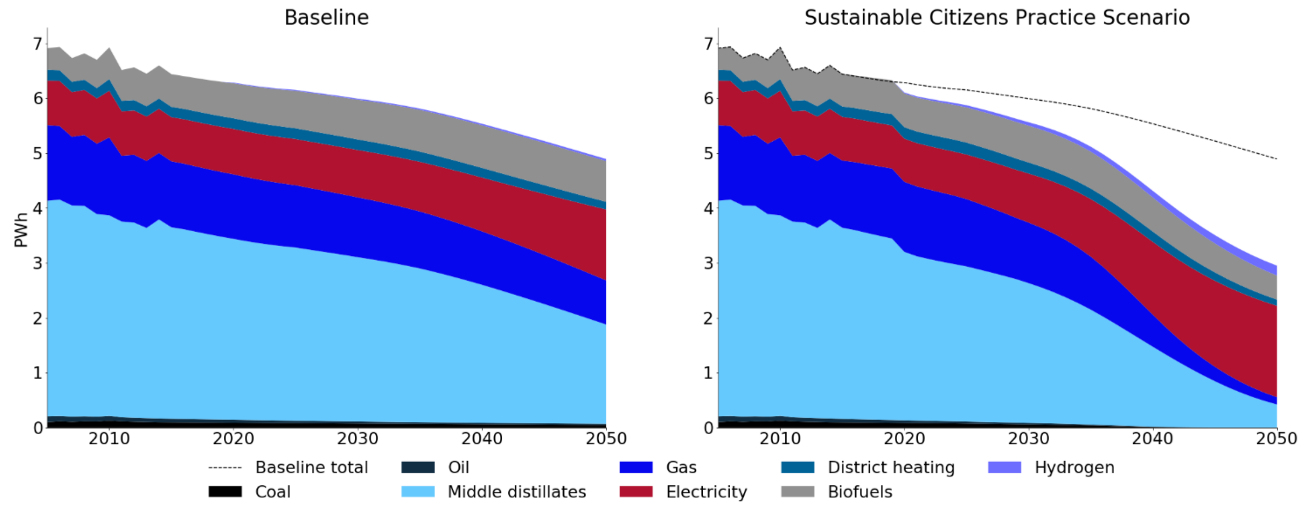


Figure 4.10 presents total household energy demand (including demand for private passenger transportation) split by fuel and thus showing the fuel savings that can be made by households. In 2050 the share of electricity in total household energy demand is 56%, up from 26% in the Baseline, while the demand for oil, middle distillates and gas has dropped to less than 25%.

4.2.1.2 Demand for electricity

In the SCP Scenario, demand for electricity falls relative to Baseline in the short term (it is 1% below Baseline in 2030) but increases thereafter (see Figure 4.11 below). The short-term trend is the result of energy efficiency measures reducing the need for electricity for

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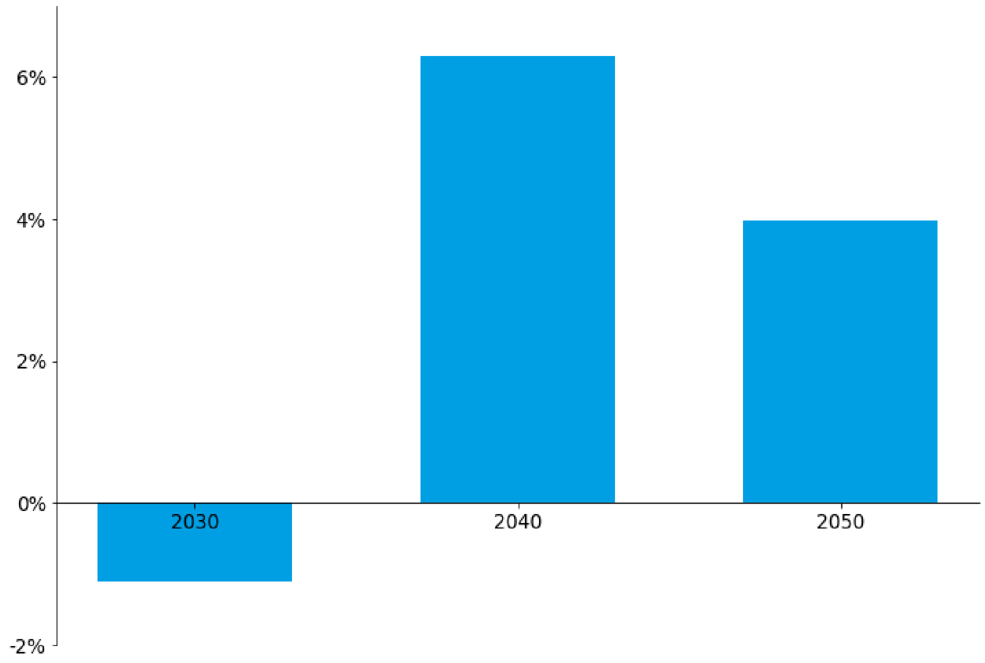
household appliances, and a slight increase in capacity of solar PV reducing the need for electricity coming from the grid. At this point the market for electric heating units and e-Mobility is still in its infancy and the phase out of petrol and diesel vehicles has only just been introduced (2030). Between 2030 and 2040, these changes in both the heating and mobility sector accelerate, and their impact on electricity demand grows. By 2040, electricity is the primary fuel for heating solutions and the market share of electric vehicles is growing steadily, which results in an increase of 6% electricity consumption compared to the baseline. By 2050, electricity consumption is only 4% larger higher than baseline. The moderation in electric demand between 2040 and 2050 is due to energy efficiency investments and solar PV deployment which have both continued to grow. Note solar PV deployment is coupled with better battery storage technology which allows the prosumer to retain a greater share of his/her electricity generation[26] thus further decreasing the demand of electricity from the grid.

Figure 4.11: Electricity consumption relative to baseline – EU28



4.2.1.3 Electricity prices

Prices are projected to increase in the Sustainable Mobility Scenario, by 2050, as a result of increasing demand for electricity from the grid and increasing CO_2 prices (and fossil fuelled plants continuing to often act as the marginal supplier of electricity, and therefore operating as price setters).
Figure 4.12 shows that price differences between regions would be expected to grow by 2050. In the scenario, the Nordic region (mostly as a result of higher renewable share) has prices that are on average 20-25 €/MWh lower than the average projected price for the Mediterranean region in 2050. Prices in Central Eastern Europe and Western Europe develop in similar ways (see Table 7.8 in Annex 7.4 for list of countries in each region).

Figure 4.12: Wholesale electricity price developments in the different scenarios for EU28 and for the pre-*

[26] Better batteries allow the household to retain a greater amount of their generated energy, it is assumed that because of this technology 95% of all generated electricity is retained by 2050.

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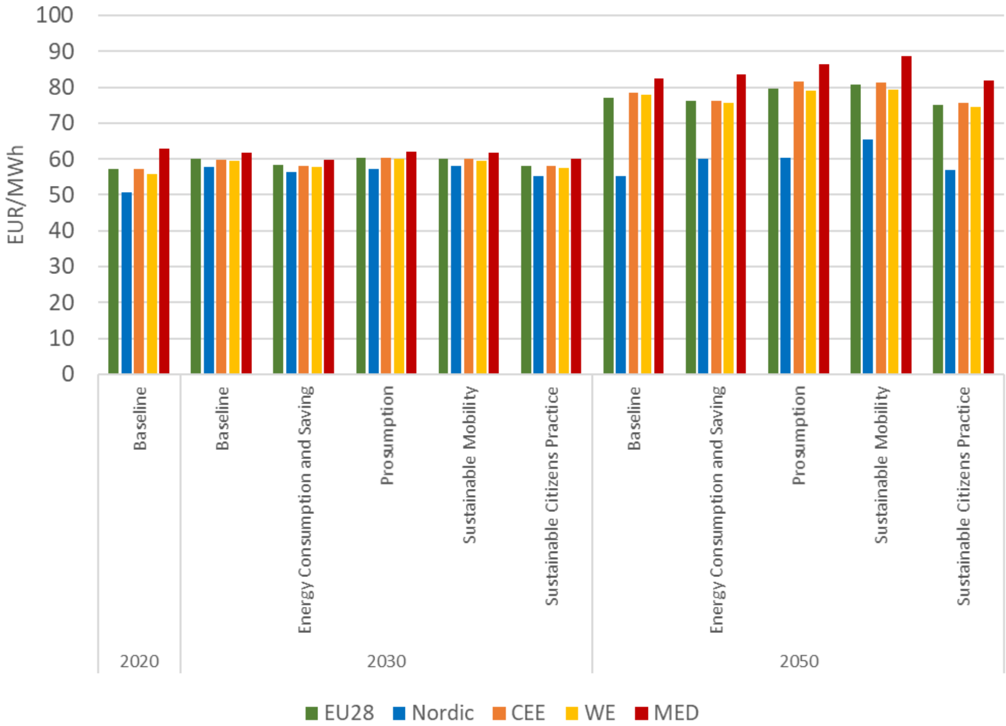
defined regions (Nordic, CEE, MED, WE)



**Cyprus and Malta are not included in the EEMM model*

Prices are projected to be highest in the Sustainable Mobility Scenario, as a result of increased consumption through higher penetration of electric vehicles. However, the differences across scenarios are very small; differences between regions and over time are much more pronounced.

4.2.1.4 Natural gas prices

Due to decreasing inland production the share of import in the gas supply mix of the European Union increases from around 75% to 82% by 2030 and to 90% by 2050. The growth of import dependency results in higher prices in the Baseline scenario. Similarly, in those scenarios where the demand for natural gas does not decrease significantly, average prices for the EU increase by around 1.5 €/MWh up to 2050. In the Energy Consumption and Saving and Sustainable Citizens Practise scenarios on the other hand, where demand decreases significantly as a result of the deployment of renewable heating technologies, the production decrease is outweighed by the lower demand, and yields that the average price in EU28 decreases by around 1 €/MWh by 2050. Consequently, despite the falling EU production and higher import dependency, European consumers in these two scenarios pay significantly less (by 26-29%) for their gas consumption by 2050 as in 2020.

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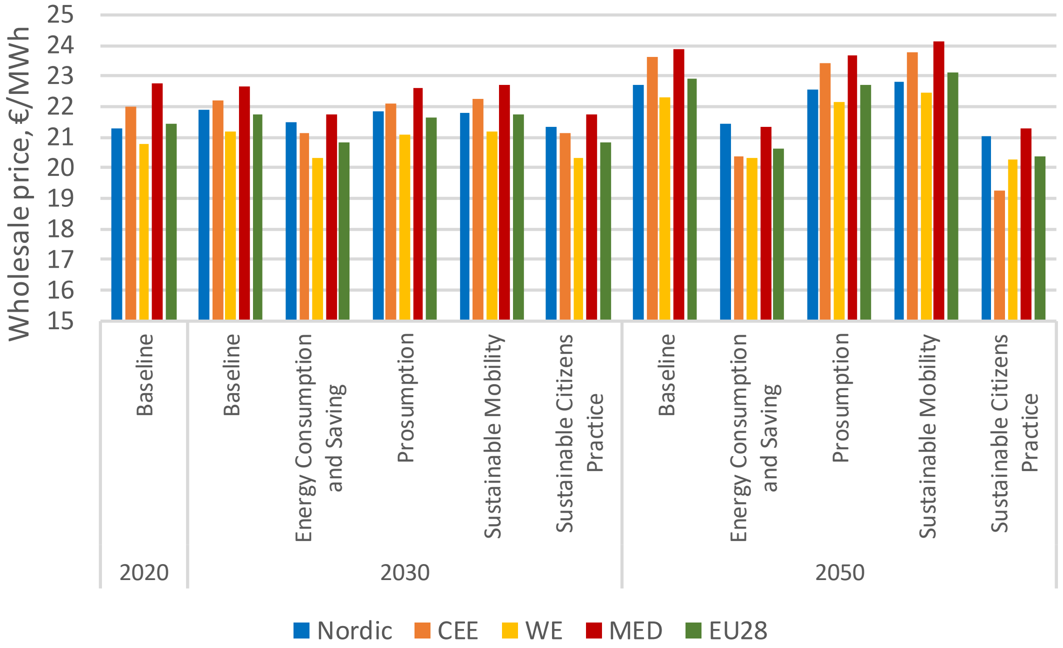
Figure 4.13: Wholesale gas price developments in the different scenarios for EU and for the pre-defined regions (Nordic, CEE, MED, WE), €/MWh



Looking at the modelled gas prices by 2050, it can be seen that prices in the Prosumption and Sustainable Mobility scenarios do not differ significantly from Baseline prices, while the Energy Consumption and Saving and Sustainable Citizens Practise scenarios bring significant price decreases (around 2.5€/MWh) for the EU on average. The highest price can be seen in the CEE region, while the lowest in the Nordic.

Further analysis of the impact on the gas market is provided in Annex 7.4.1.

4.2.1.5 Impact on the electricity generation mix in the EU

The following figure presents the changes in the electricity mix compared to the baseline developments in 2030 and 2050.

Compared to baseline, a higher share of electricity is generated by renewables in the SCP Scenario, although the difference is relatively small. By 2030, the transition in the household sectors would lead to around a 2% higher RES share, mainly driven by changes in installed capacity of solar PV

By 2050 the changes in the electricity mix are larger. There is a substantial increase in the overall electricity demand, leading to an overall 20% increase in electricity production. Coal and lignite-based generation disappears from the electricity mix, while natural gas-based generation gains much higher shares over the modelled period. More than one third of the electricity is produced from natural gas by 2050. Nuclear capacity stagnates (as a net result of outgoing capacities and some new built nuclear power plants) while all RES technologies increase their contributions to electricity production.

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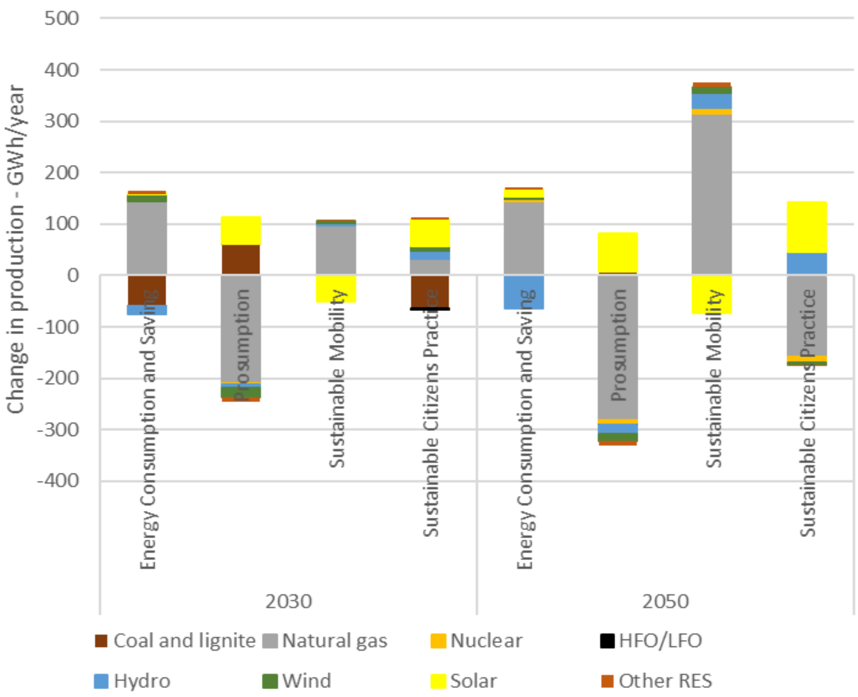
Figure 4.14: Changes in electricity mix in the different scenarios for EU



It should be noted that the overall path of different technologies is set in the Baseline, and the scenarios mark only minor variations from this. Overall, the policies and measures assumed in those scenarios have minor impact on the electricity mix because the policy packages target the household sectors; no measure targeting power companies is modelled here. The results should be interpreted as the expected impact on the electricity mix solely from changing policy in the household sectors.

Furthermore, the Baseline represents a rather conservative projection of the future of the EU's electricity markets. The underlying modelling framework, FTT:Power, has stringent limits on the ratio between intermittent and dispatchable capacities. These limits lead to the relatively small role seen for wind and solar (both intermittent technologies), and indeed by 2050 wind and solar are effectively in competition for the intermittent capacity that is available; since solar PV costs are lower, as wind generators come to the end of their life, they are increasingly replaced by solar PV as 2050 approaches. Since hydro and natural gas are both dispatchable, there is no such limit on these technologies, and instead, investment decisions are based on the core underlying drivers of relative costs and investor reluctance to shift to new technologies.

A regional disaggregation of the impact on the generation mix is provided in Annex 7.4.2.

4.2.1.6 Emissions

The changes that occur in the household sectors have knock on effects in the power sector, given the additional demand for electricity from the grid. The SCP Scenario does not assume any policies related to power sector decarbonisation.

A significant level of carbon reduction is achieved, amongst others as a result of coal to natural gas switch which is seen in the Baseline, and to some extent due to CCS power plants entering the market. This is driven by the assumed CO_2 emission quota prices at the

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end of the modelled period, based on the EU Reference Scenario (European Commission, 2016).

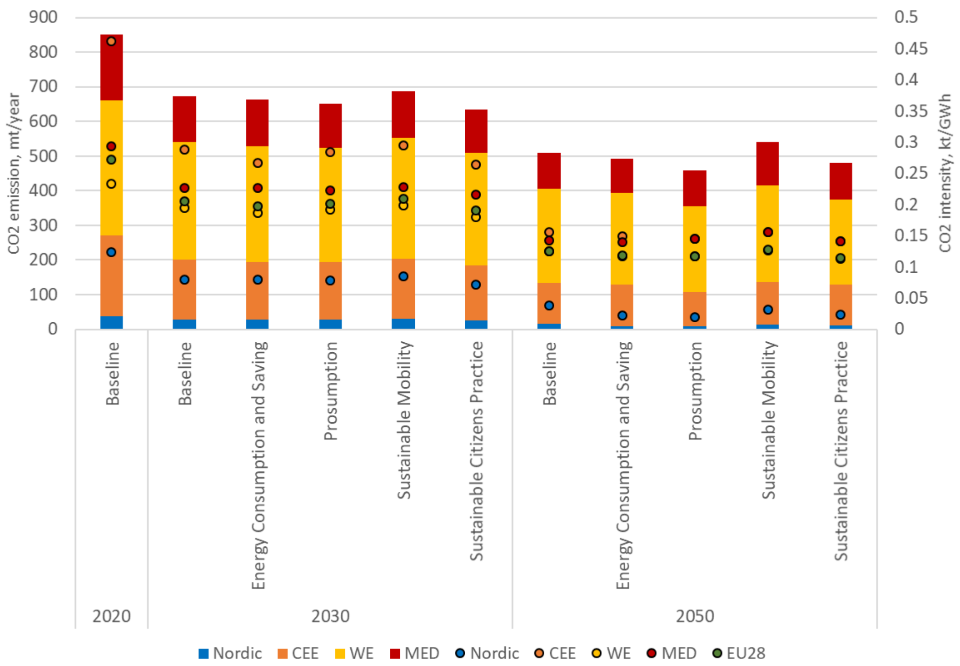
Compared to baseline, emissions in the SCP Scenario are 6% lower in 2050. There are differences between the different sector-specific scenarios though; emissions are reduced by 3% compared to baseline in the Energy Consumption and Saving Scenario, while emissions are reduced by 10% compared to baseline in the Prosumer Scenario. Because the Baseline is rather conservative in its projection of the RES share in electricity generation, emissions would increase by 6% in the Sustainable Mobility Scenario.

As outlined in the previous section, FTT:Power has stringent limits on dispatchable capacities; the remainder of generation must be provided by dispatchable or baseload technologies. As a result of this constraint, and the relative prices of the remaining technologies, natural gas sees substantial additional adoption in the Baseline and the SCP Scenario (even with an increasing carbon tax in place). The outgoing carbon intensive technologies (coal, lignite and oil) as well as any increase in electricity demand which cannot be supplied by the increasing RES tends to be largely met by natural gas-based production. This leads to a close to doubling of gas-based power production compared to 2020.

The following figure illustrates the CO_2 emissions (bars) and emission intensities (dots) in the power sector for the various scenarios with a geographical breakdown for four EU regions (detailed list of the region and country mapping can be found in Table 7.8 in the Annex).

Figure 4.15 shows that Western Europe region (WE) is the most sensitive to the assumed Policies and Measures of the scenarios. The power sector CO_2 intensities of three geographical regions (WE, MED and CEE) converge by 2050, but far exceed the intensity of the Nordic region.

