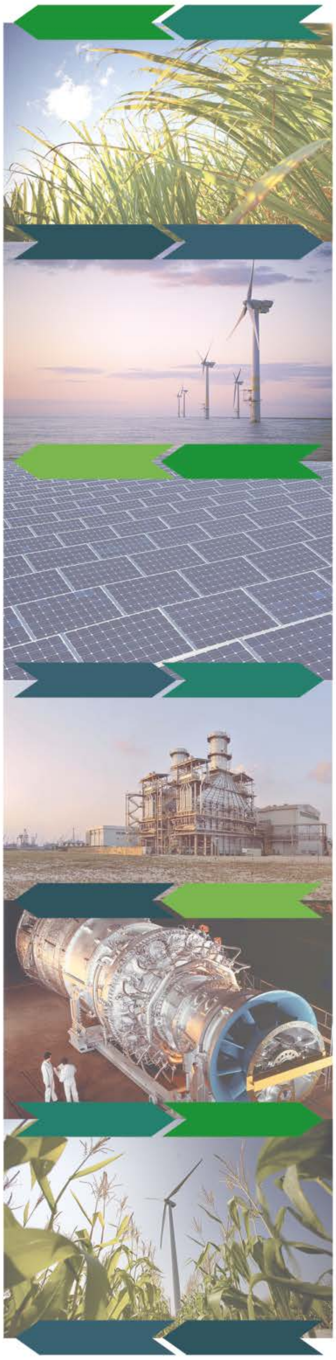
NAVIGATING THE ROADMAP FOR CLEAN, SECURE AND EFFICIENT ENERGY INNOVATION



Case study report on

Diffusion rate of Renewable Electricity

An assessment of the optimal RES share under varying determinants

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1 Introduction

This report informs on a modelling case study within the SET-Nav project dedicated to analyse the optimal diffusion rate of renewable electricity generation within the European Union in the years up to 2050. The overall objective of the work package (WP7) in which this case study is embedded is to extend and apply the modelling capabilities of the project consortium for the analysis of the supply side of energy systems, with a particular focus on the electricity sector. In this context, enabling and improving interactions between the different models is a strong focus. In a first step, existing models are extended and case studies are conducted, shedding light on specific topics of interest and aiming to derive lessons learnt for the follow-up overarching model-based assessment by means of pathways/scenarios for the decarbonisation of the EU's energy sector.

This case study is dedicated to elaborate on **the diffusion of renewable electricity generation, aiming to gain insights on the suitable/optimal share renewables may take in Europe's future electricity supply**. Generally, renewable electricity generation (RES-E) is estimated to cover a high share of the future electricity demand in the EU. The possible diffusion of RES-E generation depends on the overall policy ambition in our combat against climate change, the relative costs of RES-E to its (low-carbon) alternatives, and the capability of the system to accommodate volatile generation. All these determinants are dynamic and therefore can change over time.

In particular, we want to investigate how the diffusion rate changes as reaction to:

- **Technological learning / Cost trends:** Parameter changes in learning rates and the innovation system of renewable energy technologies. This part of the analysis has been contrasted with interim findings from our analysis within SET-Nav on technology innovation and policy implications (WP 3).
- **Market design / Flexibility provision:** The design and operation of electricity markets are broad topics of their own – within our analysis, we focus on some core issues that impact RES-E integration, including grid development, electricity market design, and sector coupling / demand-side response. The core question behind is how distinct trends within above-listed areas might affect the provision of flexibility required to accommodate variable generation. Here we build on respective assessments done within SET-Nav, e.g. the case study analysis of centralised and decentralised electricity supply and the infrastructure requirements imposed, but also on lessons learnt in other projects, e.g. the Intelligent Energy for Europe project towards2030-dialogue (www.towards2030.eu) where electricity market design trends have been subject of a thorough analysis performed.
- **Policy-related aspects / Policy ambition:** Energy and climate policy provides the guiding framework for all market actors in the energy sector. Policy decisions can lay the grounds for certain developments, ambitious policy targets may facilitate the uptake of certain energy technologies, and/or may hinder others. Without digging into details of how energy policy instruments are or should be designed, we take an umbrella view on how policy decisions may affect the optimal share of RES in the electricity sector. Three representative examples are taken up in our analysis:
    - o how policy design may facilitate or hinder the uptake of decentral RES prosumers, exemplified for the case of decentral photovoltaics;

- how the (pending) reform of the EU's Emission Trading Scheme (ETS) may impact future RES developments, and, finally,
- how the overall policy ambition for renewables determines the required uptake of RES in the electricity sector, exemplified by the assumed overall target set for RES within the EU by 2030.