Figure 4.15: CO2 emissions and CO2 intensity of the power sector in the different scenarios for EU and for the pre-defined regions



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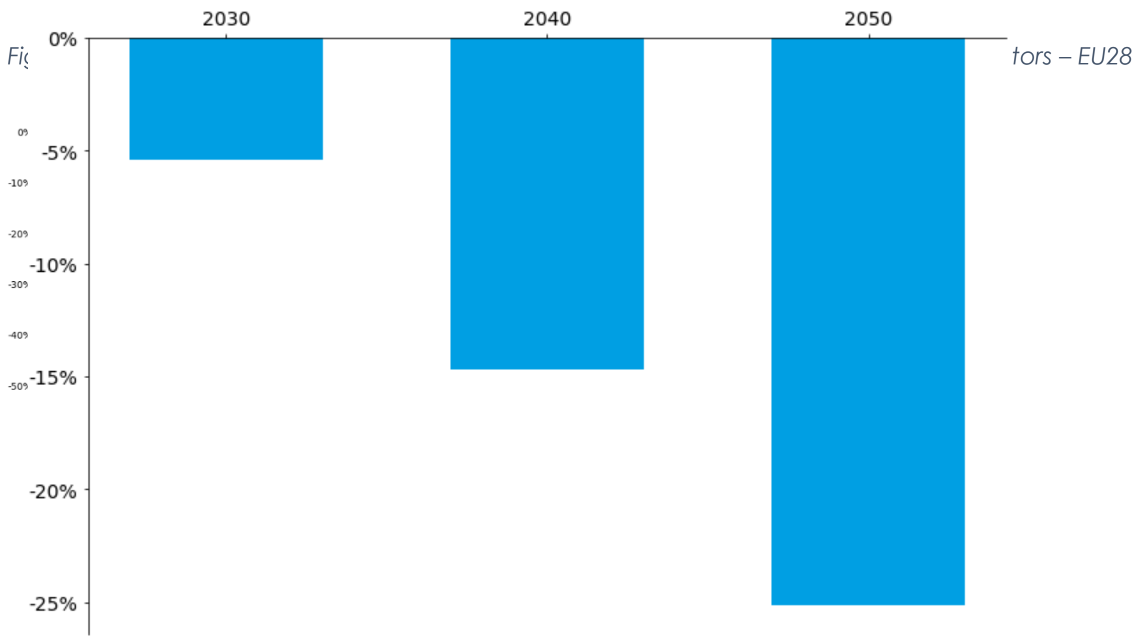
Nonetheless, the reductions in emissions within the household sectors are large enough (80% and 95% in 2050 compared to baseline) to offset any potential increase in emissions from the power sector, which causes an overall reduction in emissions throughout the projection period. Overall, emissions are reduced by 5% compared to baseline in 2030, 15% in 2040 and 25% in 2050. Figure 4.16 shows the differences from baseline in the SCP Scenario, for economy-wide CO_2 emissions.

Figure 4.16: Economy-wide emissions relative to baseline – EU28



4.2.2 Economy

The economic impacts of the SCP Scenario are described in this section, including the effects on GDP, consumer expenditure, output and employment.

4.2.2.1 Consumer spending

Decarbonisation of household energy use means less money is spent on fossil fuels and more money is spent on appliances (e.g. solar panels, household white goods), electricity and other goods and services (e.g. food, drinks, entertainment etc.). Due to efficiency improvements and relative price changes between fossil fuels and electricity, the average energy bill (i.e. spending on fuels and electricity by households) for European households will decrease when electrification is increased and the share of electricity in household energy demand increases over time (even if electricity prices are projected to go up). As shown in Figure 4.17, European household will on average be spending up to 50% less on energy by 2050. Note, 'Energy' in the figure below includes the aggregation of fossil fuels and electricity only and does not include the additional expenditure of households on solar PV panels, for example. The latter is included in non-energy expenditure.

The changes in consumer spending between categories can be seen in Figure 4.18. Spending on fossil fuels decreases by almost 100% compared to baseline, while spending on electricity, rail transport, household appliances, vehicles and other increases. This is in line with the policy measures that are introduced in the SCP to stimulate spending on e-Mobility, Solar PV and renewable heating technologies. The increases in spending on

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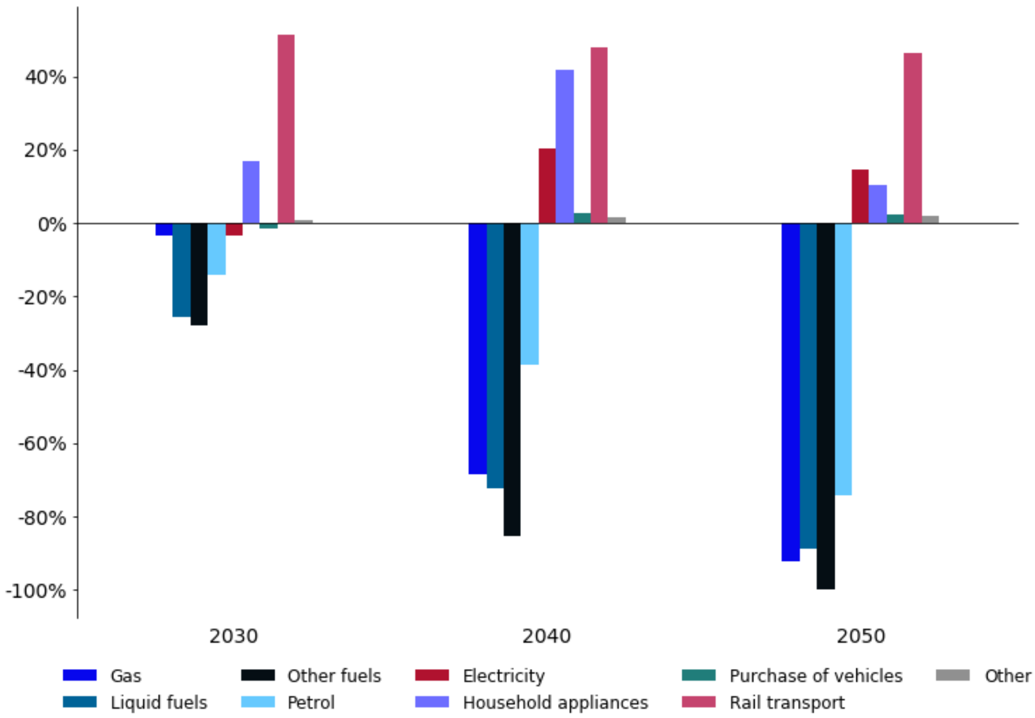
household appliances is from investment in solar PV panels and household efficiency measures, which puts downwards pressure on consumption of electricity. Rail transport represents the increase in demand for rail as a result of government subsidies for public transport use.

While these are the categories that see the largest relative changes, in absolute terms the biggest change is in the 'other' category, which encompasses all other elements of consumer expenditure (e.g. food & drink, manufactured goods, consumer services). In 2050, the absolute change in consumer expenditure relative to the baseline for 'Energy' is a reduction of €200 billion. Across non-energy categories spending increases by €330 billion

Figure 4.18: Consumer expenditure relative to baseline, by sectors – EU28



(i.e. there is a net increase in consumer expenditure of around €130 billion).

Overall, the savings that are made lead to greater consumer spending; there is a net gain across the EU28 with 0.8% higher consumption compared to baseline in 2050. This is presented in Figure 4.19.

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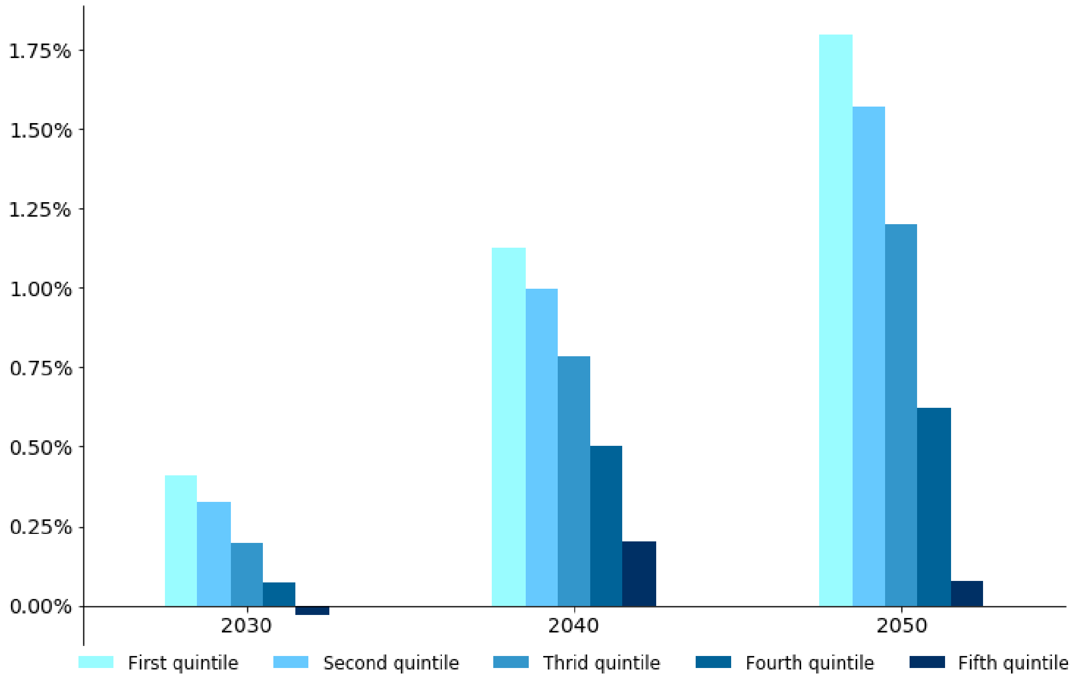
Figure 4.19: Consumer expenditure relative to baseline – EU28

Figure 4.20: Real incomes relative to baseline, by quintile – EU28



The effect on households' real income is also broadly positive in the SCP scenario, and progressive, with the largest relative change in real incomes experienced by the poorest households and the smallest relative change experienced by the richest households. This can be largely attributed to the fact that for low income households (the lowest/first quintile[27], see Figure 4.20) the energy bill is likely to make up a larger proportion of their spending, therefore any reductions in the price will have a greater effect relative to richer households – whose energy bill makes up a smaller proportion of their overall spending.

Apart from the energy bill the prices of non-energy products are also changing in the projected period, due to changes in demand, which combined with proportion of spending between poorer and richer households leads to different changes in real incomes. For example, food products which make up a larger proportion of overall spending for poorer households is reducing in price, which mean real incomes are relative better than richer households.

How governments fund their policies matters. In the modelling it is assumed that economic incentives for renewable heating units and electric mobility are funded by an increase in government revenues, evenly split between increases in the VAT rate, income rate and employers' social contribution. If economic incentives were to be funded, say, wholly

[27] The first quintile group represents the 20% of the population with the lowest income (an income smaller or equal to the first cut-off value), and the fifth quintile group represents 20% of the population with the highest income (an income greater than the fourth cut-off value).

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through VAT increases, the transition might produce smaller benefits to poorer households relative to richer ones due to the regressive nature of sales tax (because it is a steady percentage across all income groups, and low-income households spend a greater proportion of their incomes on goods and services which are subject to such taxes). Policy makers should fund schemes in a manner such that the transition does not make low income households worse off.

Although not captured in the modelling[28], the take up of solar PV is likely to first be led by higher income households who can afford the CAPEX costs. These households will then benefit from the available policies, such as feed-in tariffs and subsidies and – depending on how the measures are being funded - this could result in a negative redistribution of funds. To avoid this, policy makers should ensure that low income households can easily invest in solar PV through targeted support and financial aid to ensure that all citizens of all income levels can benefit from the available policies.

4.2.2.2 Sectoral Output

Consumption patterns from households affect sectoral output. As a result of the transition in the household sectors, the fossil fuel sectors and those producing conventional technologies (e.g. gas boilers) experience declines in output, while the power sector and those producing renewable and efficient technologies experience increased demand and therefore increase production.

This is reflected in Figure 4.21, which presents the projected output for selected sectors. As expected, the power sector (i.e. 'electricity') sees higher output, in line with the higher demand. Output from Coal, Oil and Gas, Gas supply, steam and air conditioning and manufactured fuels fall. The reduction in output in the 'Gas, steam and air conditioning' sector is almost completely driven by a reduction in demand for gas.

[28] The modelling focuses on a representative household, rather than a subset of poor, middle and rich households.

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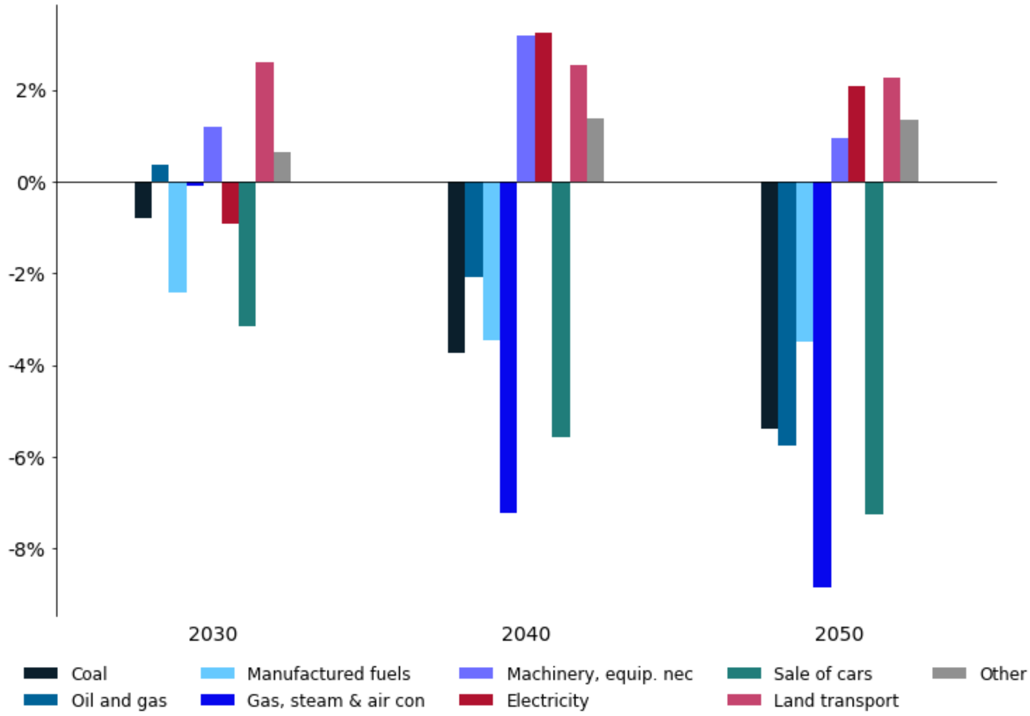
Output from the sale of cars falls over time despite an increase in household spending on vehicles in 2040 and 2050 compared to baseline. This is because EVs increase demand for electrical equipment, and other electric component supply chains, rather than demand for conventional motor vehicle components.

Figure 4.21: Economy output, by sectors – EU28



Overall, more goods and services are produced by the European economy, compared to baseline. This is primarily because reduced demand for imported fossil fuels reduces leakage from the European economy; money that was spent on imported fuels in the baseline is instead spent on domestic fuels (electricity) and other goods and services. This creates positive economic multipliers within Europe.

In the SCP, the rate of change to new technologies and shifts in consumer spending are most pronounced between 2030 and 2040. Beyond 2040, in the baseline these technologies also start to be adopted at scale, leading a slight erosion of the economic benefits compared to 2030. Beyond 2040, the benefits are still sizeable, but benefit of the SCP (since the gap between the scenario and the baseline narrows somewhat).

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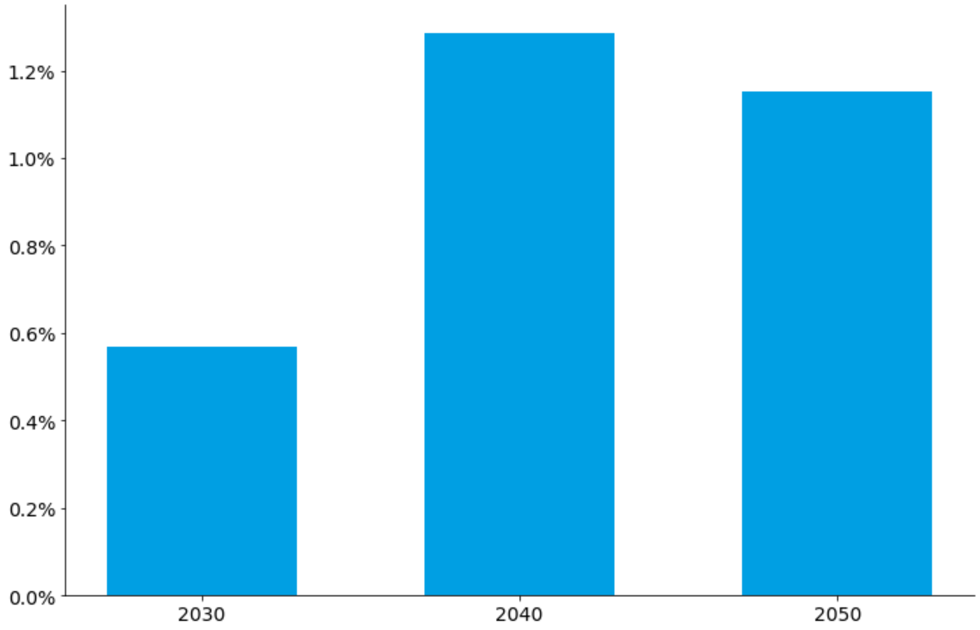
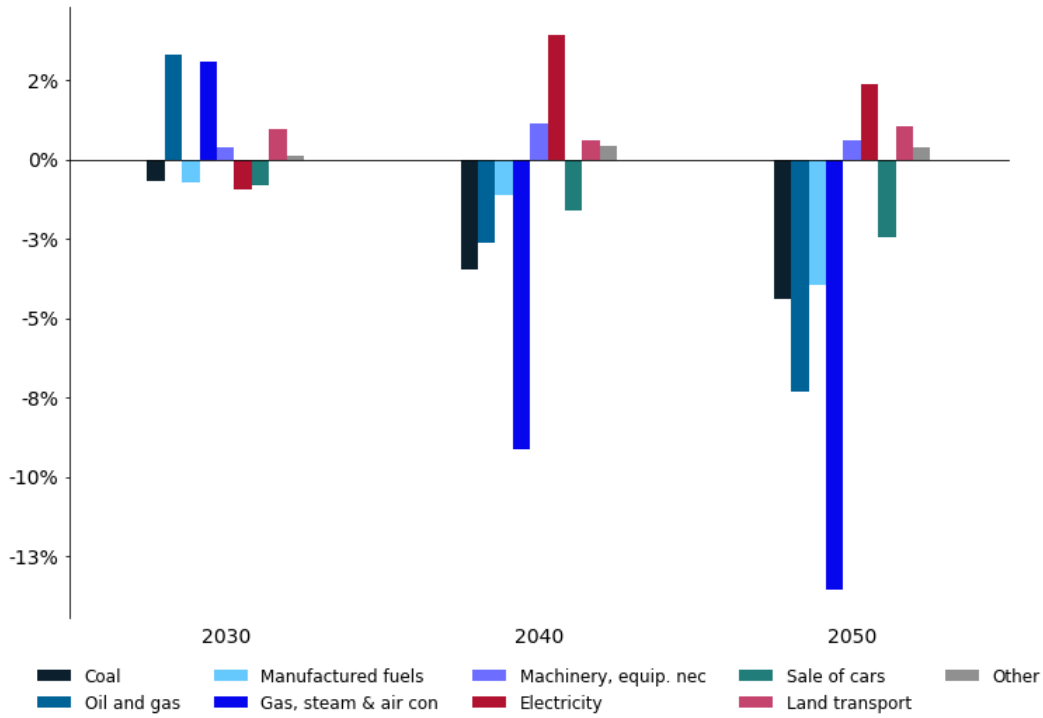
Figure 4.22: Whole economy output relative to baseline – EU28



4.2.2.3 Employment

Changes in employment follow a similar pattern to sectoral output, whereby sectors with lower output compared to baseline also generate less employment. Lower demand (and therefore production) means that fewer workers are required.

Figure 4.23: Employment relative to the baseline, by sectors – EU28



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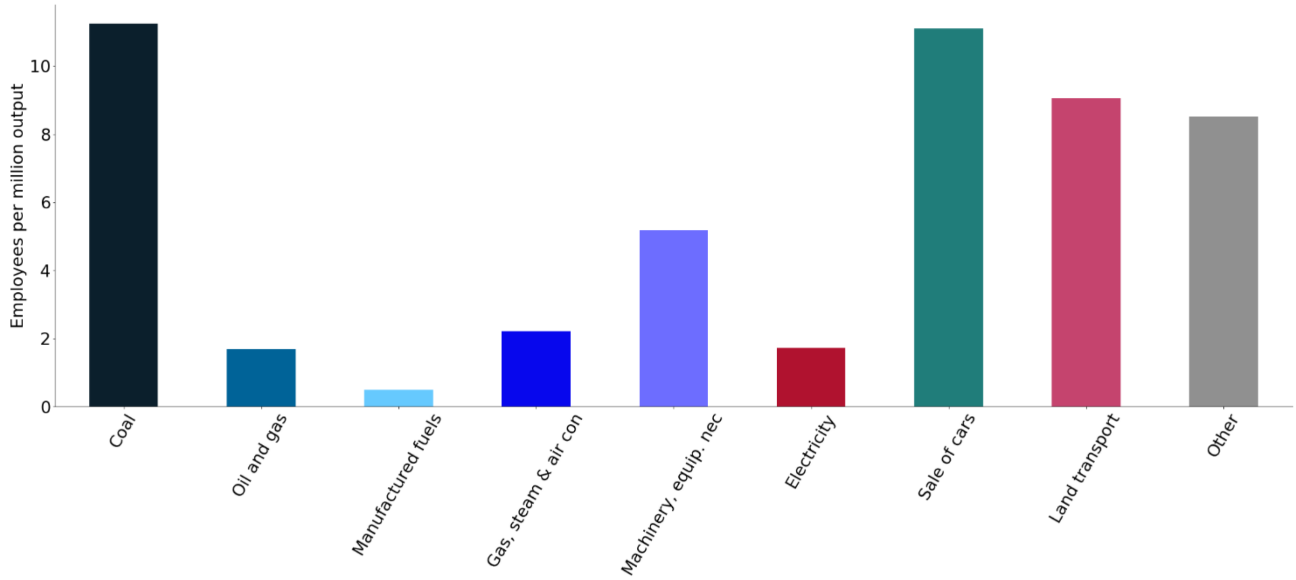
The size of the reduction in employment is proportional to the fall in output but, critically, also depends upon the labour intensity of the sector concerned. The labour intensity can be measured as the number of workers it takes to produce €1 million of output. For example, in the coal sector, 11 workers are required to produce that value of output in 2030. The figure below shows the labour intensity of each sector in the SCP Scenario in 2030.

Figure 4.24: Labour intensity, by sectors – EU28



A reduction in output in labour intensive sectors will lead to greater reductions in employment than the same reduction in output in less labour-intensive sectors. Vice versa, an increase in output in labour intensive sectors will create more jobs than the same increase in output in a less labour-intensive sector. The overall impact on employment is determined by the relative labour intensities of those sectors that are most affected by the transition in the household sectors, and the overall net impact on output. In the SCP Scenario, those sectors that see lower output tend to have lower labour intensities than those that increase output compared to baseline.

This pattern of labour intensities means that overall there is a positive net employment effect in the EU28 in the SCP Scenario. In 2040, the European economy will have employment 0.39% higher than in the baseline, while in 2050 the difference is 0.32%.

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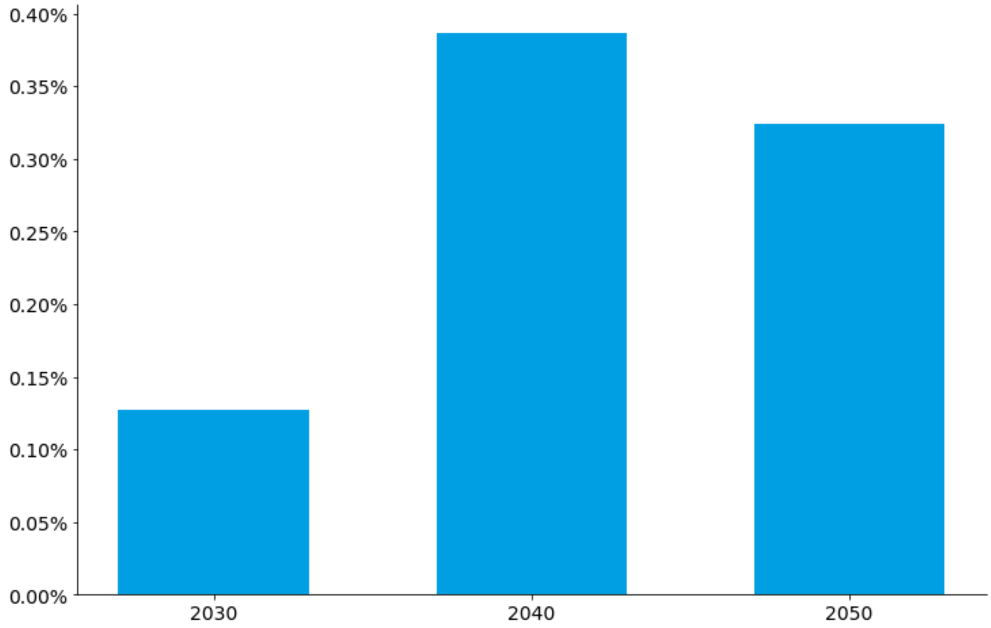
Figure 4.25: Whole economy employment relative to baseline – EU28



4.2.2.4 Gross Domestic Product

Overall there is a net positive effect to GDP in the EU28 over the projected period, as shown in Figure 4.26.

The main driver of this change is the reduction in leakage from the European economy, following changes in consumer spending. The policy packages included in the SCP Scenario are designed to affect household's behaviour and encourage purchases of renewable and fuel-efficient technologies, while reducing consumption of fossil fuels (see reduction in Gas, Liquid fuels, Other fuels and Petrol in Figure 4.18). As the majority of fossil fuels in the EU28 are imported from elsewhere (Harrison P., 2018), leakage from the European economy is reduced when demand for fossil fuels is reduced.

The modelling assumes that 'saved' expenditure is spent by consumers in proportion to the way that existing spending is done; this means that it is partly on imported goods, but also on a substantial amount of domestic goods and services. Equally, these goods and services have supply chains which involve domestic and overseas firms; so there continues to be some leakage from the European economy, but it is less than when this expenditure was being spent on fossil fuels, which are overwhelmingly imported into Europe.

The extent to which this increases employment depends on the relative labour intensity of the sector. Additional employment means incomes rise, which in turn increases spending in the economy and leads to further multiplier effects.

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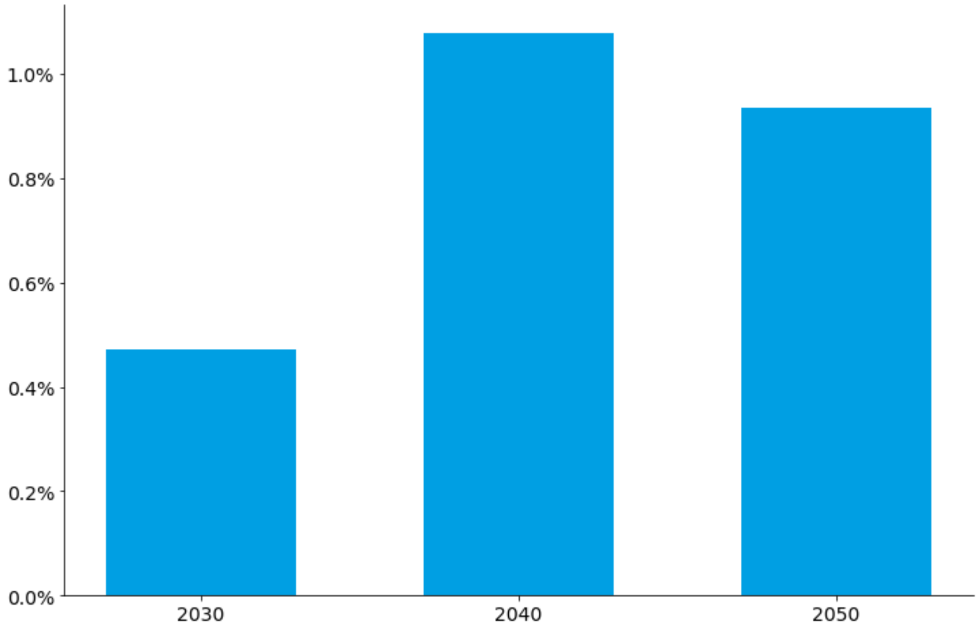
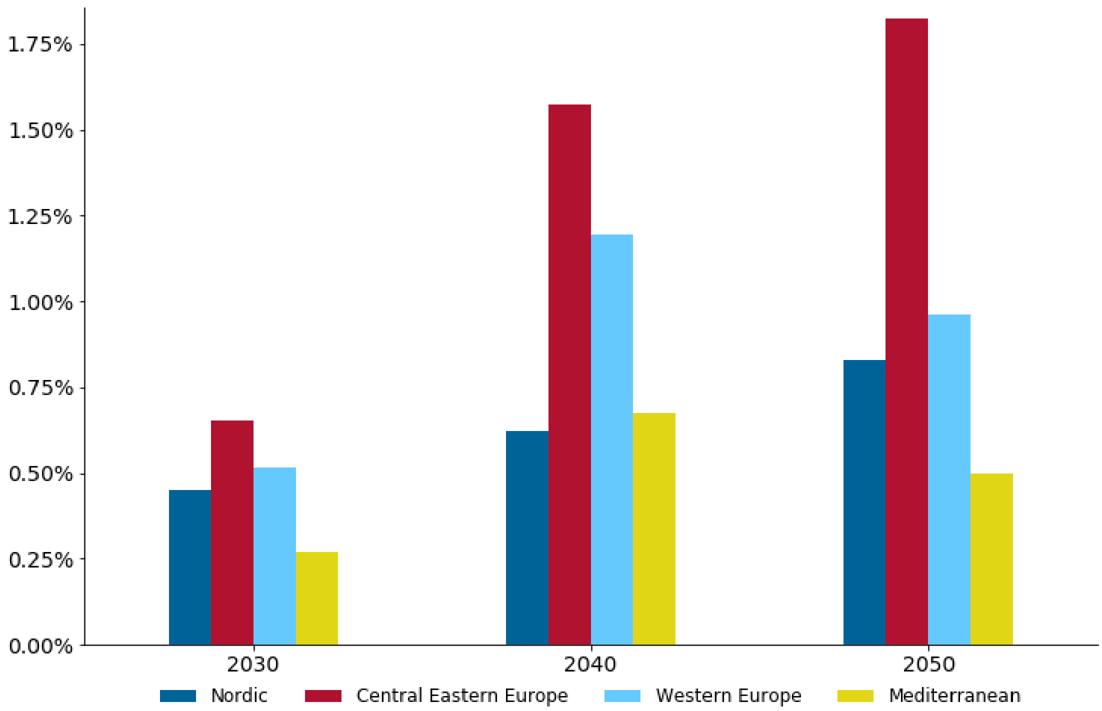
Figure 4.26: GDP relative to baseline – EU28



This does not mean, however, that all Member States benefit to the same extent; strong economic and social differences exist between regions of the European Union. At the regional level (i.e. aggregations of Member States), Central Eastern European countries benefit the most from an economic perspective. This is due to a combination of two factors: the relative starting position and trading volumes.

Figure 4.27: GDP relative to baseline, by aggregate EU regions



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In terms of the historic take up of solar PV, renewable heating units, e-Mobility and the deployment energy efficient technology, CEE is starting from a much lower base than WE. Particularly regarding energy efficiency, CEE countries have lower take-up of energy efficient technologies relative to WE and therefore receive a higher investment stimulus of energy efficient technologies in the scenario. Another example is the cumulative capacity of solar PV; in CEE in 2020 this is 4 GWs, compared to 25 GWs in WE. By 2050, solar PV capacity in CEE has increased by 620%, whereas in WE capacity increases by 360%. These examples highlight the additional investment required to transform the household sector and to meet the respective sector specific targets, which generate more economic activity which in turn leads to larger positive GDP impacts relative to baseline.

The long-term historical characteristics of CEE countries and WE countries are different which mean they respond differently to changes in demand for products. These characteristics, such as their trading behaviour and the relative prices of imports and exports over history, contribute to the differences shown in Figure 4.27. For example, Germany is a net exporter of goods and service but Romania, Poland, Austria are all net importers. This behaviour determines how the model calculates the relative size of parameters for different countries and ultimately leads to different responses. All in all, it should be noted that each region benefits positively from the transition.

It is important to note here though that in the modelling for ENABLE.EU, the likely impact from changes in the household sectors is assessed, while not explicitly assuming any changes in other sectors of the economy in addition to what is in the baseline. As such, the economic results do not capture any possible economic impacts, positive or negative, stemming from decarbonisation efforts made outside the household sectors.

4.2.3 EU 2030 Targets

In this section we compare the SCP Scenario against the targets of the Energy Union. The energy-climate targets for 2030 are to reduce greenhouse gas emissions by at least 40% (compared to 1990), increase the share of renewable energy to at least 32%, and achieve an energy efficiency improvement of at least 32.5% (compared to baseline projections).

4.2.3.1 Reduction in greenhouse gas emissions

A 40% reduction in greenhouse gas emissions compared to 1990 levels would require emissions to be no more than 3432 $MtCO_2eq$[29] in 2030. The results for the SCP Scenario show that while considerable reductions in emissions can be made in the household sectors in case ambitious policy packages are implemented, these reductions by themselves would not be sufficient to meet the EU 2030 target. Further action to reduce emission from the power sector as well as other sectors of the economy will be required in order to reduce greenhouse gas emissions to the desired level by 2030.

[29] National emissions reported to the UNFCCC and to the EU Greenhouse Gas Monitoring Mechanism provided by European Environment Agency (EEA)

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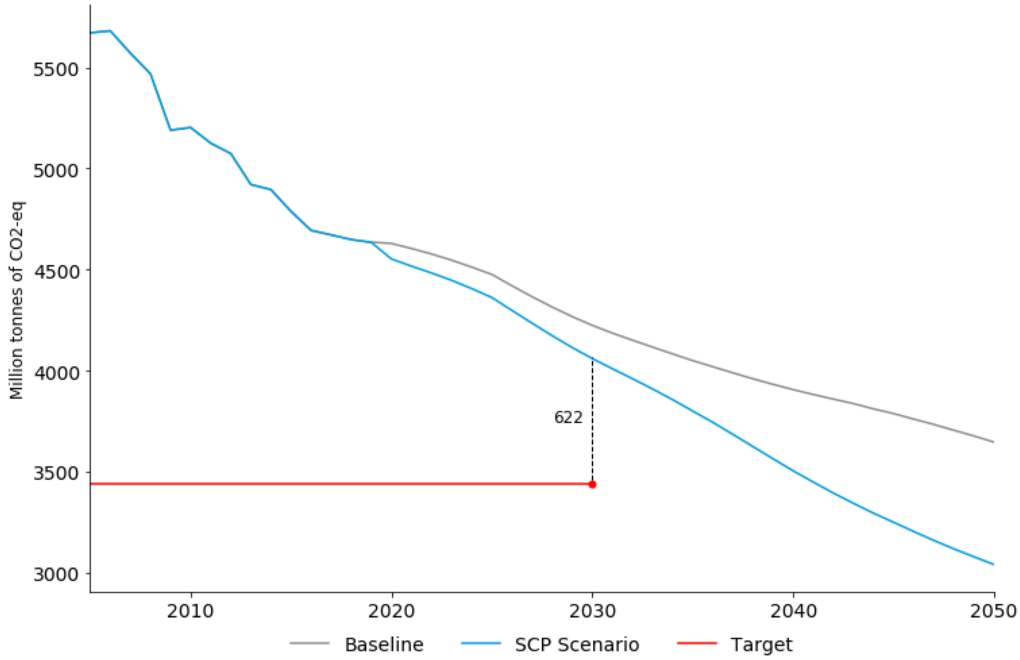
Figure 4.28 depicts the projected greenhouse gas emissions in the baseline scenario and the SCP. In comparison to 1990 levels, the household contribution achieves a 29% reduction, a total of 4059 MtCO2eq. A 622 MtCO_2-eq or a 11% further reduction in emissions is needed from other sectors of the economy to meet the overall targets.

Figure 4.28: Whole economy GHG emission – EU28



However, in the Baseline scenario emissions decrease over time in line with the historical trend and current policy, albeit at a slightly slower pace. As the transition in the household sectors incrementally unfolds, the difference to baseline grows and by 2050, emissions are considerably lower than in the Baseline. Figure 4.29 shows these clearly, by separating out the emissions from the household sectors.

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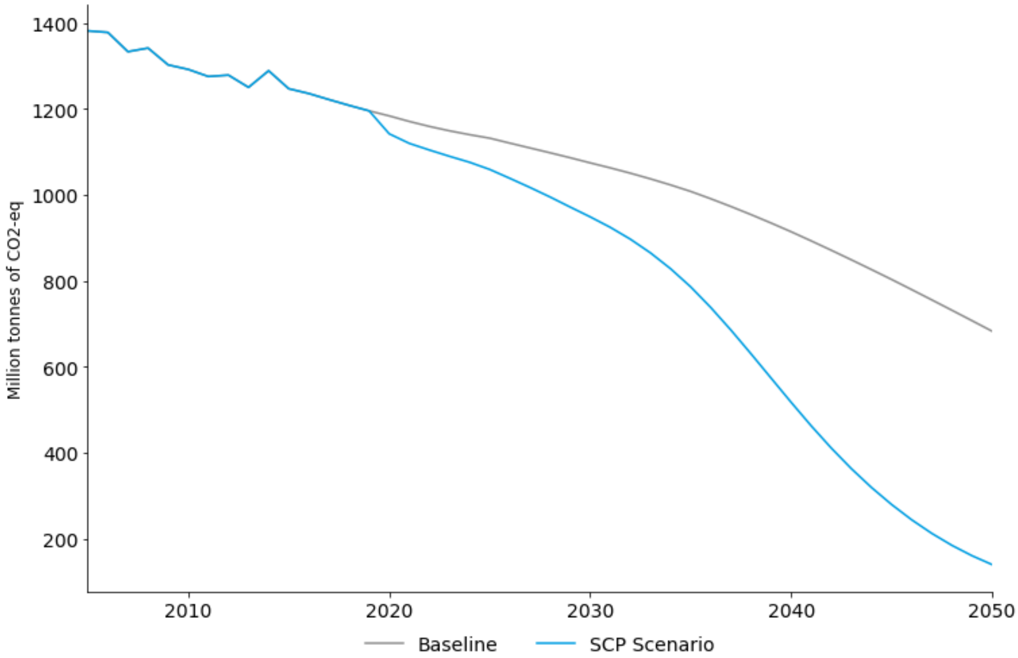
In the SCP Scenario, emissions from the household sectors drops to below 140 $MtCO_2eq$ by 2050, suggesting a deep decarbonisation of road transport and heating & cooling is possible if ambitious policies are introduced in rapid fashion.

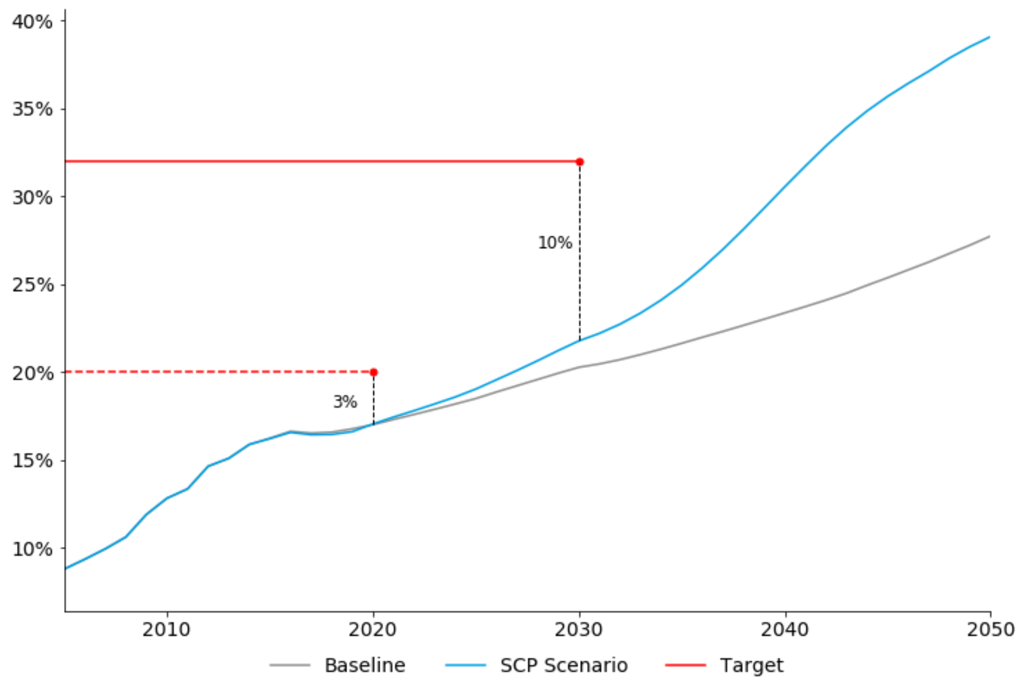
Figure 4.29: GHG emissions from households' (incl. mobility) – EU28



4.2.3.2 Share of renewable energy in final energy consumption

The 2030 Energy Union target is to achieve a 32% share of renewables in final energy consumption. In the SCP Scenario, the changes in the household sectors lead to a 22% share for renewables by 2030. By 2040 the SCP Scenario reaches 32% as more electric heating units and electric vehicles are adopted by households. In 2050, there is a 39% share of renewables in final energy consumption.