2 Method of approach

2.1 The applied modelling system: Green-X & Enertile

This analysis builds on modelling works undertaken by the use of TU Wien's Green-X model (cf. Box 1), closely linked to Fraunhofer ISI's Enertile model (cf. Box 2). More precisely, Green-X delivers a first picture of future RES developments under distinct energy policy trends and cost assumptions, indicating details on technology trends (investments, installed capacities and generation) and the geographical distribution of RES deployment as well as related costs (generation cost), expenditures (capital, operation and support expenditures) and benefits (avoided fossil fuels and related carbon emissions). For assessing the interplay between RES and the future electricity market, Green-X was complemented by its power-system companion, i.e. the Enertile model. Thanks to a higher intertemporal resolution than in the RES investment model Green-X, Enertile enables a deeper analysis of the merit order effect and related market values of the produced electricity of variable and dispatchable renewables and, therefore, can shed further light on the interplay between supply, demand and storage in the electricity sector.

Please note that for parts of the analysis, Enertile was replaced by TU Wien's HiREPS model, offering comparatively similar characteristics on power system modelling than Enertile but with additional features to assess impacts of electricity market design and system flexibility.[1]

Box 1: Brief characterization of the Green-X model

Green-X is an energy system model that offers a ***detailed representation of RES potentials and related technologies in Europe and in neighbouring countries****. It aims at indicating consequences of RES policy choices in a real-world energy policy context thanks to its comprehensive* ***incorporation of various energy policy instruments*** *including related design features. The model simulates technology-specific RES deployment by country on a yearly basis, in the time span up to 2050, taking into account the impact of dedicated support schemes as well as economic and non-economic framework conditions (e.g. regulatory and societal constraints). Moreover, the model allows for an appropriate representation of financing conditions and of the related impact on investor's risk. This, in turn, allows conducting in-depth analyses of future RES deployment and corresponding costs, expenditures and benefits arising from the preconditioned policy choices on country, sector and technology level.*

Box 2: Brief characterization of the Enertile model

Enertile is an energy system optimization model developed at the Fraunhofer Institute for System and Innovation Research ISI. The model focuses on the power sector, but also covers the interdependencies with other sectors, especially heating &cooling and the transport sector. It is used mostly for long-term scenario studies and is explicitly designed to depict the challenges and opportunities of increasing shares of renewable energies.

A major advantage of the model is its ***high technical and temporal resolution*** *– i.e. the model features a full hourly resolution: In each analysed year, 8,760 hours are covered. Since real weather data is applied, the interdependencies between weather regions and renewable technologies are implicitly included.*

Moreover, Enertile allows for a ***full optimization of the investments into all major infrastructures of the power sector*** [2]*, including conventional power generation, combined-heat-and-power (CHP), renewable power technologies, cross-border transmission grids, and flexibility options such as demand-*

[1] TU Wien's HiREPS model can build here on already established linkages between electricity and heating & cooling as well as transport, as analysed in the course of the Towards2030-dialogue project (cf. Resch et al, 2017). Such a model extension will be undertaken in a more detailed manner within Enertile in the course of this project.

[2] For the purpose of this case study, investments in RES technologies were taken from Green-X modelling. Thus, Enertile focussed on modelling complementary investment needs as well as power plant dispatch.

side-management (DSM) and power-to-heat storage technologies. The model chooses the optimal portfolio of technologies while determining the utilization of these for all hours of each analysed year.

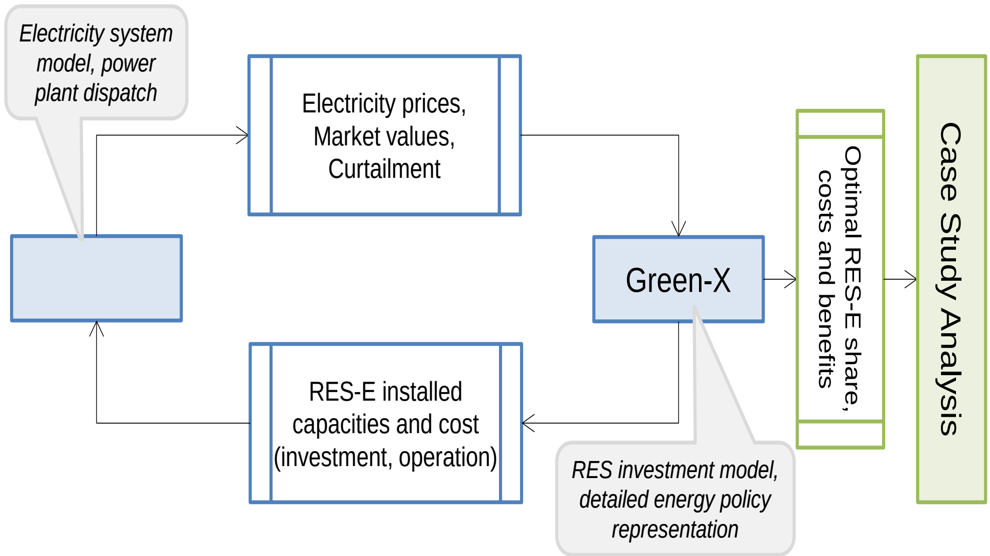

Figure 1: Model coupling between Enertile (left) and Green-X (right) for a detailed assessment of RES developments in the electricity sector