Figure 4.30: Share of renewable energy in final energy consumption – EU28



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This is in line with expectations; the SCP Scenario does not include any decarbonisation policies applied to the non-household sectors and only assumes a take up of decentralised solar PV plus an electrification of the heating sector and changing household mobility. While electrification of heating and mobility leads to some efficiency gains, and shifts away from 100% fossil fuel use, the precise impact upon the take-up of renewables in the power sector is unclear (and likely to be minor) – policies to directly decarbonise the power sector can help to ensure that this shift leads to higher use of renewables. The 10%-point shortfall in 2030 can realistically be recovered through power sector decarbonisation policies (e.g. coal power plant phase-out and feed-in tariffs for renewables) and an industry switch to renewable technologies, e.g. for heating would also help contribute to meeting the target.

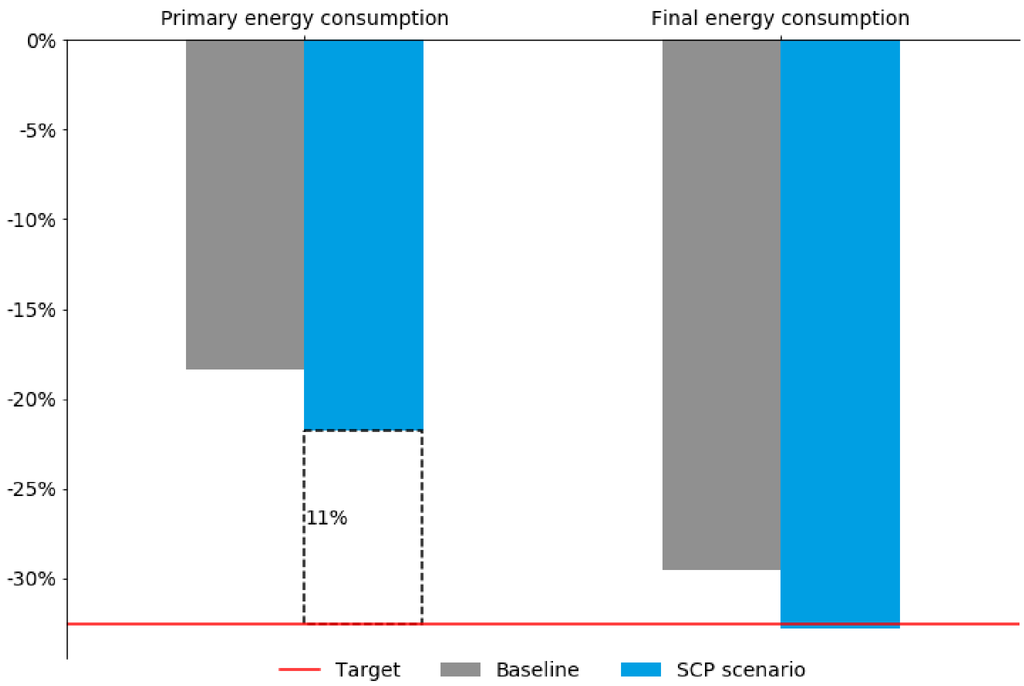
4.2.3.3 Energy efficiency

The 2030 targets for energy efficiency in the Energy Union are for primary and/or final energy consumption. A 32.5% reduction from the EU Reference Scenario in (2007)[30] results in an energy demand no greater than 1273 Mtoe for primary energy demand and 956 Mtoe for final energy demand (Directive EU 2018/2002).

When assessed against primary energy consumption, a reduction of 22% is reached by changes in the household sectors only. This is in line with expectations as the scenario does not include any efficiency measures or decarbonisation strategy which would reduce primary energy demand in the power sector.

However, when assessed against final energy consumption only, the household contribution narrowly exceeds the target; reaching 33% energy efficiency compared the EU Reference Scenario (2007) projections for 2030. This is the result of take up of e-Mobility, more efficient heating technologies and ambitious energy efficiency measures at the level of households.

Figure 4.31: 2030 primary and final energy consumption – EU28



[30] The baseline projections are from PRIMES EU reference scenario (2007). In this projection the 2030 primary energy consumption was 1887 Mtoe and final energy consumption was 1416 Mtoe.

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5 Conclusions

Households can deliver a significant contribution to the European energy transition. The modelling of a package of policy measures under the 'ENABLE.EU – Sustainable Citizens Practice (SCP) Scenario' indicates that, by 2030, households can help reduce by 29% the EU GHG emissions compared to 1990 levels, develop renewables so they account for 22% of the EU final energy consumption and increase energy efficiency by 23% (for primary energy consumption) or 33% (for final energy consumption). The area where household can contribute most is that of energy efficiency; with just ambitious changes within households, the energy efficiency target for final energy consumption could be met (albeit not for primary energy consumption).

However, while the contribution from households can be substantial, it is not sufficient to meet the EU energy-climate targets. To meet these targets, action and ambitious policy will be needed in other areas of the economy. On the one hand, the scenarios assessed in this report did not assume any policy intervention to decarbonise areas other than those directly related to household energy use, nor economy-wide policy measures to improve energy efficiency. On the other hand, the analysis shows that, by themselves, the changes in the household sectors have limited impacts on the power sector, and consequently on the CO_2 emissions from electricity generation. Additional policy measures targeting the power sector (e.g. higher carbon taxation, support schemes and probably direct control mechanisms), as well as a transition in industry to cleaner technologies and economy-wide improvements in energy efficiency, are needed to achieve the energy-climate targets.

Overall, the net economic impacts of the household transition in the EU is positive in the ENABLE.EU (SCP) Scenario. The policy packages included in this scenario are designed to encourage purchases of renewables and fuel-efficient technologies, while reducing consumption of fossil fuels, which are largely imported from outside the EU. The associated savings are likely to be spent, by households, on goods and services with a substantial domestic content, generating domestic multiplier effects and employment along supply chains in the European economy. There is a net positive effect to GDP in the EU28 over the projected period due to the changes in household spending, once adjustments (e.g. increased tax rates) are introduced to ensure that government balances are unaffected by the policy package. At the regional level (i.e. aggregations of Member States), Central Eastern European countries benefit the most from an economic perspective. This is due to a combination of two factors: the relative starting position and trading volumes.

The results also underline that, while both poor and rich households see a positive net change in their real incomes as a result of the transition in the household sectors, the relative change in real income is higher for poorer households. This shows that the energy transition does not need to affect low income groups negatively, provided that policy packages are designed in ways that safeguard real incomes and spread the cost of government policy fairly across the economy by using instruments that have progressive, rather than regressive, effects.

In short, the analysis of the ENABLE.EU (SCP) Scenario shows that ambitious policy action engaging households in the energy transition do provide a significant household contribution to reducing greenhouse gas emissions, developing renewables and increasing energy efficiency in Europe.

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7 Annexes

7.1 Scenario framework

Each section below contains a table which explains in detail how each policy and action are modelled. Below each table are a number of charts which present the data of some of the policies, in particular those policies which are not official policy levers in the model, but exogenous trends which have been inputted. 'All countries' in the text below refers to the EU 28 Members States plus Norway and Ukraine.

7.1.1 Sustainable Mobility

Policy and actions	How it was modelled
Subsidies for the purchase of electric vehicles	Three components were considered here: a subsidy, additional expenditure from households and a modal shift away from private vehicle demand to rail. 1. The subsidy was assumed to be 11% for all countries. The reduction in price causes a modal shift away from road transportation to rail; 2. The modal shift was calculated using the price elasticity of demand (PED) based on Spainish consumers of transportation (Hortelano A-O., 2016). A percentage drop in the price of rail tickets increases the demand for rail transportation by 0.58%, therefore a reduction in price of tickets by 11% increases the demand for rail by 6.4%, all things being equal. 3. Additional expenditure on rail by households was calculated by multiplying the shift in travel demand by the current unit expenditure on rail (current expenditure/current rail demand). This was then multiplied by 89% to reflect the proportion of the original ticket price that consumers pay (as the other 11% was paid for by the government).
Higher taxes on more polluting fuels and vehicles (including aviation)	Three separate taxes were imposed in the model to represent the policy. 1. A carbon registration tax of €45/gCO_2/km was inputted into the model between 2020 to 2030, it was increased to €90/gCO_2/km between 2030 and 2040, and €135/gCO_2/km (2015 prices) between 2040 and 2050. 2. A fuel tax of €0.10/L in 2020 gradually increasing to €1/L in 2050 (2015 prices) 3. Kerosene tax at €313 per toe (€330 per m3) imposed, on all flights in all countries.
Urban planning to promote cycling and car free zones in cities	Modal shift from private passenger vehicles to cycling in city centres - represents the introduction of car free zones in all EU28 MS's cities. Urban pkm is taken from the EU Reference Scenario (European Commission, 2016). In 2021, car free zones are introduced at 5% of all urban areas, representing bans

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	of smaller city centres. By 2050, this increases to 55%, representing car free zones in all city centres across EU28 MS. Once the forgone pkm was calculated this was then taken away from the exogenous trend of demand for vehicle transportation (veh-km).
No-emission zones in urban areas	Only electric vehicles are allowed to enter outer city ring and suburban areas.
Phase out of petrol and diesel ICEs country-wide	The new sales of petrol and diesel ICEs have been banned from 2030 onwards in all countries.
Car sharing	The figures for car sharing users and forgone sales are taken from the *Environmental potential of collaborative economy report* for DG Environment (Trinomics, 2017). 1. As a result of car sharing some individuals find that they no longer need to own a vehicle so the demand for vehicles reduces. Car sharing is introduced into the scenario package in 2020 with 9.3 million users across the EU. As more people utilise the same vehicle the required fleet to service the car sharing users is less than the amount required to service non-car sharers. It is assumed that the number of persons per car is equal to 2.3 in 2020, up from 2.04 in the baseline. This means there would be a reduction of 0.5 million sales in 2020 across the EU. Each year the number of car sharing users is assumed to increase reaching 29 million users by 2030, equivalent to the ambitious scenario in the DG Environment report. More car shares are assumed to utilise the same vehicle and the number of persons per car is assumed to be 4.1. This equates to a reduction of 7 million vehicles by 2030 of total sales in the EU. These amounts are based on the simplfying assumption that all new users of car sharing services were also in the market for purchasing a new car. 2. The reduction in sales is split across EU countries based on the number of urban inhabitants, the greater the number of urban inhabitants the greater possibilities for car sharing services, therefore higher number of users and forgone sales. 3. To capture the economic impacts of reduction in car demand vehicle purchases (consumer expenditure of vehicles) are expected to fall by 1% in 2020, rising to 3% in 2030. In line with the change in expenditure from the DG Environment report (Trinomics, 2017).
Subsidy for the purchase of electric vehicles	Subsidies were made available in the all countries for all electric vehicles, the subsidy imposed varied for the size of vehicle. €3,500 for luxury vehicles, €2625 for medium vehicle (75% of the subsidy for luxury) and €1750 for economy vehicles (50% of subsidy for luxury vehicles). The subsidy for luxury vehicles is based on the maximum amount of subsidy available for electric vehicles in the UK (gov.uk, 2019).
Public procurement for electric vehicles	Exogenous shares of electric mobility were added to all countries. This is to boost the model solution in some countries which already have electric mobility, and also to kick-start the transition in other countries which have no take up of electric vehicles at all, this is a problem for the modelling as it

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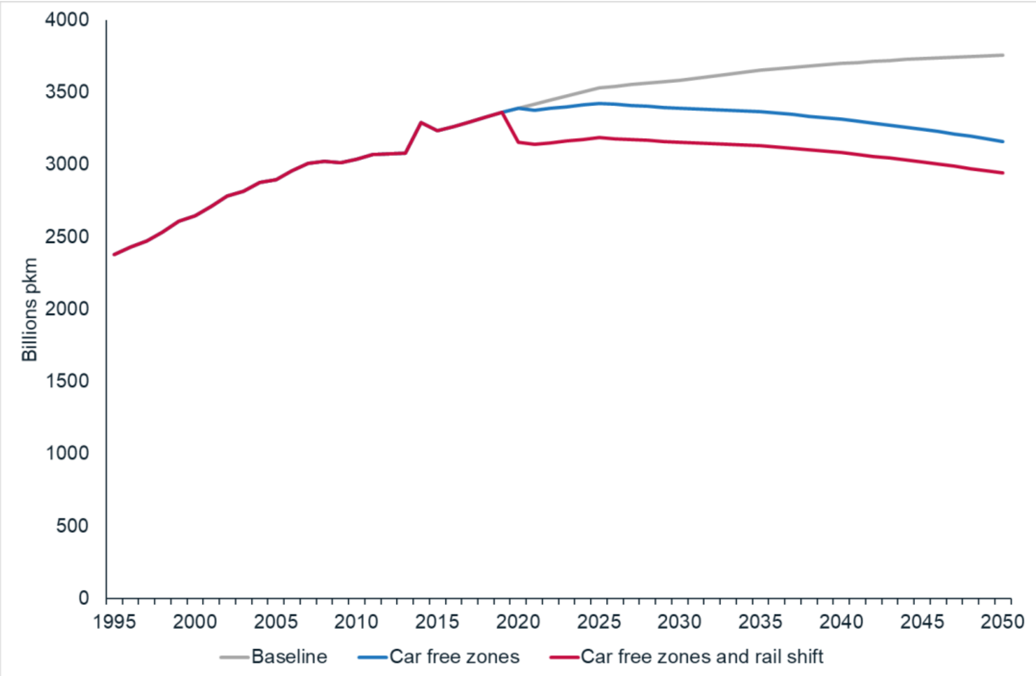
	requires some historical share to exist in order to increase its market share in future periods. This reflects the real-world situation that you can only buy goods which are available in the marketplace, it is not possible to buy something which no-one else has/not offered by the market. In 2025, all countries received a kick start to their electric fleet of half a percentage, reflecting government investment into public charging infrastructure and an electric vehicle fleet of company cars for government employees. Additions to the electric fleet continue.

The modal shift from cars to bikes, and cars to rail arising from car free zone and rail subsidy policies, respectively reduced the demand for private passenger kilometres by about 12% in 2030 and 22% in 2050 compared to baseline.

Figure 7.1: Private passenger transportation demand from car free zones and modal shift to rail – EU28



The size of the reduction in each country is presented in Figure 7.2 below for 2030 and 2050. The largest reductions are in countries with the biggest cities and therefore the highest amount of urban travel demand: The UK, Germany, France, Italy and Spain. This excludes Ukraine as there is insufficient data to include Ukraine in FTT:Transport.

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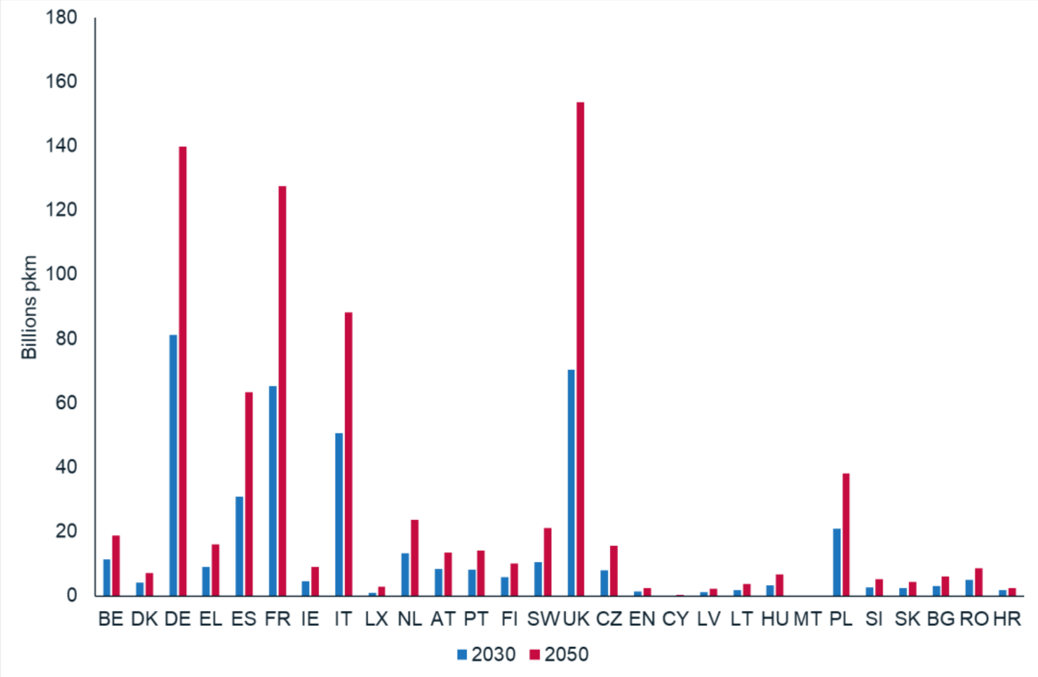
Figure 7.2: Size of reduction of private passenger demand from car free zones and rail transportation, by countries



A greater demand for rail transportation (from the subsidy on ticket prices) results in increased consumer expenditure for the sector. This is inputted into the macroeconometric model to capture the economic impacts of this shift. Figure 7.3 below shows the amount of additional rail expenditure in each MS in 2030 and 2050. Note Malta and Cyprus are not included here as they do not have any rail infrastructure, Ukraine is included here because the macroeconometric impacts of Ukraine are possible to capture.

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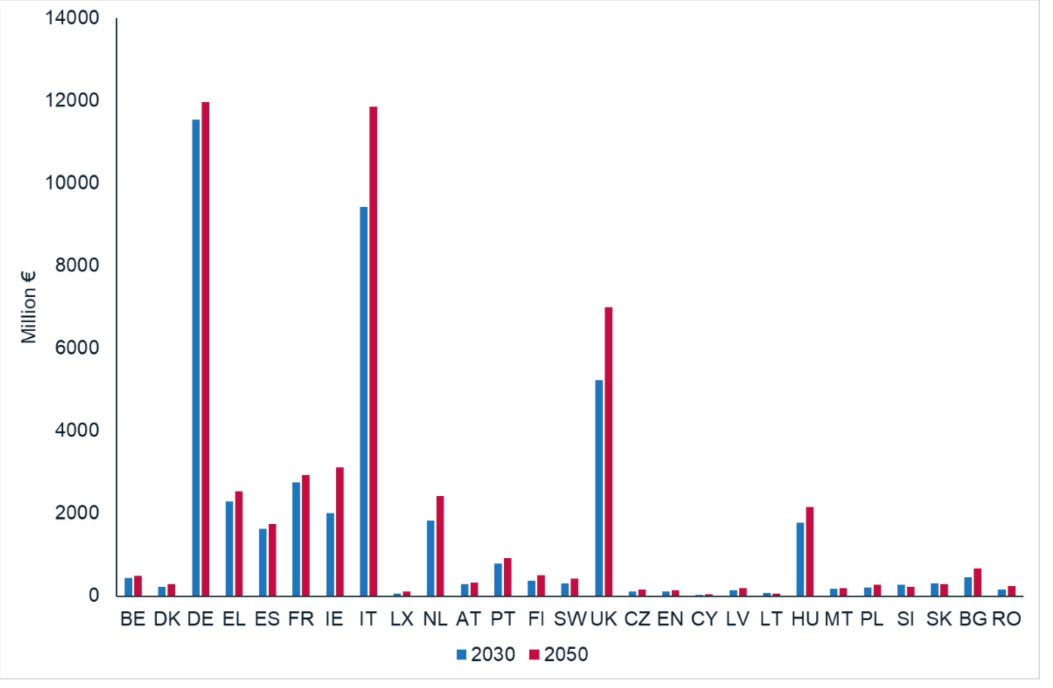
Figure 7.3: Additional consumer expenditure on rail transport services



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7.1.2 Energy Consumption and Saving

Policy and actions	How it was modelled
Subsidies and taxes	There are two components to this policy; an incentive and a disincentive: 1. The incentive is a subsidy equal to 50% of purchase and installation cost, for heat pumps, solar thermal systems and modern biomass boilers, this starts in 2020 and is phased out after 2030, eventually falling to zero in 2050. 2. Disincentive tax on residential use of fossil fuel: €45/tCO_2 in 2020 to increase to €180/tCO_2 in 2050 (2015, prices).
Government impose ban on fossil fuels	A ban is introduced in 2025 in all counties for all fossil fuel heat technologies (i.e. oil, gas and coal).
Government incentive for energy efficiency technology to reflect investment in education and awareness programmes	This is proxied in the model by government incentives for non-heating energy efficient technologies for households. There are two components to implement this in the model, investment and energy saving. 1. It is assumed that the government will fund the take up of energy efficient technologies, this is modelled by introducing exogenous investment across industrial sectors reflecting additional demand for builders of energy efficient technology. The exogenous amount is taken from the IEA 450 scenario, albeit with an increase of 25% to reflect greater ambition. The exogenous amount from IEA 450 scenario represents investment across all fuel users, not just households. Therefore, a scaling factor is applied to the investment to reflect only the household part. The scaling factor is equal to the ratio of household exogenous energy savings compared to total exogenous energy saving. 2. Exogenous household energy savings are added to household fuel demand. Again, this is in line with household savings from IEA 450 scenario plus an additional 25%.
More ambitious efficiency mandate for cooling technologies	Higher efficiency targets of cooling technologies are set in the Cooling model. These targets are based on the Efficient Cooling Scenario from the IEA (adjusted for Europe). See Figure 7.5 in section 7.2 Residential Cooling Model.
Government mandate the scrappage of inefficient/fossil fuel boilers	An endogenous scrappage rate is applied to countries which still have an existing share of fossil fuel heating systems left in the stock. The scrappage starts in 2030 and continues until the fossil fuel shares of a country are 0.
Public procurement (government installs tech in publicly owned housing	Countries without any share of renewable heating technologies receive an exogenous share of 1% to kick start the solution. This is a one off policy which occurs in 2020.