Figure 1 gives an overview on the interplay of both models. Both models are operated with the same set of general input parameters, however in different spatial and temporal resolution. Green-X delivers a first picture of renewables deployment and related costs, expenditures and benefits by country on a yearly basis (2010 to 2050). The output of Green-X in terms of country- and technology-specific RES capacities and generation in the electricity sector for selected years (2020, 2030 and 2050) serves as input for the power-system analysis done with Enertile. Subsequently, the Enertile model analyses the interplay between supply, demand, and storage in the electricity sector on an hourly basis for the given years. The output of Enertile is then fed back into the RES investment model Green-X. In particular, the feedback comprises the amount of RES that can be integrated into the grids, the electricity prices, and corresponding market revenues (i.e. market values of the electricity produced by variable and dispatchable RES-E) of all assessed RES-E technologies for each assessed country.

2.2 Overview on key assumptions and assessed scenarios

Aiming at an analysis of the optimal diffusion rate of renewable electricity in dependence of key determinants, a set of seven different scenarios has been assessed so far. An overview on their definition is given in Table 1, providing a key characterisation of the individual scenarios and listing key input parameters and assumptions. From a topical viewpoint, we distinguish between three topical areas: technological learning / cost trends, market design / flexibility provision, and policy-related aspects.[3]

[3] The scenario(s) assessed under these topical areas show how the optimal diffusion rate / share of RES-E changes in comparison to the reference scenario (of aiming for 27% RES by 2030 under default assumptions).

Table 1: Overview on assessed scenarios

Scenario acronym	27% RES	27% RES - low learning	27% RES - high learning	27% RES - trend market design	27% RES - no prioritisation of decentral PV	27% RES - high carbon prices	30% RES - strong EE
Topical area		Technological learning / Cost trends		Market design / Flexibility provision	Policy-related aspects / Policy ambition		
Characterisation	Default (reference) scenario	Low technological learning of key technologies	High technological learning of key technologies	Trend market design (non-optimal framework conditions for RES integrat.)	No prioritisation (higher retail value) of decentral RES (PV)	High carbon prices (major ETS reform)	Strong policy ambition for RES and EE by 2030
Energy demand trend	**27% EE* by 2030** (PRIMES euco27)	**27% EE by 2030** (PRIMES euco27)	**27% EE by 2030** (PRIMES euco27)	**27% EE by 2030** (PRIMES euco27)	**27% EE by 2030** (PRIMES euco27)	**27% EE by 2030** (PRIMES euco27)	**30% EE by 2030** (PRIMES euco30)
Fossil energy price trend	**Default** (PRIMES 2016)	**Default** (PRIMES 2016)	**Default** (PRIMES 2016)	**Default** (PRIMES 2016)	**Default** (PRIMES 2016)	**Default** (PRIMES 2016)	**Default** (PRIMES 2016)
Carbon price trend	**Default** (PRIMES reference)	**Default** (PRIMES reference)	**Default** (PRIMES reference)	**Default** (PRIMES reference)	**Default** (PRIMES reference)	**High** (PRIMES euco27)	**Default** (PRIMES reference)
Market design / Flexibility provision	**Optimal** (grid extension, energy only markets, demand response)	**Optimal** (grid extension, energy only markets, demand response)	**Optimal** (grid extension, energy only markets, demand response)	**Trend** (delayed grid ext., capacity markets, no demand response)	**Optimal** (grid extension, energy only markets, demand response)	**Optimal** (grid extension, energy only markets, demand response)	**Optimal** (grid extension, energy only markets, demand response)
RES ambition	at least **27% by 2030** (and beyond)	at least **27% by 2030** (and beyond)	at least **27% by 2030** (and beyond)	at least **27% by 2030** (and beyond)	at least **27% by 2030** (and beyond)	at least **27% by 2030** (and beyond)	at least **30% by 2030** (and beyond)
RES policy concept	**Least cost** (support expenditures)	**Least cost** (support expenditures)	**Least cost** (support expenditures)	**Least cost** (support expenditures)	**Least cost** (support expenditures)	**Least cost** (support expenditures)	**Least cost** (support expenditures)

*Abbreviation: EE ... energy efficiency

Before discussing the concept and related assumptions for each of the scenarios under these topical areas, we introduce the set of common key input parameter and assumptions below.

2.2.1 General input parameter and assumptions

In order to ensure maximum consistency with existing EU scenarios and projections the key input parameters of the scenarios presented in this report are derived from PRIMES modelling and from the Green-X database (www.green-x.at) with respect to the potentials and cost of RES technologies. As indicated in Table 1 (above), PRIMES comes into play for **energy demand developments** as well as **fossil energy and carbon price trends**. The specific PRIMES scenarios used are the latest publicly available reference scenario (European Commission, 2016f) and the climate mitigation scenarios PRIMES euco27 and PRIMES euco30 that build on the targeted use of renewables (i.e. 27% RES by 2030) and an enhanced use of energy efficiency (EE) compared to reference conditions – i.e. 27% (euco27) or 30% EE (euco30) by 2030, respectively. Please note that all PRIMES scenarios are intensively discussed in the EC's winter package, cf. the Impact assessment of the recast RED (SWD (2016) 410 final) (European Commission, 2016).