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7.1.3 Prosumption

Policy and actions	How it was modelled
Improve batteries technology and performance	Improvement of battery technologies increases the household's ability to retain its generated electricity rather than feed it back into the grid. This is modelled through reducing the export rate: By 2050 it is assumed that only 5% is exported to the grid. Note that the cost of battery storage is not considered here.
Greater provision of information - reduce regulatory barriers to investment	Regulator barriers in the model affect the required rate of return on investment (the amount of return needed for the investment to be attractive for the individual to invest). In the baseline these barriers (administrative, permitting requirements and rules of access to the grid) take on the value of 1, 0 or -1, representing low, medium and high barriers/rules. To represent a relaxed regulatory framework these barriers are set to 1 for all countries in the model. Apart from Italy, where the rules to access the grid were set to 0 in order to avoid overestimation.
Mandatory installation of solar PV in all new buildings	All new buildings in the model are assumed to come fitted with a solar PV. The cost of investment is assumed to be passed on to the consumer through an increase in the house price.
Feed-in-Tariff	All countries received a FiT between: €0.05/kWh and €0.75/kWh.
Green loans	Green loans were only provided to a select number of countries where the FiT was no longer effective. Countries with green loans were able to receive loans 1 percentage point lower than the available interest rate.
Subsidies	Subsidies were introduced in the model to boost the take up even further, where FiT and Green loans were no longer effective. The subsidy is 40% of the eligible costs of CAPEX and is based on the average of all the current available subsidies.

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Countries	Feed-in-Tariff (€/kWh)	Interest rate (%)	Subsidy (€)
Belgium	0.09	2.09	-
Bulgaria	0.10	2.50	1,624
Czech Republic	0.12	2.72	-
Denmark	0.75	3.46	-
Germany	0.00	1.83	-
Estonia	0.50	2.38	-
Ireland	0.40	1.59	1,261
Greece	0.12	1.39	1,972
Spain	0.12	0.95	1,898
France	0.10	0.80	2,492
Croatia	0.40	2.32	2,227
Italy	0.00	2.05	-
Cyprus	0.07	2.77	2,628
Latvia	0.50	1.99	-
Lithuania	0.12	0.81	2,813
Luxembourg	0.10	0.87	1,459
Hungary	0.11	2.39	1,682
Malta	0.10	3.14	1,175
Netherlands	0.00	1.41	-
Austria	0.75	1.85	794
Poland	0.18	3.70	1,255
Portugal	0.25	0.82	1,335
Romania	0.40	2.45	977
Slovenia	0.40	1.17	893
Slovakia	0.11	0.97	1,945
Finland	0.25	0.52	1,034
Sweden	0.20	1.71	2,526
United Kingdom	0.06	1.24	2,610

Table 7.1: Values of economic incentives for Energy Production

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Note countries with green loans are Spain, Finland, France, Greece, Ireland, Lithuania, Luxembourg, Latvia, Portugal, Slovenia, Bulgaria, Croatia, Hungary, Romania, United Kingdom. All these countries have a 1 percentage point rate lower than the rate in the baseline.

Note countries with subsidies at 40% of CAPEX cost are Bulgaria, Greece, Spain, France, Croatia, Hungary, Portugal, Romania, Slovakia, United Kingdom. Subsidies in other countries included in the table above are not additional policies of this scenario package but based on existing policies. Other additional policies include reduced or exempt VAT rates and net-metering.

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7.1.4 ENABLE.EU: Sustainable Citizens Practice Scenario

This scenario is the combination of all of the above policies, no additional policies are added here.

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7.2 Residential Cooling Model

7.2.1 Methodology

The energy demand for AC units (AC_{demand}) is a function of the average energy consumption, measured as the unit energy consumption (UEC) of households with AC units multiplied by the number of dwellings with AC units.

$$AC_{demand} = UEC_{eff} * Dwl_{AC}$$

The UEC_{eff} is the UEC divided by the year on year change in efficiency of AC units. The inclusion of a change in efficiency means that any improvements in AC efficiency are taken into via lower levels of UEC_{eff} (e.g. a large increase in energy efficiency from one year to the next will reduced demand for cooling).

$$UEC_{eff} = \frac{UEC}{Efficiency\ improvements}$$

The UEC (kWh/household/year) is parameterised by Isaac and van Vuuren (2009) based on regional UEC data in the literature. The equation assumes a linear relationship with cooling degree days (CDD) and a logarithmic relationship with income per capita GDP_{pc}.

$$UEC = CDD * (0.865 * \ln(GDP_{pc}) - 6.04)$$

The number of dwellings with AC units is the number of total dwellings (Dwl) multiplied by the share of dwellings with AC units, referred to here as the $Penertation\ rate$.

$$Dwl_{AC} = Dwl * Penertation\ rate$$

The penetration rate is a function of the diffusion of AC units ($Diffusion\ rate$) and maximum climate saturation of AC units.

$$Penertation\ rate = Diffusion\ rate * Max\ climate\ saturation$$

The maximum climate saturation represents the demand for AC units given the number of cooling degree days. The higher the cooling degree days the greater demand there is for AC units, however because the function follows an exponential form a sufficiently high CDD will result in only a small increase demand for AC units, i.e. the demand reaches saturation.

$$Max\ climate\ saturation = 1 - 0.949 * e^{-0.00187*CDD}$$

The diffusion rate of AC units is a function of the average level of income per capita. A higher level of income will result in a higher diffusion rate.

$$Diffusion\ rate = \frac{1}{1 + e^{4.152-0.237*\frac{GDP_{PC}}{1000}}}$$

The penetration rate is therefore a function of cooling degree days and income level. Consumer base their decisions on whether to invest in AC units given their level of income

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and the temperature of their country.

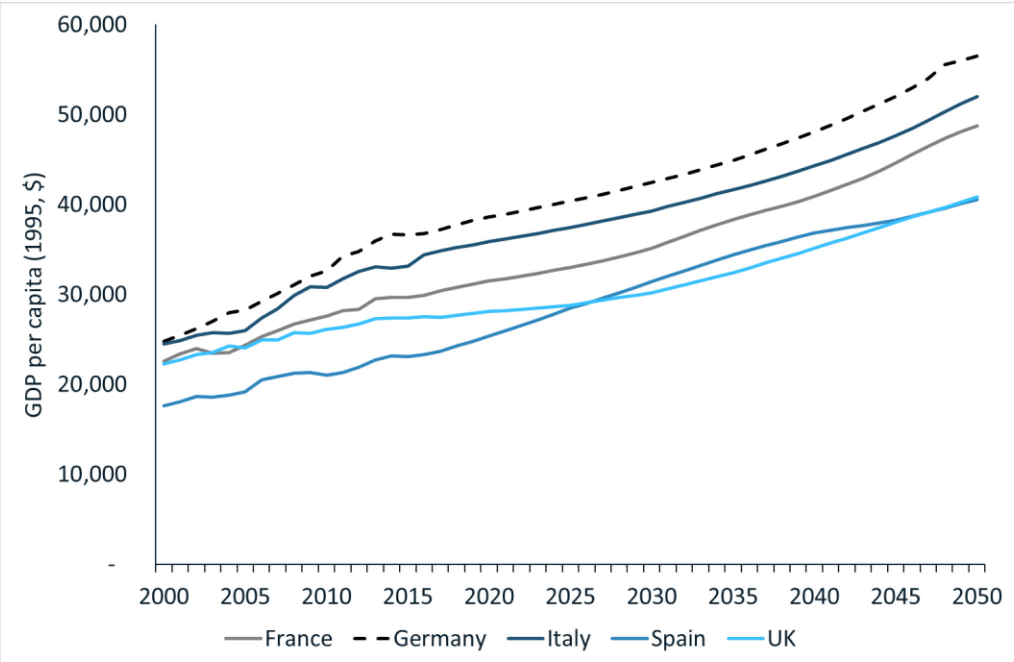
7.2.2 Calibration

Since there is a lack of historic data on energy cooling from AC units for EU countries the model was calibrated based on the penetration rate. Historic data for penetration rate was available data from Odyssee database available on the EU Buildings Database[31]. Historic data penetration was available from Germany, Spain, France, Netherlands, Portugal, Cyprus, Malta, Slovenia, Bulgaria and Croatia. The difference was used to adjust the model penetration to match that of the real data. The calibration factor was then applied to the available countries for both the historic and projected years.

7.2.3 Income per capita

Income per capita is proxied by GDP per capita estimates from the World Bank. The metric has been rebased to the year 1995, consistent with the data used in the original study, and grown in line with GDP per capita from the E3ME baseline (see Figure 7.4).

Figure 7.4 GDP per capita



7.2.4 Energy efficiency of AC units

[31] EU Building Database (2019). *Share of dwelling with residential AC.* https://ec.europa.eu/energy/en/eu-buildings-database

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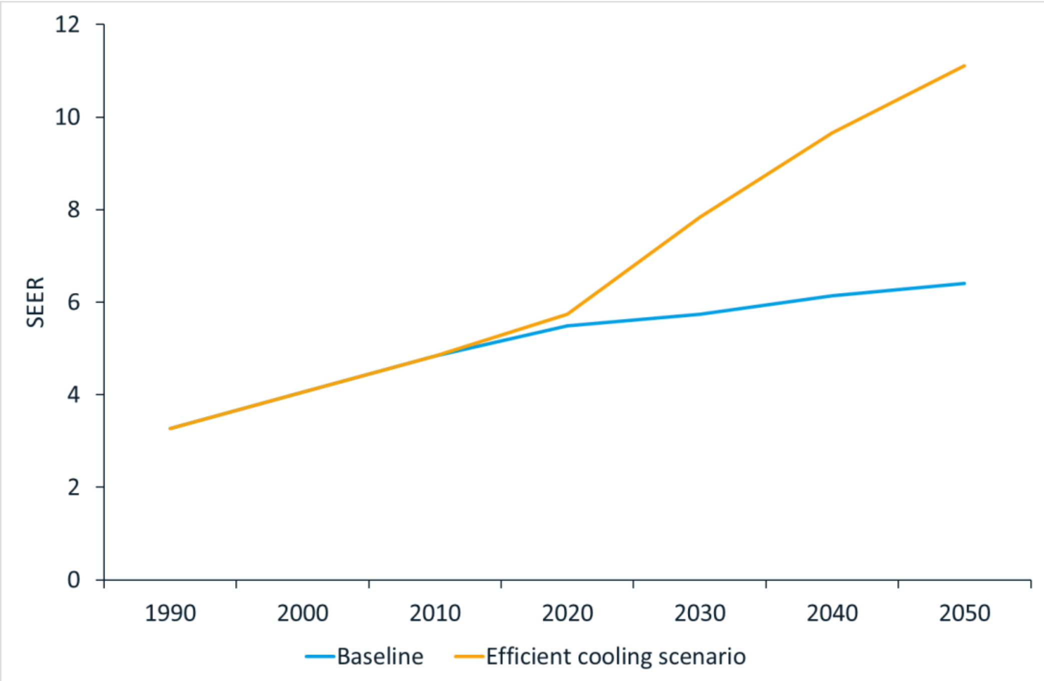
Energy efficiency of AC units are measured as the seasonal energy efficiency ratio (SEER), the baseline and efficient cooling scenario values are taken from *The Future of Cooling* report by the IEA (2018). The SEER used in this methodology has been adjusted to European

Figure 7.5: Energy efficiency of AC units



SEER - the IEA estimated only a global average SEER.

7.2.5 Cooling degree days

Historic cooling degree days data are from Eurostat and available on a per country basis, except for Ukraine, which is proxied by Romania[32]. Cooling degree days are projected based on findings from a paper by Spinoni et. al (2017). They predict the change in cooling degree days in specific regions of Europe up to 2100 under two representative concentration pathways (RCP4.5 and RCP8.5). Figure 7.6 below shows the (historic and projected) cooling degree days in Italy under both scenarios. As can be expected the historical data show fluctuations in cooling degree days, due to temperature variations between years caused by the presence/absence of summer heat waves. Unfortunately, this data is not accounted for when the data is projected forward. RCP8.5 is used for the modelling which is consistent to the RCP used in the Baseline of the E3ME model.

As Spinoni et. al (2017) evaluate the change in cooling degree days for European regions a mapping exercise was carried out – each country was mapped to the corresponding European region (see Table 7.2). We have attempted to be consistent with the mapping used in the active energy consumption case study, however in the paper there is additional disaggregated regions which means it is not entirely consistent.

[32] Although Romania has a slightly different latitude it is situated in a similar part of Europe, has a similar landmass and similar exposure to the Black Sea.

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Figure 7.6: Cooling degree days

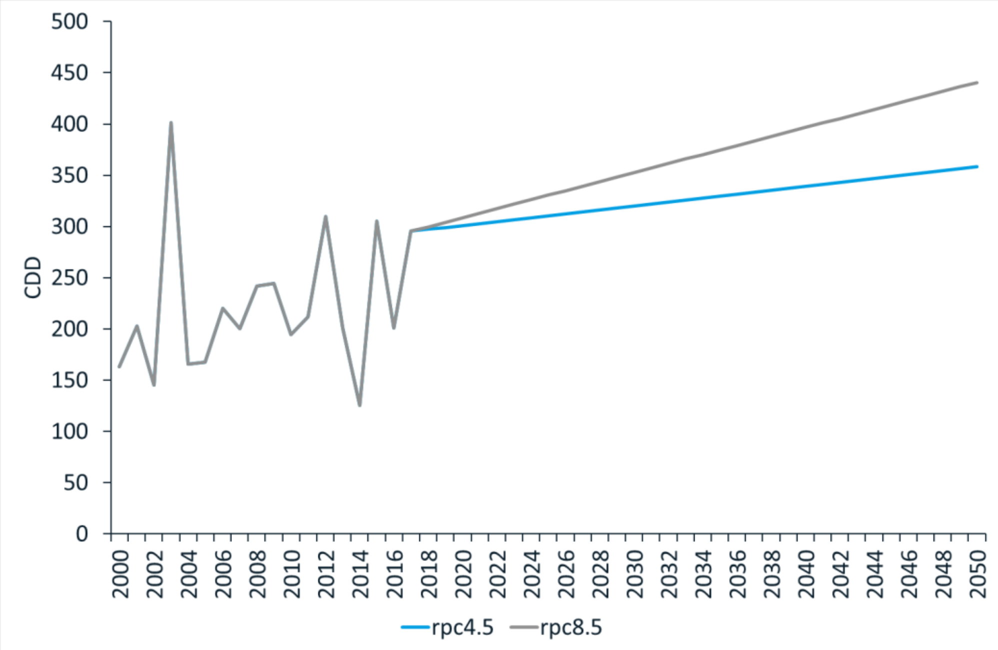

Table 7.2: Country mapping to European Region

Countries	Region (Spinoni et. al, 2017)
Belgium	France + Benelux
Denmark	Northern Europe
Germany	Central Europe
Greece	Mediterranean region
Spain	Iberian Peninsula
France	France + Benelux
Ireland	British Isles
Italy	Mediterranean region
Luxembourg	France + Benelux
Netherlands	France + Benelux
Austria	Central Europe
Portugal	Iberian Peninsula
Finland	Northern Europe
Sweden	Northern Europe
UK	British Isles
Czech Republic	Central Europe
Estonia	Eastern Europe
Cyprus	Mediterranean region
Latvia	Eastern Europe
Lithuania	Eastern Europe
Hungary	Central Europe
Malta	Mediterranean region
Poland	Central Europe
Slovenia	Mediterranean region
Slovakia	Eastern Europe
Bulgaria	Eastern Europe
Romania	Eastern Europe
Croatia	Mediterranean region

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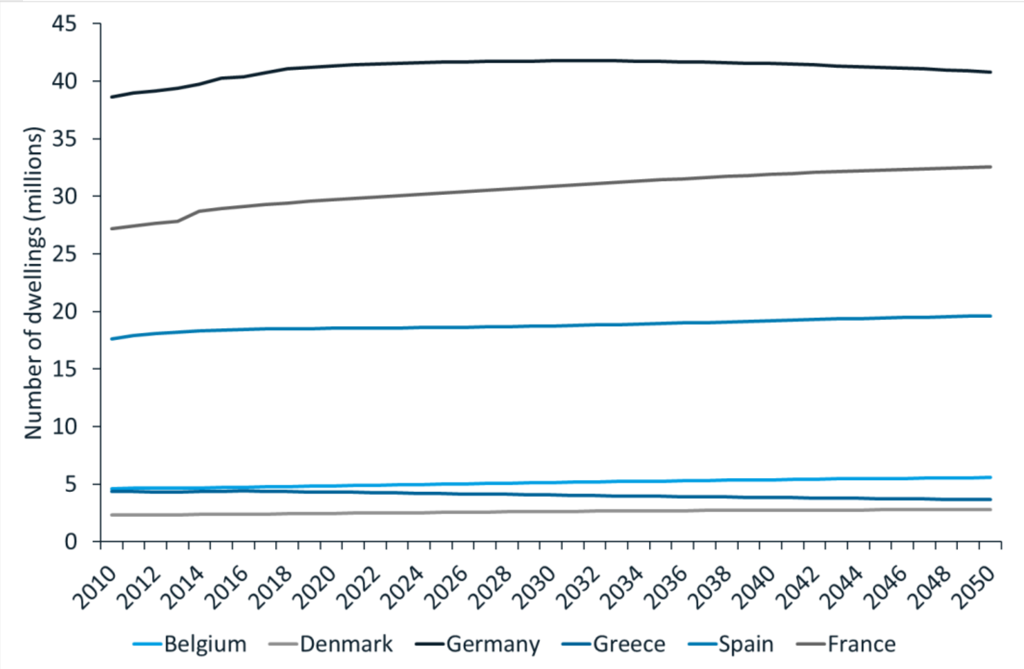
Ukraine	European Russia

7.2.6 Number of dwellings

Number of dwellings was taken from Eurostat for EU Member States and for Ukraine from their State Statistics Service[33]. The numbers of dwellings are assumed to grow in line with Eurostat's population projections. The UN population projections were used for Ukraine.

Figure 7.7: Number of dwellings



[33] Number of dwellings: State Statistic Services of Ukraine. https://ukrstat.org/en/druk/publicat/kat_e/pubhousehold_e.htm

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7.3 Residential Prosumer Model: key data and assumptions

The residential prosumer model simulates the take up of solar PV in European Member States, Iceland and Norway. The starting point for the model is the calculation of technical potential.

The technical potential is the upper limit of solar PV that can be installed per country. In this calculation it is assumed that only homeowners (with or without mortgage) are able to invest in solar PV, renters do not enter the market because of split incentives– asymmetry between who pays and who benefits (i.e. benefits accrue to residents who pay the electricity bill, while the cost of installation would fall on owners). Based on the average size of dwellings and number of households from Eurostat an estimate for the total roof area is determined. A reduction factor is then applied to include only those households which are suitable for investment (e.g. have a south facing roof).