With respect to the underlying **policy concept and ambition level for RES and energy efficiency,** the following assumptions are taken for the assessed scenarios:

- *A common policy framework until 2020:* All scenarios build on common ground for the near future, i.e. the years up to 2020. Here, a strengthening of national RES policies is presumed, serving to meet the given 2020 RES targets. Each country uses national (in most cases technology-specific) support schemes in the electricity sector to meet its own 2020 RES target, complemented by RES cooperation between Member States in the case of insufficient or comparatively expensive domestic renewable sources. Please note that support levels are tailored to the national needs, in other words, they are generally based on the technology specific generation costs at country level.
- *A "least-cost" approach for RES post 2020:* For renewables, the default ambition level is generally set at 27% - i.e. ***achieving a RES share in gross final energy demand in size of at least 27% by 2030 and beyond***. [4] Conceptually, the scenarios follow a simplified policy concept for renewables: The underlying policy concept for incentivising RES can be characterised as a "least-cost" approach, enhancing an efficient use of RES for meeting the 2030 EU RES target in a cost-effective manner as outlined in Box 3.

  Please note that *this "virtual" policy concept matches perfectly with the objective of this case study*. Thus, the ***RES policy approach taken in modelling allows for deriving the optimal RES-E share under given assumptions from a European least (policy) cost perspective*** – i.e. allowing for minimising support expenditures required for meeting a certain overall RES target by 2030 and beyond. Thus, the undertaken least cost allocation of the RES efforts to the available RES technologies across all energy sectors (electricity, heat, transport fuels) and countries (EU28 Member States) delivers an optimal RES deployment under given constraints.
- Concerning the role of *energy efficiency* a moderate ambition level is presumed – i.e. in accordance with the PRIMES euco27 scenario, gross final energy demand is reduced by 27% in 2030 compared to baseline conditions.

[4] The overall RES target as presumed for 2030 – i.e. as default (at least) 27% RES share in gross final energy demand – is maintained in modelling as minimum target also for the period post 2030 (until 2050). Draft results show, however, that in all assessed scenarios the minimum target level is over fulfilled, meaning that RES deployment is then well above 27% in the years up to 2050.

Box 3: A least-cost approach to allocate investments in RES technologies post 2020

The selection of RES technologies in the period post 2020 in all assessed cases within this exercise follows a least-cost approach, meaning that all additionally required future RES technology options are ranked in a merit-order, and it is left to the economic viability which options are chosen for meeting the presumed 2030 RES target. In other words, a least-cost approach is used to determine investments in RES technologies post 2020 across the EU. This allows for a full reflection of competition across technologies and countries (incorporating well also differences in financing conditions etc.) from a European perspective. Support levels and related expenditures follow then the marginal pricing concept where the marginal technology option determines the support level (like in the ETS or in a quota/certificate trading regime, or similar to the concept of liberalised electricity markets).

2.2.2 Scenario-specific assumptions (by topical area)

Technological learning / Cost trends:

Here we assess *how parameter changes in learning rates and the innovation system of key renewable energy technologies affect the optimal diffusion rate of renewables in the electricity sector*. This part of the analysis has been contrasted with interim findings from our analysis within SET-Nav on technology innovation and policy implications (WP 3).

Default assumptions concerning learning rates for wind energy and solar PV as well as the assumed changes to these in the case of lower or higher learning are listed in Table 2.

Table 2: Assumptions used for learning rates of wind energy and photovoltaics in assessed scenarios related to technological learning / cost trends

Scenario acronym	27% RES (reference)	27% RES - low learning	27% RES - high learning
Topical area		Technological learning / Cost trends	
Characterisation	Default (reference) scenario	Low technological learning of key technologies	High technological learning of key technologies
Learning rates: (for the period post 2020*)			
Wind energy	**7%**	**5.6%** (-20% compared to default)	**8.4%** (+20% compared to default)
Photovoltaics	**17.5%**	**14%** (-20% compared to default)	**21%** (+20% compared to default)

*Remark: Please note that in the case of photovoltaics in the years up to 2020 in accordance with historic trends a higher learning rate is presumed in all assessed scenarios (i.e. 20% instead of 17.5% as assumed for the years post 2020). Thus, we assume a slow-down of technological progress after 2020 due to saturation effects in the progress chain for this technology.

More precisely, we focus on *wind energy (on- and offshore) and solar PV* – from the current and also from a forward looking perspective the key renewable energy technologies in electricity supply – and analyse how a lower or higher than as default expected technological learning affects their future deployment under the given "least (policy) cost" approach used for allocating the presumed overall EU RES target (i.e. as default a 27% RES share in gross final energy demand) to the available RES technologies across all energy sectors and countries. Thus, expectations are that a higher learning and consequently stronger cost reductions of wind and solar PV might enhance their deployment and, in turn, reduce the deployment of other RES technologies in the electricity sector – but also in heating & cooling and in transport. In the case of lower learning, the opposite trends can be expected.

Please note that the general approach and assumptions used in Green-X modelling on technology learning and cost reductions of RES technologies are briefly described in Box 4 below.

Box 4: Approach and assumptions used in Green-X on modelling technological learning of energy technologies

Thus, for most RES-E technologies, the future development of investment cost is based on technological learning. As learning is generally taking place on the international level (i.e. presuming a global learning system) the deployment of a technology on the global market must be considered. For the model runs, global deployment consists of the following components:

- *Deployment within the EU 28 Member States is endogenously determined, i.e. is derived from the model.*
- *Expected developments in the "rest of the world" are based on forecasts as presented in the IEA World Energy Outlook 2017 (IEA, 2017).*

Market design / Flexibility provision:

As outlined in the introductory section, the design and operation of electricity markets are broad topics of their own. Within our related topical assessment, we thus focus on some core issues that impact RES-E integration, including grid development, electricity market design, and sector coupling / demand-side response. The underlying question is how distinct trends within abovelisted areas might affect the provision of flexibility required to accommodate variable generation stemming from renewable sources. Concerning the approach taken and the assumptions used, we partly base our model-based assessment on related analysis done within SET-Nav, specifically the case study analysis of centralised and decentralised electricity supply and the infrastructure requirements imposed. For the definition of scenarios and related assumptions, we build on the lessons learnt and the approach taken within the Intelligent Energy for Europe project towards2030-dialogue (www.towards2030.eu) where electricity market design trends have been subject of a thorough analysis. Box 5 (below) summarises some of the key electricity market design trends identified within this project.

Box 5: Electricity market design trends across Europe
(Source: towards2030-dialogue, cf. Resch et al. (2017))

The integration of renewable energy sources is only one out of several challenges governments face. Many changes in electricity market design can be traced back to the liberalisation process. In total, six trends have been analysed in more detail.

Regional pricing *describes the integration of markets to ensure efficient use of generation capacity. Market coupling and the adjustment of bidding zones to network constraints are mainly steered from the European level. Member states announce their willingness to cooperate, but at the same time, they try to prevent effects of international trade in their markets. Technically, the process is ongoing on the transmission level, but there are first attempts to open markets also on distribution grids level to balance out demand and supply locally instead of building additional lines.*

Capacity payments *are often justified by the "missing-money problem". Generators that set the marginal price for electricity have problems to recover their total generation costs. This missing-money* *problem is known in any liberalised market, but it is aggravated by increasing shares of variable renewable energies with negligible variable costs. The decision in favour or against capacity payments is currently taken on Member State level, but the European Commission increasingly monitors the discussed systems to prevent barriers for free trade of electricity. Capacity payments are common in balancing systems and other security strategies that are operated by transmission grid operators. For security on the distribution grid level, they play a minor role.*

Incentivising demand response *is another electricity market design trend. Historically, demand was assumed to be inflexible. Tariff structures and technical prequalification standards for markets have been designed accordingly. Member states and the European Commission increasingly demand for changes in the systems. Markets are to be opened for demand side bidding, prequalification standards are changed to allow for demand side participations. Consumers are equipped with metering technology that allows for variable tariffs. Many of the ongoing pilot projects are established on the distribution grid level (smart grid pilot projects). Big industrial consumers and pooled smaller consumers are increasingly influencing the development on the transmission grid level.*

Short-term trading *describes the trend to allow for trading close to the time of physical delivery. Forecasts for the infeed from fluctuating renewable energy sources are better the closer they are in time to the delivery date. Balancing responsible parties increasingly need opportunities to balance their schedule by buying electricity at "last minute". This is facilitated by the introduction of intraday markets which are currently only implemented on Member State and transmission grid level.*

Accountability of renewables: *Renewable energy sources are increasingly integrated into market systems. On the one hand, this opens new opportunities for profits, and, on the other hand, they are increasingly subject to competition. The European Commission pushes for stronger accountability of renewables, while the implementation varies broadly on Member State level, depending on the support scheme. Renewables are increasingly used to balance variations in demand and supply on the transmission grid level as well as in smart grid projects on the distribution grid level.*