The cost-effectiveness distribution curve takes into account the financial benefits and costs from solar PV installations. These costs are spread over the lifetime of the solar PV. In order to determine today's value, i.e. the net present value (NPV), these benefits and costs are discounted using the market interest rate. The market interest rate is the rate at which households can borrow money against their mortgage (to reflect the probable decision environment of an investment by a household). The net present value is the net present benefit minus the net present cost. The net present benefit is defined by the discounted future revenue from the electricity bill savings, Feed-in-Tariff income and net metering income. The net present cost is the CAPEX cost, discounted OPEX costs, grid fees and taxes. The NPV is calculated for the mean household in each country in each year up to 2050.

To carry out the calculation of technical potential and for the NPV a number of assumptions are made, based on the most recent data available for each country. Below, the key data and assumptions are presented.

7.3.1 Population

Eurostat is the source for past, current and future population levels in the EU28 countries, covering the period 2007 - 2070. Specifically, historical data up to 2018 are retrieved from the *demo_pjan* series[34] , while future projections are taken from the *proj_15npms* series (2017). Table 7.3 provides an overview of the assumed population levels in 2030, 2050 and 2070 together with the annual growth rates in each country over the projected periods.

Table 7.3: Population projections

	2020 - 2030		2030 - 2050		2050 - 2070	
	('000) 2030	% pa	('000) 2050	% pa	('000) 2070	% pa
Belgium	12,264	0.6	13,273	0.4	13,888	0.2
Bulgaria	6,408	-0.8	5,564	-0.7	4,872	-0.7
Czech Republic	10,692	0.0	10,478	-0.1	9,983	-0.2
Denmark	6,298	0.7	6,685	0.3	6,826	0.1
Germany	84,613	0.1	82,687	-0.1	79,293	-0.2
Estonia	1,306	-0.1	1,257	-0.2	1,178	-0.3
Ireland	5,146	0.6	5,693	0.5	6,035	0.3

34 https://ec.europa.eu/eurostat/web/products-datasets/-/demo_pjan

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Greece	9,945	-0.6	8,919	-0.5	7,686	-0.7
Spain	47,110	0.1	49,257	0.2	49,828	0.1
France	70,525	0.4	74,377	0.3	76,947	0.2
Croatia	3,955	-0.3	3,675	-0.4	3,402	-0.4
Italy	60,350	-0.1	58,968	-0.1	54,936	-0.4
Cyprus	920	0.6	984	0.3	1,019	0.2
Latvia	1,744	-0.9	1,506	-0.7	1,343	-0.6
Lithuania	2,411	-1.3	1,957	-1.0	1,724	-0.6
Luxembourg	755	1.8	938	1.1	1,035	0.5
Hungary	9,665	-0.1	9,287	-0.2	8,884	-0.2
Malta	489	0.8	513	0.2	521	0.1
Netherlands	18,393	0.6	19,235	0.2	19,539	0.1
Austria	9,676	0.7	10,248	0.3	10,172	-0.0
Poland	37,214	-0.2	34,373	-0.4	30,966	-0.5
Portugal	9,880	-0.3	9,116	-0.4	8,009	-0.6
Romania	18,024	-0.7	16,331	-0.5	15,015	-0.4
Slovenia	2,080	0.0	2,045	-0.1	1,957	-0.2
Slovakia	5,464	0.0	5,262	-0.2	4,909	-0.3
Finland	5,698	0.2	5,688	-0.0	5,626	-0.1
Sweden	11,237	0.9	12,681	0.6	13,842	0.4
United Kingdom	71,564	0.6	77,569	0.4	80,960	0.2

Source: Eurostat, Statistics Iceland, Statistical Office of the Republic of Serbia and World Population Prospects 2017.

7.3.2 Number of households

Population projections were used to determine future changes in the number of households in each country, with the results presented in Table 7.4 for 2020, 2030, 2040 and 2050. Historical data on the number of households up to 2017 is taken from Eurostat (*lfst_hhnhtych*)[35].

Table 7.4: Projections for the number of private households

	2020	2030	2040	2050
	('000)	('000)	('000)	('000)
Belgium	4,858	5,144	5,388	5,568
Bulgaria	2,845	2,622	2,427	2,276
Czech Republic	4,730	4,748	4,686	4,653
Denmark	2,454	2,625	2,736	2,786
Germany	41,330	41,755	41,518	40,804
Estonia	585	580	570	558
Ireland	1,824	1,935	2,028	2,140
Greece	4,309	4,058	3,844	3,639
Spain	18,526	18,744	19,196	19,598
France	29,760	30,947	31,996	32,637
Croatia	1,449	1,401	1,353	1,302
Italy	25,920	25,763	25,605	25,173

[35] https://ec.europa.eu/eurostat/web/products-datasets/-/lfst_hhnhtych

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Cyprus	323	342	355	366
Latvia	833	760	697	657
Lithuania	1,310	1,149	1,014	933
Luxembourg	258	310	353	385
Hungary	4,128	4,076	3,994	3,916
Malta	148	159	165	167
Netherlands	7,970	8,420	8,713	8,805
Austria	3,992	4,289	4,472	4,543
Poland	14,450	14,177	13,653	13,094
Portugal	4,063	3,932	3,802	3,628
Romania	7,335	6,865	6,501	6,220
Slovenia	885	887	881	872
Slovakia	1,883	1,884	1,853	1,815
Finland	2,684	2,749	2,761	2,744
Sweden	5,008	5,467	5,835	6,169
United Kingdom	29,432	31,326	32,832	33,955

Source: Cambridge Econometrics.

7.3.3 Technical potential

The technical potential reflects the upper limit of solar PV capacity which can be installed in a given country. The number of households and average size of dwellings are used to estimate the total rooftop area, then reduction factors are applied to account for shading and houses without space for solar PV (e.g. apartments) to arrive at an estimate for technical potential. A similar approach is used in Brinkerhoff (2015), Wiginton, L.K. et al. (2010) and Lehman and Peter (2003).

Table 7.5: Technical potential in 2017

	Number of households (000s)	Estimated total rooftop area of residential dwellings (km sq)	Proportion of homes suitable for Solar PV	Percentage usable roof area	Potential residential Solar PV capacity (GW)
Belgium	4,762	370	59%	40%	10.5
Bulgaria	2,905	133	45%	40%	2.9
Czech Republic	4,698	229	37%	40%	4.1
Denmark	2,396	177	45%	40%	3.8
Germany	40,723	2,400	19%	40%	22.1
Estonia	584	24	29%	40%	0.3
Ireland	1,798	91	65%	40%	2.9
Greece	4,394	243	28%	40%	3.3
Spain	18,513	1,147	24%	40%	13.1
France	29,314	1,717	45%	40%	37.4
Croatia	1,472	75	72%	40%	2.6
Italy	25,865	1,513	34%	40%	24.6
Cyprus	318	28	54%	40%	0.7
Latvia	850	33	25%	40%	0.4
Lithuania	1,357	54	36%	40%	0.9
Luxembourg	242	20	52%	40%	0.5

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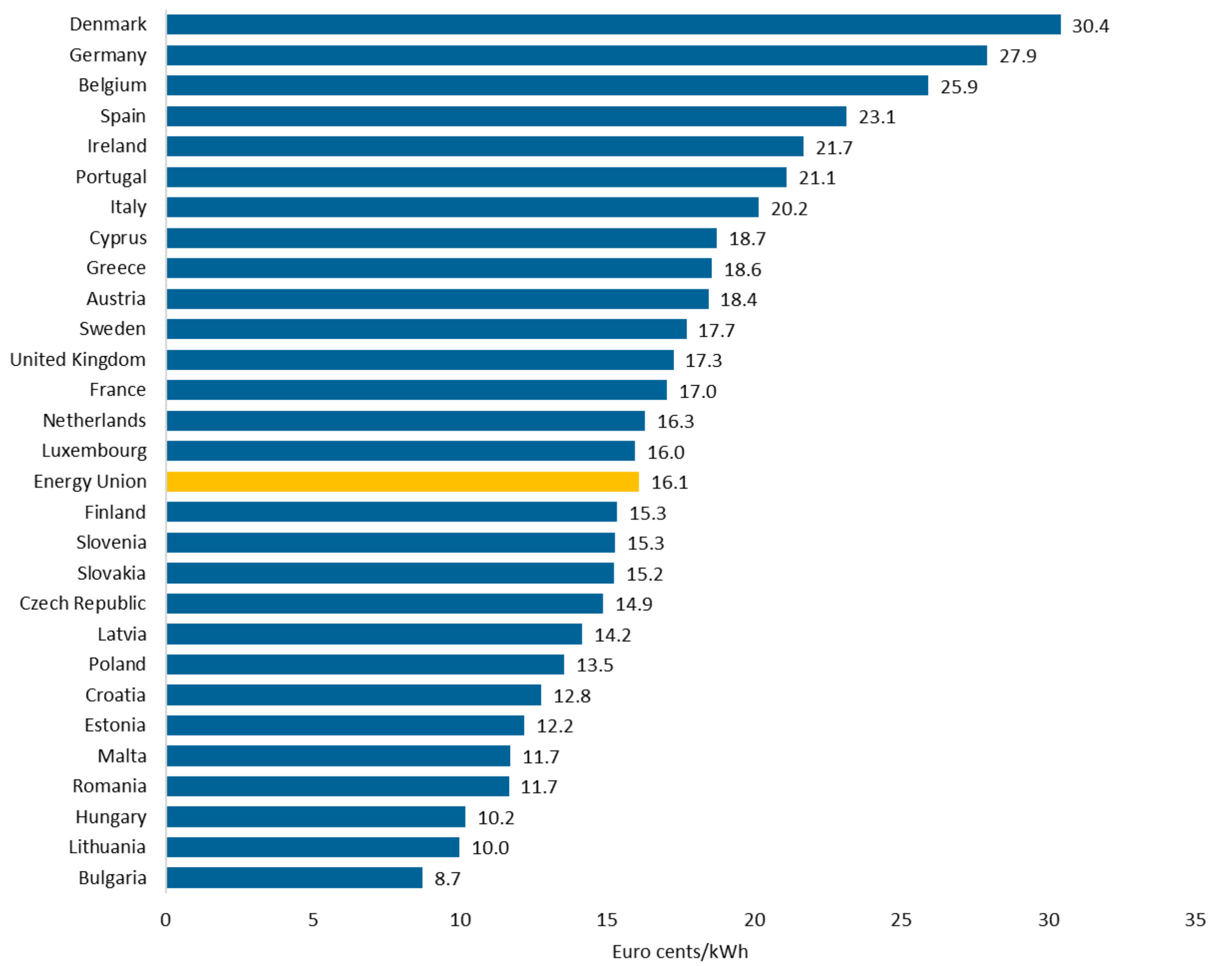
Hungary	4,131	195	61%	40%	5.7
Malta	150	9	37%	40%	0.2
Netherlands	7,819	521	53%	40%	13.2
Austria	3,889	242	31%	40%	3.6
Poland	14,466	680	48%	40%	15.6
Portugal	4,103	273	42%	40%	5.5
Romania	7,482	205	64%	40%	6.3
Slovenia	881	44	55%	40%	1.2
Slovakia	1,875	102	45%	40%	2.2
Finland	2,656	147	48%	40%	3.4
Sweden	4,863	314	36%	40%	5.5
United Kingdom	28,822	1,369	58%	40%	38.0

7.3.4 Electricity prices

Electricity prices faced medium size households are sourced from Eurostat (*ten00117*)[36] and

Figure 7.8: Electricity prices for medium sized households incl. taxes levies (Euro cents/kWh, 2014 prices), by Member States



36 http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&plugin=1&language=en&pcode=ten00117

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assumed to grow in line with electricity price projections from the EU Reference Scenario (European Commission, 2016).

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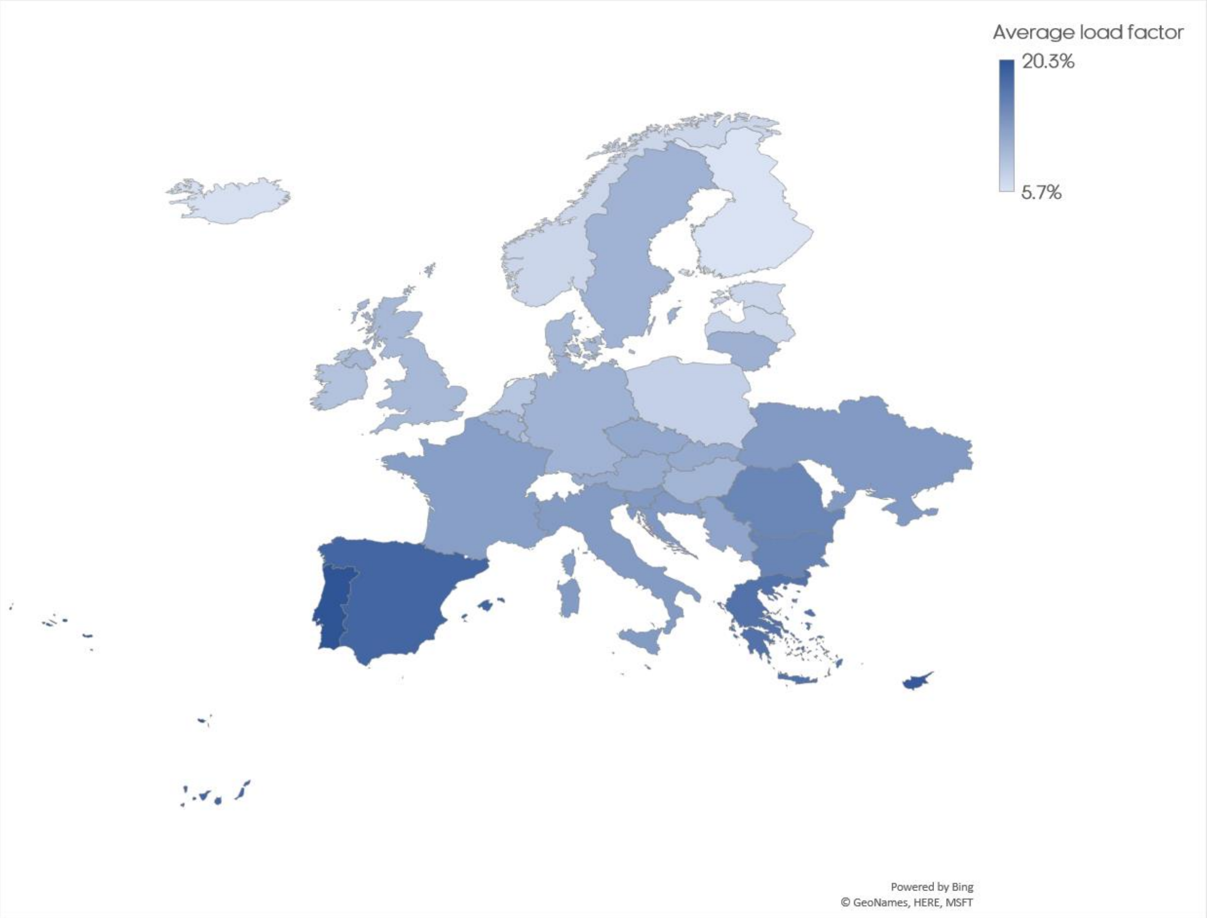
7.3.5 Load factor

The load factor is the average quantity of electricity generated per hour relative to the maximum possible amount that could be generated for a given capacity. Being influenced by a range of factors, including weather conditions, air particulates and the efficiency of solar modules, it varies across countries. Load factors were estimated from infrastructure[37] and production[38] data from Eurostat. The load factor is then kept constant over the projected period. When data was not available for a specific country, the load factor for a country at the same latitude was used.

Figure 7.9: Average load factors (%), by Member States



Source: Eurostat.

7.3.6 CAPEX and OPEX cost

The large economies of scale and the efficiency improvements in the manufacturing process have already caused large reductions in the CAPEX costs for solar PV (Figure 7.10). Going into the projected period the CAPEX costs are assumed to continue to decrease, especially with the relaxation of the anti-dumping legislation in the European Union (2018)[39]

[37] https://ec.europa.eu/eurostat/web/products-datasets/-/nrg_113a
[38] https://ec.europa.eu/eurostat/web/products-datasets/-/nrg_109a
[39] http://trade.ec.europa.eu/doclib/press/index.cfm?id=1904

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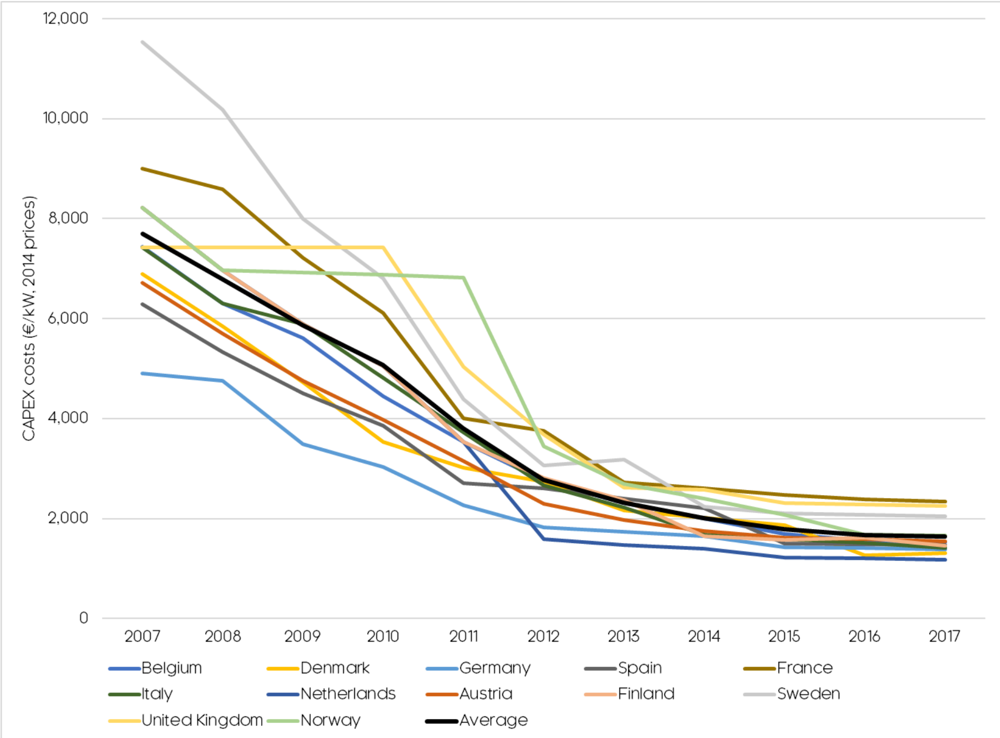
– this is considered. The capex cost is projected to fall at a rate of 1.4% per annum in each Member State.

Figure 7.10: Historical CAPEX costs (€/kW, 2014, prices)



Source: Cambridge Econometrics on IEA estimates.

OPEX costs are taken from Brinkerhoff (2015) and Fraunhofer ISE (2016), and rely on the assumption that a €1,000 inverter needs to be replaced once every ten years in all countries. The OPEX cost is projected to fall at a rate of 0.2% per annum in each Member State.

7.3.7 Historical policy

The following tables summarise the assumed policies in the latest years of history in the model. Table 7.6 shows feed-in-tariffs, export tariffs and net metering generating an income for prosumers in each country, Table 7.7 presents the assumed subsidies to reduce PV installation costs and reduced VAT rates on solar panels.

Table 7.6: Latest policy assumptions for feed-in tariffs, export tariffs and net metering schemes

	FiT rates (€/kWh, real 2014)			Export tariffs (€/kWh, real 2014)		
	2016	2017	2018	2016	2017	2018
Belgium	-	-	-	n.m.	n.m.	n.m.
Bulgaria	-	-	-	0.125	0.128	0.110
Czech Republic	-	-	-	-	-	-
Denmark	-	-	-	n.m.	n.m.	n.m.
Germany	-	-	-	0.119	0.117	0.113

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Estonia	-	-	-	0.052	0.050	0.049
Ireland	-	-	-	-	-	-
Greece	-	0.102	0.092	n.m.	n.m.	n.m.
Spain	-0.049	-0.042	-	-	-	-
France	-	-	-	0.129	0.098	0.097
Croatia	-	-	-	0.146	0.146	0.144
Italy	-	-	-	0.042	0.053	0.060
Cyprus	-	-	-	n.m.	n.m.	n.m.
Latvia	-	-	-	n.m.	n.m.	n.m.
Lithuania	0.067	0.064	0.062	n.m.	n.m.	n.m.
Luxembourg	-	-	-	0.159	0.165	0.138
Hungary	-	0.096	0.090	n.m.	n.m.	n.m.
Malta	-	-	-	0.159	0.155	0.150
Netherlands	-	-	-	n.m.	n.m.	n.m.
Austria	-	-	-	0.080	0.075	0.074
Poland	0.170	-	-	-	-	-
Portugal	-	-	-	0.091	0.090	0.089
Romania	-	-	-	-	-	-
Slovenia	-	-	-	n.m.	n.m.	n.m.
Slovakia	0.086	0.084	0.091	-	-	-
Finland	-	-	-	-	-	-
Sweden	-	-	-	-	-	-
United Kingdom	0.047	0.046	0.042	0.059	0.057	0.056

Notes: 'n.m.' stands for 'net metering'.