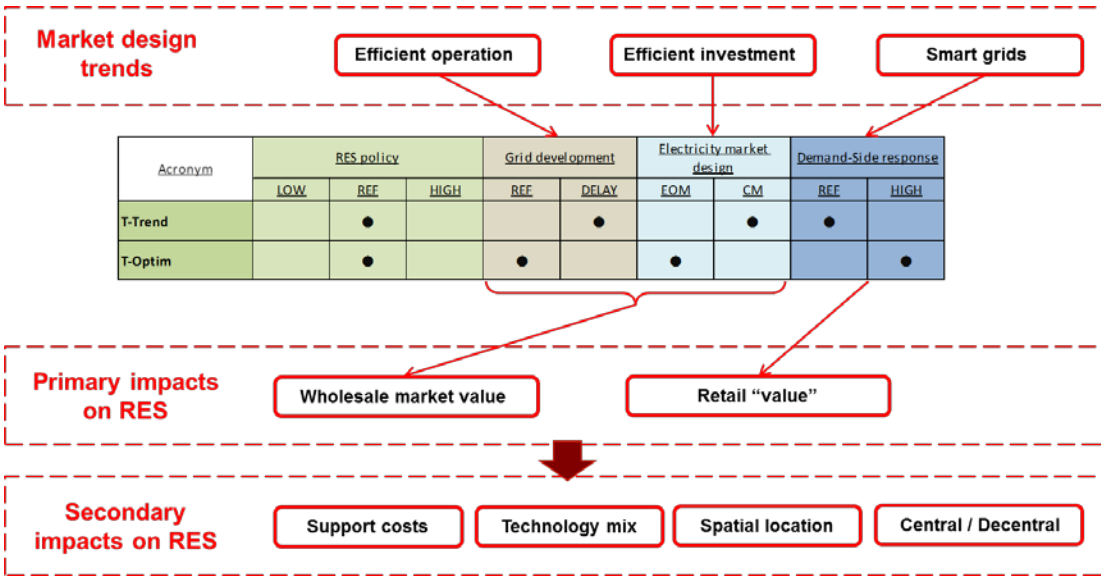

Figure 2: Mapping electricity market design trends to scenarios
(Source: based on towards2030-dialogue, cf. Ortner et al. (2016)).

Scenarios reflecting major market design trends: The electricity market design trends described above needed to be concretized in the form of assumptions that can be used to operate electricity market models. Concrete design elements that have been included are capacity markets vs. Energy-Only markets (CM vs. EOM), the enabling and regulation of demand response participation (HIGH/REF), and progress in international high-voltage grid expansion (REF/DELAY). An overview on the modelled scenarios is given in Figure 2.

The trends were summarized within the three categories efficient operation, efficient investment, and smart grids. For each of these trend packages, a dedicated set of modelling assumptions was foreseen. As a next step, two scenarios were derived: one representing selected ongoing trends (Trend) and another one reflecting a first-best solution to have optimal framework assumptions (Optimal) in the sense of efficiently working markets according to standard economic theory. In modelling, we take as default the assumption that optimal framework conditions are reached in forthcoming years. To contrast this assumption and to analyse related impacts within this topical assessment, we add another scenario presuming ongoing trends to define the framework conditions for RES-E market integration, cf. Table 3. A comparison of the model results from both scenarios will, thus, allow us to derive quantitative insights in the relevance of selected electricity market framework conditions for revenues of RES-E technologies and their future deployment.

Table 3: Assumptions used in assessed scenarios related to market design / flexibility provision

Scenario acronym	27% RES (reference)	27% RES - trend market design
Topical area		Market design / Flexibility provision
Characterisation	Default (reference) scenario	Trend market design (non-optimal framework conditions for RES integrat.)
Market design / Flexibility provision	**Optimal** (grid extension, energy only markets, demand response)	**Trend** (delayed grid ext., capacity markets, no demand response)

Policy-related aspects / Policy ambition:

As outlined in the introductory part of this report, energy and climate policy provides the guiding framework for all market actors in the energy sector. Thus, policy decisions can stipulate certain developments in energy markets, ambitious policy targets may facilitate the uptake of specific energy technologies and/or may hinder others, etc... Without digging into details of how energy policy instruments are or should be designed, we take an umbrella view on how policy decisions may affect the optimal share of RES in the electricity sector. Three representative examples are taken up in our analysis:

- ***No prioritisation of decentral PV:*** Here, we analyse how policy design may facilitate or hinder the uptake of decentral RES prosumers, exemplified for the case of decentral photovoltaics. More precisely, we showcase the impact of whether or not a prioritisation of decentral PV will be given in future years post 2020. Two distinct scenario settings come into play:
    - *No higher market value for decentral PV (at the retail level):* This scenario serves to illustrate the impacts that arise if no prioritisation of decentral PV generation will be undertaken in future years (and in modelling). Thus, within this scenario, we treat decentral PV systems similarly to other forms of central electricity supply as a supply option to compete in the wholesale electricity market. In other words, we do not acknowledge the

higher value of decentral generation that is applicable at household level for prosumers when used for self-consumption.

- *Higher market value of decentral PV (at the retail level) (default assumption):* As default, we take the assumption that a prioritisation of decentral PV is maintained in future years. In other words, we acknowledge the higher value of decentral electricity supply when used for self-consumption (as represented by the energy-related part of retail electricity tariffs). With regard to the future development of retail electricity tariffs, we take the assumption that a convergence and alignment of tariff structures will take place across the EU. As part of that process we assume that capacity-related fees increase by 50% compared to default, and that, in turn, the energy-related part is reduced accordingly.

- ***High carbon prices (major ETS reform):*** One scenario is dedicated to assess how the (pending) reform of the EU's Emission Trading Scheme (ETS) may impact future RES developments and in particular the uptake of RES in the electricity sector (in competition to RES in other energy sectors). We assume here a strong uptake of carbon prices within the ETS in future years, building on outcomes of recent PRIMES modelling in this topical area. More precisely, we assume that carbon prices evolve as proclaimed by the PRIMES euco27 scenario, serving as a guiding scenario in line with energy and climate targets within the EC's 2016 winter package. In contrast, our default assumption used in modelling is that in the years up to 2050 carbon prices increase moderately (in accordance with the 2016 PRIMES reference scenario), cf. Figure 3.

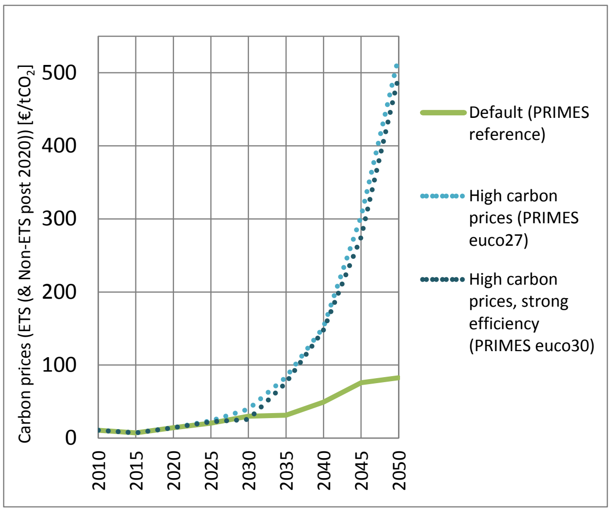

Figure 3: Carbon price trends according to recent PRIMES modelling
(Source: NTUA, 2016)

- ***Strong 2030 targets for RES (and energy efficiency):*** Here, we analyse how the overall policy ambition for renewables (and for energy efficiency) determines the required uptake of RES in the electricity sector, exemplified by the assumed overall target set for RES within the EU by 2030 (i.e. assuming a 2030 RES target in size of 30% instead of 27%).[5]

Table 4 (below) provides an overview on the assumptions taken in the scenarios of this topical assessment.

[5] We acknowledge that this is still below the actually agreed one (i.e. 32% - as agreed in Council and Parliament during 2018) – but since it is here combined also with a lower energy efficiency target (i.e. 30% instead of 32.5%) this causes a comparatively similar level of overall RES ambition. Thus, in other words, the RES volumes required for meeting 30% RES in combination with a 30% energy efficiency target are comparatively similar than to strive for 32% RES combined with 32.5% energy efficiency. If accounted precisely, the required RES volumes by 2030 would be less than 3% smaller under the assessed combination (i.e. 30% RES, 30% EE) than under the politically agreed one (i.e. 32% RES, 32.5% EE).

Table 4: Assumptions used in assessed scenarios related to policy-related aspects / policy ambition

Scenario acronym	27% RES (reference)	27% RES - no prioritisation of decentral PV	27% RES - high carbon prices	30% RES - strong EE
Topical area		**Policy-related aspects / Policy ambition**		
Characterisation	Default (reference) scenario	No prioritisation (higher retail value) of decentral RES (PV)	High carbon prices (major ETS reform)	Strong policy ambition for RES and EE by 2030
Energy demand trend	**27% EE by 2030** (PRIMES euco27)	**27% EE by 2030** (PRIMES euco27)	**27% EE by 2030** (PRIMES euco27)	**30% EE by 2030** (PRIMES euco30)
Carbon price trend	**Default** (PRIMES reference)	**Default** (PRIMES reference)	**High** (PRIMES euco27)	**Default** (PRIMES reference)
RES ambition	at least **27% by 2030** (and beyond)	at least **27% by 2030** (and beyond)	at least **27% by 2030** (and beyond)	at least **30% by 2030** (and beyond)

3 Results of the model-based analysis

3.1 RES deployment at the aggregated level

We start with an analysis of RES deployment according to the Green-X scenarios conducted within this case study. Since Green-X modelling builds on PRIMES scenarios that have been developed for and are discussed in the Impact Assessment accompanying the Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources (COM(2016) 767 final), we involve these as well. In this context, Figure 4 below shows the development of the RES share in gross final energy demand throughout the period 2015 to 2030 in the EU28 according to the assessed Green-X scenario. As reference for 2030 also the shares in the PRIMES scenarios (i.e. PRIMES reference as of 2016 as well as PRIMES euco27and euco30 – the EU's central scenarios related to RES use post 2020) are indicated. Noticeably, an alignment to PRIMES results could be achieved at the aggregated level (i.e. on total RES deployment, EU28) for the policy track aiming for a (minimum) RES share of 27% by 2030.