Source: Cambridge Econometrics.

Table 7.7: Latest policy assumptions for subsidies and VAT rate

	Subsidy value (€ real 2014)			VAT rate on solar panels		
	2016	2017	2018	2016	2017	2018
Belgium	-	-	-	21%	21%	21%
Bulgaria	-	-	-	20%	20%	20%
Czech Republic	-	-	-	21%	21%	21%
Denmark	-	-	-	25%	25%	25%
Germany	-	-	-	19%	19%	19%
Estonia	-	-	-	20%	20%	20%
Ireland	-	-	1,282	23%	23%	23%
Greece	-	-	-	24%	24%	24%
Spain	-	-	-	21%	21%	21%
France	-	-	-	10%	10%	10%
Croatia	-	-	-	25%	25%	25%
Italy	-	-	-	10%	10%	10%
Cyprus	-	2,707	2,673	19%	19%	19%
Latvia	-	-	-	21%	21%	21%

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Lithuania	3,479	3,430	3,382	21%	21%	21%
Luxembourg	1,804	1,779	1,754	17%	17%	17%
Hungary	1,560	1,539	-	27%	27%	27%
Malta	1,453	1,433	1,413	18%	18%	18%
Netherlands	-	-	-	0%	0%	0%
Austria	831	820	808	20%	20%	20%
Poland	1,552	1,530	1,509	0%	0%	0%
Portugal	-	-	-	23%	23%	23%
Romania	-	-	-	19%	19%	19%
Slovenia	1,105	1,090	1,074	22%	22%	22%
Slovakia	1,058	1,058	-	20%	20%	20%
Finland	1,146	1,034	1,034	24%	24%	24%
Sweden	2,562	2,526	2,526	25%	25%	25%
United Kingdom	-	-	-	5%	5%	5%

Source: Cambridge Econometrics.

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7.4 Detailed results from EEMM and EEGM

This section provides a detailed regional breakdown of the EEMM (power sector) and EGMM (gas sector) modelling on four EU regions. More detailed gas market results are introduced first, followed by the results for power sector developments.

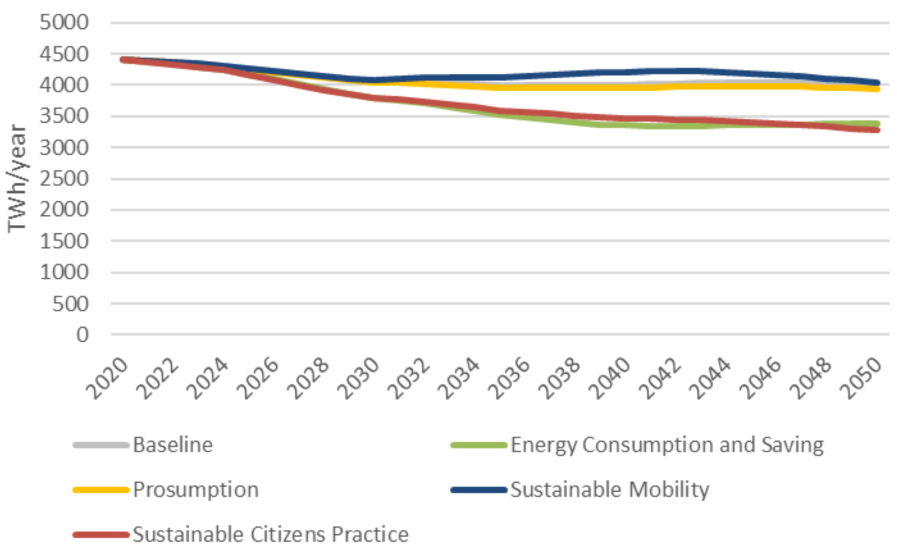
Table 7.8: Pre-defined regions classifications

Pre-defined regions	Countries
Nordic region (Nordic)	Denmark, Estonia, Latvia, Lithuania, Finland and Sweden,
Central Eastern Europe (CEE)	Austria, Bulgaria, Czech Republic, Croatia, Hungary, Poland, Romania, Slovenia and Slovakia
Western Europe (WE)	Belgium, France, Netherlands, Luxembourg, Germany, Ireland and United Kingdom
Mediterranean region (MED)	Cyprus, Greece, Italy, Malta, Portugal and Spain

7.4.1 Decomposition of results from EEGM

Based on the change of natural gas consumption modelled by E3ME, the effects of different gas demand paths on the European gas markets were modelled using EGMM. The effect on wholesale gas prices, on gas expenditures and on import dependency of different European regions were quantified.

Figure 7.11 Total modelled gas consumption in the scenarios, EU28, TWh/year



Concerning gas demand deployment, the Baseline and Prosumption scenarios assume a moderate demand decrease by 2050 (by around 400 TWh, 9%). Estimated demand in the Sustainable Mobility scenario is slightly higher between 2030 and 2050. The Energy Consumption and Saving and SCP scenarios assume a significant demand decrease by 2050 (around 1000 TWh, 15%).

Figure 7.12: Import dependency in the different scenarios for EU and for the pre-defined regions (Nordic, CEE,

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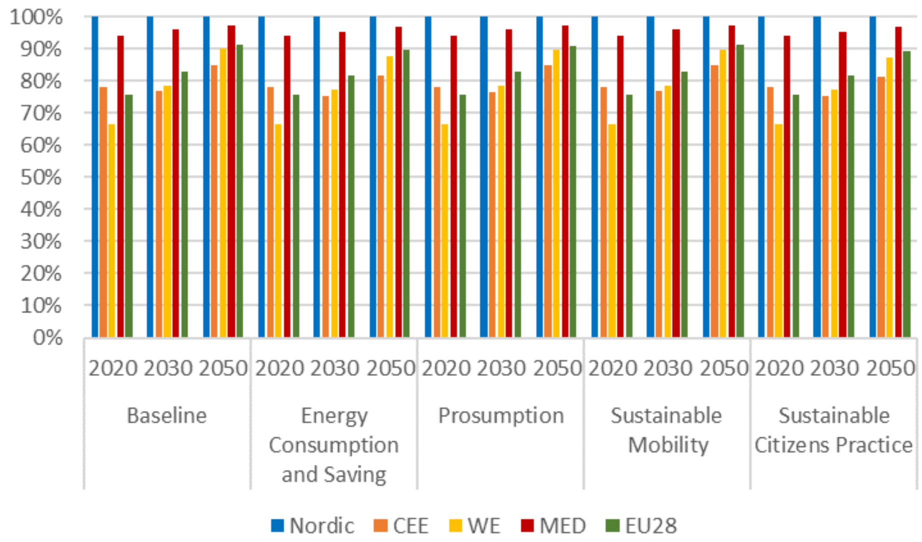
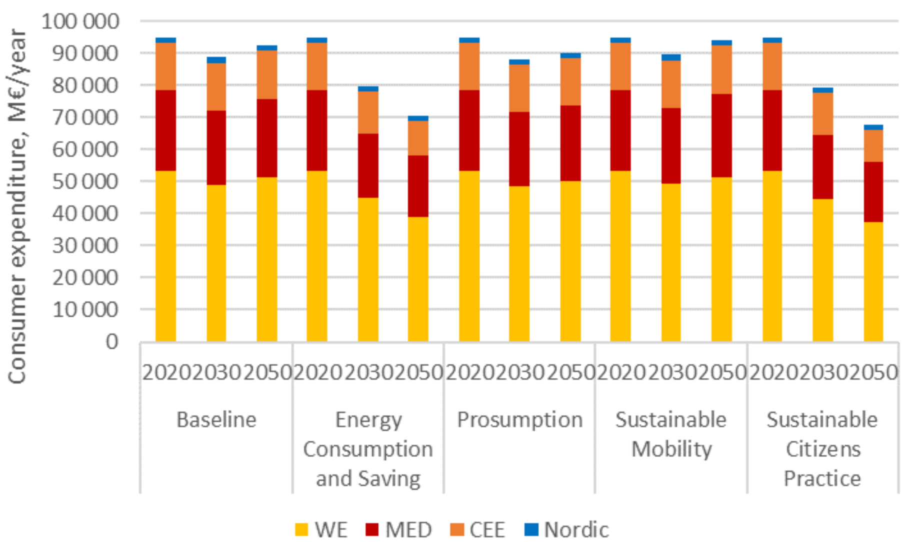
MED, WE)



Gas import dependency in the European Union level increases from around 75% to 82% by 2030 and to 90% by 2050 due to decreasing inland production. Import dependency does not differ significantly in the different scenarios at the EU level as due to the very low share of inland production, net imported quantity changes proportionally with the demand changes. The share of import is constantly high in the Nordic (100%) and Mediterranean (94-97%) region, while the CEE region and Western Europe, where import dependency is lower in 2020 (66 and 78% respectively), face an increase of import dependency by 2050 (up to 81-85% and 87-90%).

Figure 7.13: Total consumer expenditures of natural gas procurement for EU consumers



Total consumer expenditures are related to the cost of gas used in the EU28[40]. Compared to the 2020 Baseline, 1 to 29% cost decrease is modelled to 2050 on the EU28 level. The effects are unique on country- and regional level, so in some markets procurement costs or prices may increase despite the fact that on a European level we see lower figures.

[40] Calculated as total consumption multiplied by the wholesale clearing price.

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Table 7.9: Total change in total procurement costs compared to 2020 base case

	2030					2050				
	Baseline	Energy Consumption and Saving	Prosumption	Sustainable Mobility	Sustainable Citizens Practice	Baseline	Energy Consumption and Saving	Prosumption	Sustainable Mobility	Sustainable Citizens Practice
Nordic	-8%	-9%	-8%	-10%	-13%	-5%	-11%	-6%	-11%	-26%
CEE	0%	-11%	-1%	1%	-11%	1%	-28%	-1%	1%	-34%
WE	-8%	-15%	-8%	-7%	-16%	-4%	-27%	-6%	-4%	-30%
MED	-8%	-21%	-9%	-6%	-21%	-2%	-24%	-6%	4%	-24%
EU28	-7%	-16%	-7%	-6%	-16%	-3%	-26%	-5%	-1%	-29%

Scenario results are driven by gas demand assumed. Consequently, total procurement cost effects are similar in case of Baseline, Prosumption and Sustainable Mobility (1-5% cost decrease by 2050) and in Energy Consumption and Saving Scenario and SCP cases (26-29% cost decrease).

Since more than 75% of consumption is related to Western Europe and the Mediterranean region, the cost change related to these regions should be given more weight. In Western Europe, all scenarios bring lower costs, SCP and Energy Consumption and Saving Scenario delivering the most. For the Mediterranean region, the Sustainable Mobility Scenario has adverse effects on the gas bill of European consumers. For CEE, the Baseline and the Sustainable Mobility Scenario incur some increase in gas procurement costs. For the Nordic region, a cost decrease is simulated in all scenarios.

The cost decrease can be attributed to two factors: (i) volumetric effect, i.e. lower costs due to lower gas consumption (ii) price effect, i.e. lower costs due to lower gas prices.

Table 7.10: Price effect decomposed for the total gas procurement cost, % change compared to 2020

	2030					2050				
	Baseline	Energy Consumption and Saving	Prosumption	Sustainable Mobility	Sustainable Citizens Practice	Baseline	Energy Consumption and Saving	Prosumption	Sustainable Mobility	Sustainable Citizens Practice
Nordic	3%	1%	3%	2%	0%	7%	1%	6%	7%	-1%
CEE	1%	-4%	0%	1%	-4%	9%	-7%	5%	8%	-11%
WE	2%	-2%	2%	2%	-2%	8%	-2%	6%	8%	-2%
MED	0%	-4%	-1%	0%	-4%	5%	-6%	4%	6%	-6%
EU28	1%	-3%	1%	1%	-3%	7%	-3%	6%	9%	-4%

In the Baseline and the Prosumption and Sustainable Mobility Scenario 6-9% price increase is modelled for the EU28 by 2050. The reason for this is the stagnating gas consumption accompanied with diminishing European gas production. For the other two scenarios, the same falling production is sufficient to alleviate the import dependency and lead to 3-4% lower gas prices from 2020 to 2050. Altogether, the volume effect is much more decisive and a stronger driver of gas procurement cost.

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Table 7.11: Volume effect for total gas procurement costs, % change compared to 2020

	2030					2050				
	Baseline	Energy Consumption and Saving	Prosumption	Sustainable Mobility	Sustainable Citizens Practice	Baseline	Energy Consumption and Saving	Prosumption	Sustainable Mobility	Sustainable Citizens Practice
Nordic	-11%	-10%	-11%	-12%	-14%	-13%	-12%	-13%	-18%	-25%
CEE	-1%	-7%	-1%	-1%	-7%	-8%	-21%	-6%	-7%	-23%
WE	-10%	-14%	-10%	-9%	-14%	-11%	-25%	-13%	-12%	-28%
MED	-8%	-17%	-8%	-6%	-17%	-7%	-19%	-9%	-2%	-18%
EU28	-8%	-13%	-8%	-7%	-14%	-10%	-23%	-11%	-10%	-25%

Due to lower gas consumption, gas procurement costs drop by 10-25% across the EU28 by 2050. The price effect is adverse in some scenarios (Baseline, Prosumption and Sustainable Mobility), but this is balanced out by the strong volumetric effect. To sum up, despite the falling EU production and higher import dependency, European consumers pay less (or nearly the same) for their gas consumption by 2050 as in 2020.

7.4.2 Regional disaggregation of results from EEMM

The analysis of the power market reveals that the policies and measures assumed in the SCP Scenario have minor impact on the energy mix. The highest impact is observable in the Prosumer Scenario, but even in this scenario the changes are mainly driven by changes in the electricity demand of the final consumers that have an impact on the overall production level. The shares of the various technologies do not change significantly.

Nonetheless, there are significant (existing and projected) differences in the generation mixes between regions, as presented in the four figures below. In the Nordic region the increase in the contribution from hydro- and wind-based generation is most significant by 2050. With their contribution, the RES generation share in the overall electricity generation reaches more than 70%. The contribution of the PV technology remains minor in the Nordic region even by 2050, most probably as a result of less favourable weather conditions.

Figure 7.14: Changes in electricity mix compared to Baseline (same year) in the different scenarios – Nordic region

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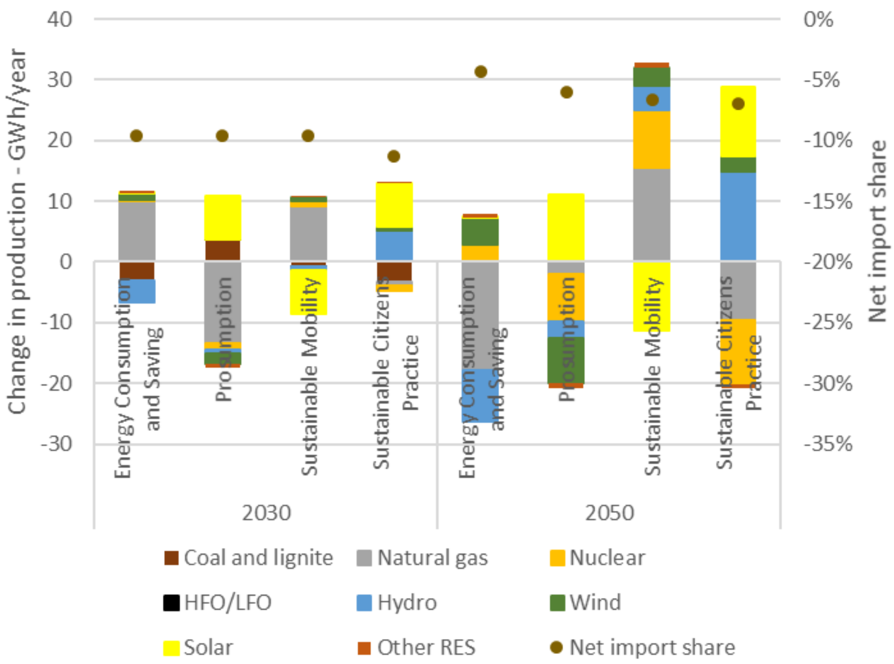

The following three regions (Central Eastern Europe , Western Europe and the Mediterranean region) present a different pathway compared to the one in the Nordic countries. In these regions, there is a strong increase in natural gas-based production in the power sector compared to 2020 due to its cost advantages and flexibility, as well as due to the constrained intermittent capacities. Between 2030 and 2050, gas consumption increases by more than 77% in the baseline, and more than doubles in the SCP Scenario. The increase in solar generation in these regions is much higher than in the Nordic region due to the better weather conditions. In the Mediterranean region, solar PV could contribute to electricity generation with almost 25%. However, the RES-E shares does not exceed 40 % in these regions in 2050.

Figure 7.15: Changes in electricity mix compared to Baseline (same year) in the different scenarios – Central Eastern Europe

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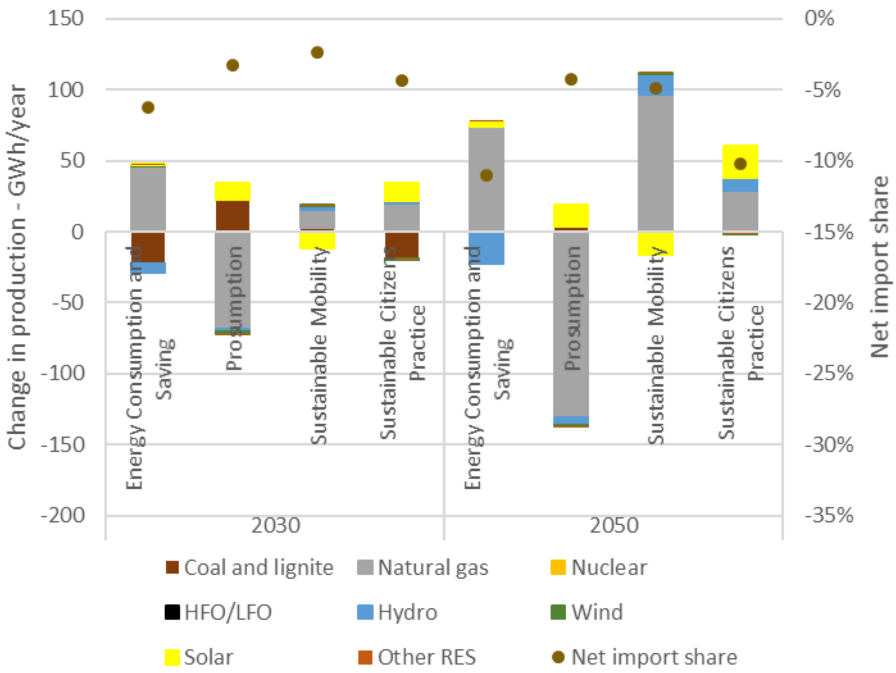

In the Prosumption Scenario electricity consumption is reduced by 10 % compared to Baseline as a result of household solar PV deployment. The difference in demand mainly reduces gas-based power generation.

The Western European region follows a very similar pattern as CEE in its power mix development. Although nuclear plays a more important role and hydro a less important role compared to the CEE region, their RES-E shares are in a similar range. Gas-based generation takes over most of the increase in power production due to the electrification process assumed in the scenarios. Overall, differences with baseline are small in the SCP Scenario, limited to few % changes compared to the baseline.

Figure 7.16 Changes in electricity mix compared to Baseline (same year) in the different scenarios - Western

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Europe

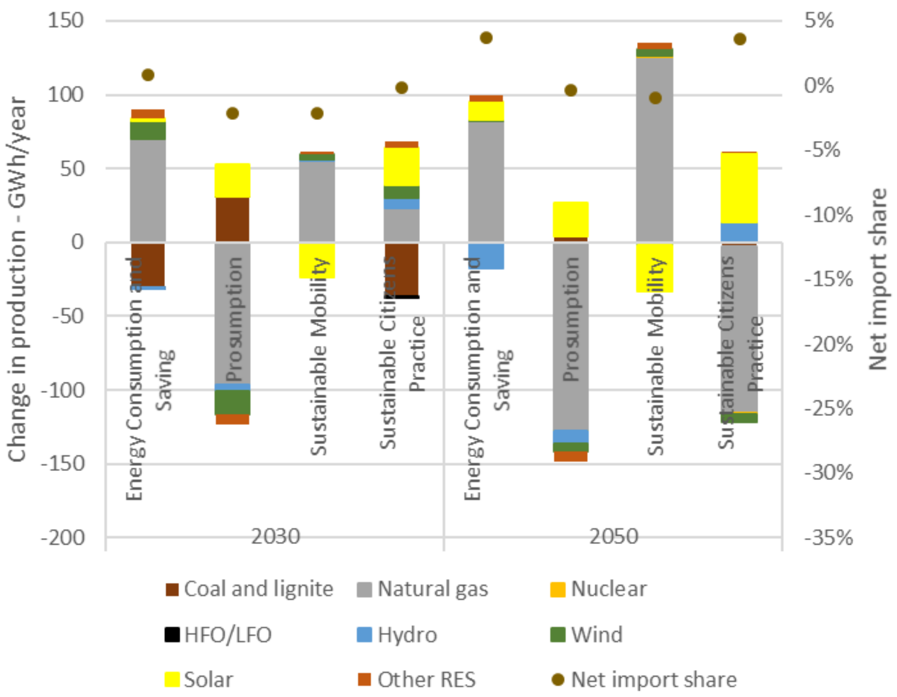
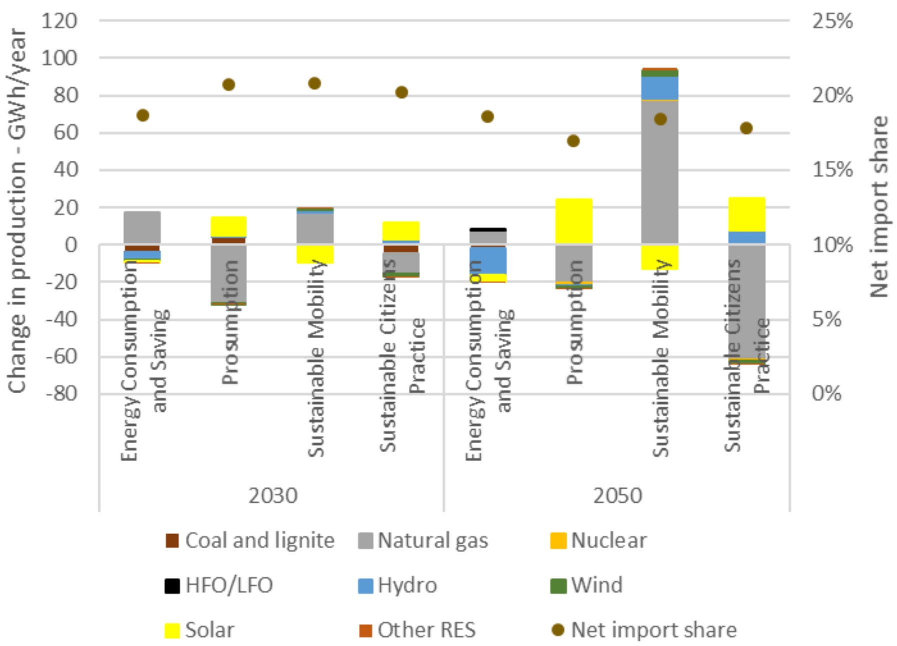


Figure 7.17: Changes in electricity mix compared to Baseline (same year) in the different scenarios - Mediterranean region



As presented in Figure 7.18*Figure 7.18*, only small differences are visible in case of RES-E shares in 2050. The only exception is the Nordic region, with a significant hydro power plant portfolio. In the SCP Scenario, the total RES production growth resulting from all the policies can outweigh the growing consumption of electricity.

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Figure 7.18: RES-E shares in 2050, for all regions

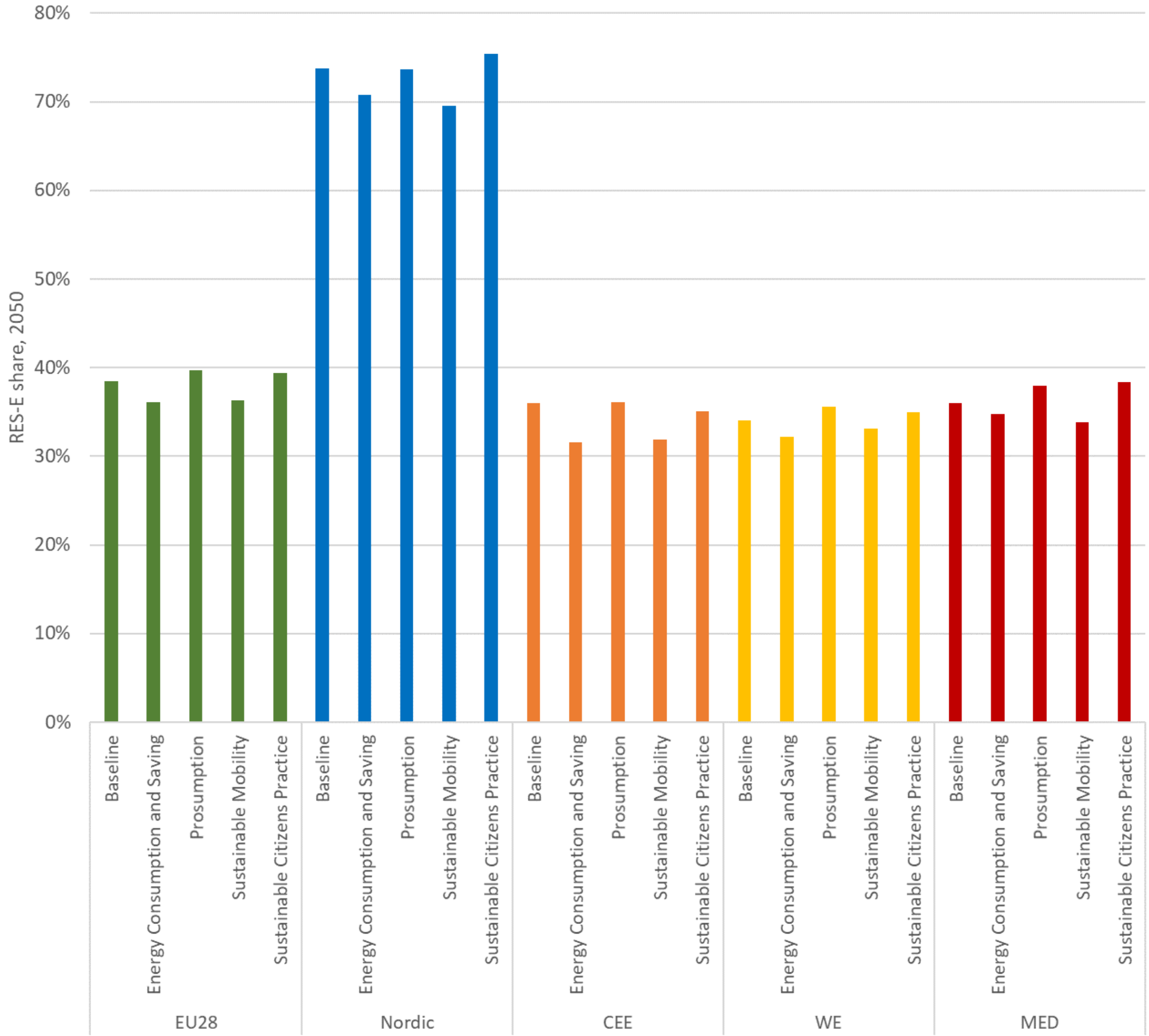

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Table 7.12: Region fact sheet – EU28

EU28*			2020	1. 2030					2050				
			Baseline	Baseline	Energy Consumption and Saving	Prosumption	Sustainable Mobility	Sustainable Citizens Practice	Baseline	Energy Consumption and Saving	Prosumption	Sustainable Mobility	Sustainable Citizens Practice
Installed capacity, GW	Coal, lignite	- Existing	147	87	87	87	87	87	40	40	40	40	40
		- New	0	7	7	7	7	7	23	7	7	7	7
	Natural gas	- Existing	205	188	188	188	188	188	56	56	56	56	56
		- New	0	71	88	63	75	80	314	273	238	277	267
	Nuclear	- Existing	120	92	92	92	92	92	16	16	16	16	16
		- New	0	18	18	18	18	18	112	112	112	112	112
	HFO/LFO		23	14	14	14	14	14	6	6	6	6	6
	Hydro		152	184	178	175	177	184	266	238	231	245	264
	Wind		142	236	244	233	236	241	215	217	211	216	214
	Solar		96	178	179	227	178	229	403	421	481	417	514
	Other RES		29	30	31	29	30	30	30	31	29	30	30
Net electricity generation, TWh		Total	3 120	3 272	3 363	3 230	3 287	3 337	4 066	4 173	3 923	4 225	4 193
		Coal and lignite	537	311	251	312	315	252	3	2	9	8	5
		Natural gas	729	994	1 138	928	1 022	1 053	1 594	1 740	1 459	1 774	1 619
		Nuclear	795	742	743	741	742	742	867	869	860	871	860
		HFO/LFO	8	4	4	4	4	4	1	1	1	1	1
		Hydro	325	382	368	361	365	382	579	516	499	528	573
		Wind	403	497	511	493	498	506	463	469	455	466	462
		Solar	137	189	190	241	190	243	411	423	496	425	523
		Other RES	187	151	158	150	152	156	148	153	144	152	150
Gross consumption, TWh			3 135	3 342	3 447	3 296	3 361	3 421	4 165	4 326	4 011	4 321	4 332
Net import, TWh			15	70	84	66	73	84	100	153	88	95	140
Net import ration, %			0.5%	2.1%	2.4%	2.0%	2.2%	2.5%	2.4%	3.5%	2.2%	2.2%	3.2%
RES-E share, %			33.6%	36.5%	35.6%	37.7%	35.8%	37.6%	38.4%	36.1%	39.7%	36.4%	39.4%
CO_2 emission, mt			850	673	663	652	687	634	509	492	458	540	481
Natural gas consumption, PJ			5 073	6 508	7 425	6 104	6 687	6 889	9 820	10 759	9 034	10 926	10 036
Weighted average wholesale price, €/MWh			57.3	59.9	58.1	60.3	60.0	57.9	76.7	75.8	79.1	80.3	74.5

*Excluding Cyprus and Malta.
source: REKK

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Table 7.13: Region fact sheet – Nordic

Nordic			2020	2030					2050				
			Baseline	Baseline	Energy Consumption and Saving	Prosumption	Sustainable Mobility	Sustainable Citizens Practice	Baseline	Energy Consumption and Saving	Prosumption	Sustainable Mobility	Sustainable Citizens Practice
Installed capacity, GW	Coal, lignite	- Existing	8	5	5	5	5	5	1	1	1	1	1
		- New	0	0	0	0	0	0	2	0	0	0	0
	Natural gas	- Existing	6	5	5	5	5	5	1	1	1	1	1
		- New	0	4	6	4	5	6	20	8	6	8	8
	Nuclear	- Existing	12	8	8	8	8	8	0	0	0	0	0
		- New	0	4	4	4	4	4	14	14	14	14	14
	HFO/LFO		1	0	0	0	0	0	0	0	0	0	0
	Hydro		22	28	27	27	27	28	41	39	38	39	43
	Wind		13	23	23	22	22	23	35	37	34	35	36
	Solar		1	3	3	11	3	11	7	7	19	7	19
	Other RES		5	6	6	6	6	6	6	6	6	6	6
Net electricity generation, TWh		Total	294	343	349	342	344	353	427	409	399	421	429
		Coal and lignite	27	13	10	13	12	9	0	0	0	0	0
		Natural gas	16	40	50	37	46	45	48	31	28	44	34
		Nuclear	86	98	99	98	99	98	98	101	93	103	92
		HFO/LFO	1	0	0	0	0	0	0	0	0	0	0
		Hydro	83	102	98	98	97	102	150	141	138	142	157
		Wind	50	62	63	62	62	63	97	102	94	97	100
		Solar	2	3	3	11	3	11	7	7	18	7	18
		Other RES	29	25	25	25	25	25	26	27	26	27	27
Gross consumption, TWh			292	313	318	312	314	317	381	392	376	394	401
Net import, TWh			-1	-30	-31	-30	-30	-36	-47	-17	-23	-26	-28
Net import ration, %			-0.5%	-9.6%	-9.6%	-9.6%	-9.6%	-11.2%	-12.2%	-4.3%	-6.0%	-6.7%	-6.9%
RES-E share, %			55.8%	61.4%	59.9%	62.4%	59.7%	63.3%	73.8%	70.8%	73.7%	69.5%	75.4%
CO2 emission, mt			36	27	28	27	29	25	16	9	8	13	10
Natural gas conumption, PJ			115	257	321	236	293	290	295	189	175	271	211
Weighted average wholesale price, €/MWh			50.9	57.8	56.6	57.3	58.1	55.2	56.4	60.4	60.9	65.6	57.5

source: REKK

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Table 7.14: Region fact sheet – Central Eastern Europe

CEE			2020	2030					2050				
			Baseline	Baseline	Energy Consumption and Saving	Prosumption	Sustainable Mobility	Sustainable Citizens Practice	Baseline	Energy Consumption and Saving	Prosumption	Sustainable Mobility	Sustainable Citizens Practice
Installed capacity, GW	Coal, lignite	- Existing	49	23	23	23	23	23	5	5	5	5	5
		- New	0	6	6	6	6	6	10	6	6	6	6
	Natural gas	- Existing	15	12	12	12	12	12	2	2	2	2	2
		- New	0	21	27	18	19	22	79	71	55	67	73
	Nuclear	- Existing	12	12	12	12	12	12	4	4	4	4	4
		- New	0	4	4	4	4	4	16	16	16	16	16
	HFO/LFO		1	1	1	1	1	1	0	0	0	0	0
	Hydro		34	42	40	39	40	41	62	54	52	57	60
	Wind		12	22	22	22	22	22	18	18	18	19	19
	Solar		7	14	14	27	14	27	52	56	72	55	79
	Other RES		4	5	5	5	5	5	3	3	3	3	3
Net electricity generation, TWh	Total		505	604	623	584	591	605	753	809	690	786	845
	Coal and lignite		193	101	78	101	104	84	0	1	4	4	3
	Natural gas		66	204	250	181	194	214	360	434	303	399	428
	Nuclear		94	120	120	120	120	120	145	145	144	145	144
	HFO/LFO		0	0	0	0	0	0	0	0	0	0	0
	Hydro		76	91	86	83	86	88	144	121	116	130	139
	Wind		37	49	50	49	49	49	40	40	40	41	41
	Solar		10	15	15	27	15	27	50	54	69	53	75
	Other RES		31	23	24	23	23	23	14	14	14	15	14
Gross consumption, TWh			515	575	586	566	577	580	689	728	662	750	767
Net import, TWh			9	-29	-36	-18	-14	-25	-64	-80	-28	-36	-78
Net import ration, %			1.8%	-5.0%	-6.2%	-3.2%	-2.4%	-4.4%	-9.3%	-11.0%	-4.2%	-4.9%	-10.2%
RES-E share, %			29.7%	31.1%	29.7%	32.1%	30.0%	32.2%	36.0%	31.5%	36.1%	31.8%	35.1%
CO_2 emission, mt			233	174	166	166	174	160	117	120	100	122	119
Natural gas consumption, PJ			454	1 311	1 606	1 173	1 252	1 376	2 206	2 645	1 833	2 421	2 605
Weighted average wholesale price, €/MWh			57.2	59.8	58.0	60.4	60.1	58.1	78.4	76.1	81.5	81.2	75.5

source: REKK

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727524.

Table 7.15: Region fact sheet – Western Europe

WE			2020	2030					2050				
			Baseline	Baseline	Energy Consumption and Saving	Prosumption	Sustainable Mobility	Sustainable Citizens Practice	Baseline	Energy Consumption and Saving	Prosumption	Sustainable Mobility	Sustainable Citizens Practice
Installed capacity, GW	Coal, lignite	- Existing	71	45	45	45	45	45	22	22	22	22	22
		- New	0	1	1	1	1	1	8	1	1	1	1
	Natural gas	- Existing	91	81	81	81	81	81	14	14	14	14	14
		- New	0	37	44	34	41	44	159	156	141	153	147
	Nuclear	- Existing	88	64	64	64	64	64	4	4	4	4	4
		- New	0	10	10	10	10	10	75	75	75	75	75
	HFO/LFO		7	4	4	4	4	4	1	1	1	1	1
	Hydro		45	54	54	52	52	55	83	75	71	70	76
	Wind		77	151	159	150	152	158	138	139	136	138	136
	Solar		60	109	111	133	109	135	244	261	275	250	298
	Other RES		15	16	17	16	16	17	18	19	17	18	18
Net electricity generation, TWh		Total	1 677	1 739	1 798	1 727	1 765	1 797	2 160	2 243	2 120	2 223	2 162
		Coal and lignite	237	150	120	151	151	115	0	1	5	4	1
		Natural gas	374	521	591	494	549	573	895	977	849	975	862
		Nuclear	560	469	469	469	469	469	514	514	513	514	514
		HFO/LFO	5	4	3	4	4	3	1	1	1	1	1
		Hydro	95	108	106	102	103	110	169	152	144	142	156
		Wind	234	307	319	304	307	316	281	283	277	282	276
		Solar	78	101	103	124	101	126	211	223	245	214	261
		Other RES	93	81	87	80	81	85	89	93	86	90	90
Gross consumption, TWh			1 618	1 718	1 813	1 691	1 727	1 795	2 200	2 330	2 113	2 201	2 244
Net import, TWh			-59	-22	15	-36	-38	-2	39	87	-7	-21	82
Net import ration, %			-3.6%	-1.3%	0.8%	-2.2%	-2.2%	-0.1%	1.8%	3.7%	-0.4%	-1.0%	3.7%
RES-E share, %			31.0%	34.7%	33.9%	36.1%	34.3%	35.5%	34.1%	32.2%	35.6%	33.1%	34.9%
CO_2 emission, mt			391	339	334	331	350	323	272	263	247	281	245
Natural gas consumption, PJ			2 565	3 399	3 847	3 232	3 578	3 728	5 496	5 966	5 185	5 949	5 280
Weighted average wholesale price, €/MWh			56.1	59.5	57.6	60.0	59.5	57.4	77.4	75.4	78.7	79.0	74.3

source: REKK

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727524.

*Table 7.16: Region fact sheet – Mediterranean**

MED			2020	2030					2050				
			Baseline	Baseline	Energy Consumption and Saving	Prosumption	Sustainable Mobility	Sustainable Citizens Practice	Baseline	Energy Consumption and Saving	Prosumption	Sustainable Mobility	Sustainable Citizens Practice
Installed capacity, GW	Coal, lignite	- Existing	19	14	14	14	14	14	11	11	11	11	11
		- New	0	1	1	1	1	1	2	1	1	1	1
	Natural gas	- Existing	93	88	88	88	88	88	39	39	39	39	39
		- New	0	10	11	7	10	8	57	38	36	49	39
	Nuclear	- Existing	7	7	7	7	7	7	7	7	7	7	7
		- New	0	0	0	0	0	0	7	7	7	7	7
	HFO/LFO		14	9	9	9	9	9	5	5	5	5	5
	Hydro		52	60	57	57	58	60	80	71	70	79	84
	Wind		39	40	39	39	40	39	23	23	22	24	23
	Solar		28	50	50	57	51	57	100	97	115	105	117
	Other RES		5	4	4	4	4	4	3	3	3	3	3
Net electricity generation, TWh	Total		644	585	594	577	588	582	725	713	714	796	757
	Coal and lignite		79	47	43	48	48	43	2	0	0	0	0
	Natural gas		273	229	247	215	232	221	291	299	278	356	294
	Nuclear		56	56	56	56	56	56	110	110	109	110	109
	HFO/LFO		1	0	0	0	0	0	0	0	0	0	0
	Hydro		72	81	77	78	79	82	116	102	101	113	121
	Wind		81	79	78	78	79	78	45	44	44	46	45
	Solar		47	70	70	80	71	79	142	139	163	150	168
	Other RES		34	23	23	22	23	23	19	19	18	20	19
Gross consumption, TWh			710	736	730	728	742	729	896	876	860	975	921
Net import, TWh			66	151	136	151	155	147	171	163	146	180	164
Net import ration, %			9.3%	20.5%	18.7%	20.8%	20.9%	20.2%	19.1%	18.6%	17.0%	18.4%	17.8%
RES-E share, %			33.0%	34.3%	33.9%	35.4%	33.8%	35.9%	36.0%	34.7%	38.0%	33.8%	38.3%
CO_2 emission, mt			189	133	135	129	134	126	104	100	103	124	107
Natural gas consumption, PJ			1 939	1 541	1 651	1 463	1 564	1 495	1 824	1 959	1 841	2 285	1 941
Weighted average wholesale price, €/MWh			62.8	61.7	59.9	62.1	61.8	60.0	82.3	83.7	86.3	88.5	81.7

*excluding Cyprus and Malta
source: REKK

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