A closer look at the impact of assessed determinants concerning the optimal diffusion of RES electricity, done by conducting a set of sensitivity scenarios under the same RES policy concept / ambition (i.e. the 2030 target of (at least) 27% RES by 2030 under a least-cost policy framework), shows only a small changes at the aggregated level (i.e. on the overall RES share). As shown in Figure 4 or, specifically for 2030, in Figure 5 (left), in the case of high learning of selected key RES-E technologies (i.e. wind and photovoltaics) (i.e. scenario "27% RES – high learning") the minimum share would be succeeded – but only by 0.1 percentage points. A more pronounced impact arises in the case of a proactive ETS-reform, leading presumably to high carbon prices, specifically in the long term close to 2050 (i.e. scenario "27% RES – high carbon prices"): here overall RES deployment increases to a 27.4% RES share in gross final energy demand by 2030. The upper boundary of RES deployment within this modelling exam is set by the scenario "30% RES – strong EE": the 2030 RES share increase to 30% by 2030 because of the higher imposed RES policy ambition – i.e. a minimum RES target of 30% instead of 27% is imposed under this scenario.

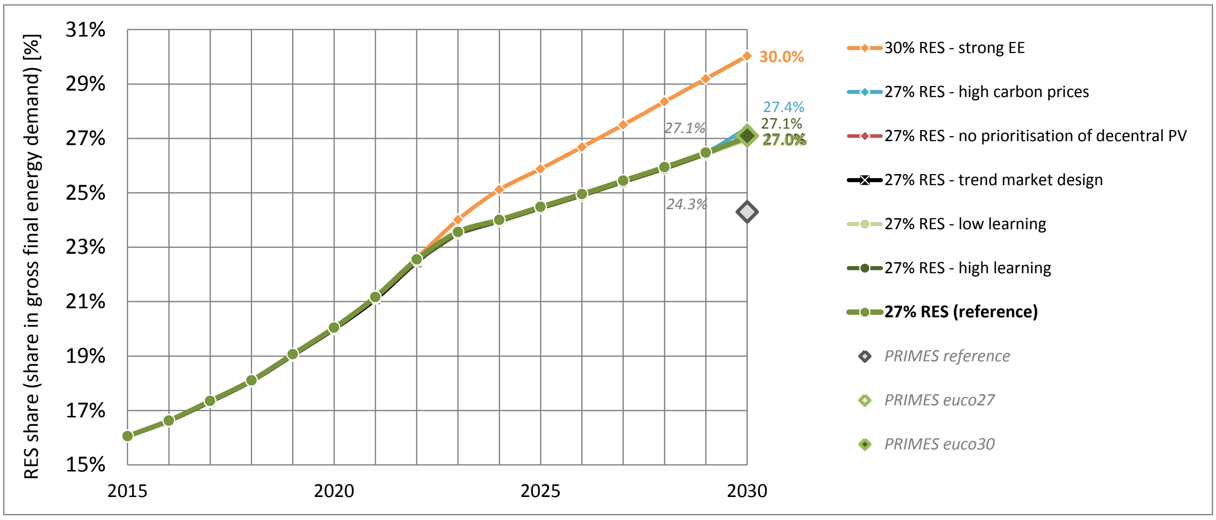

Figure 4: RES deployment in relative terms (i.e. as share in gross final energy demand) over time in the EU 28 for assessed scenarios

The right-hand side of Figure 5 provides interesting insights on how RES deployment in relative terms translates into absolute energy volumes – i.e. Mtoe or TWh of energy that need to be produced from renewable sources by 2030. Apparently, with stronger ambition related to energy efficiency the need for deploying renewables declines. As a consequence, only a 6% higher amount of renewables is needed to reach a 30% RES by 2030 under strong energy efficiency instead of striving for 27% RES in the case of moderate energy efficiency, cf. scenario "30% RES – strong EE" with e.g. scenario "27% RES (reference)".[6] In general terms, RES electricity is expected to provide the strongest contribution to overall RES target achievement: already by 2020 around 1,300 TWh, corresponding to ca. 48% of total RES generation in 2020, is expected to stem from RES in the electricity sector. According to the modelling conducted, reflecting a least-cost allocation of the 2030 RES target, RES-E generation would then increase further until 2030, reaching 1,713 TWh in 2030, corresponding to a share of 50.6% in total RES use, in a scenario that reflects a continuation of current trends of electricity market design (i.e. scenario "27% RES – trend market design", with delayed grid development, capacity markets as common market design, and no demand response). These scenario settings can be classified as least beneficial circumstances among the analysed cases. At the positive end, scenario "27% RES – high carbon prices" indicates an increase of RES-E generation up to 1,801 TWh until 2030, corresponding to a share of 52.5% in total RES use by then. With a range from 1,412 to 1,446 TWh RES in heating & cooling is expected to deliver the second largest contribution, achieving a share of 41.1%-42.8% in total RES use, depending on the assessed underlying circumstances. A comparatively stable deployment of biofuels in transport is observable, driven by the moderate sectoral target imposed for RES in transport (and in consequence causing slight deviations from a purified cross-sectoral least cost allocation of RES use)

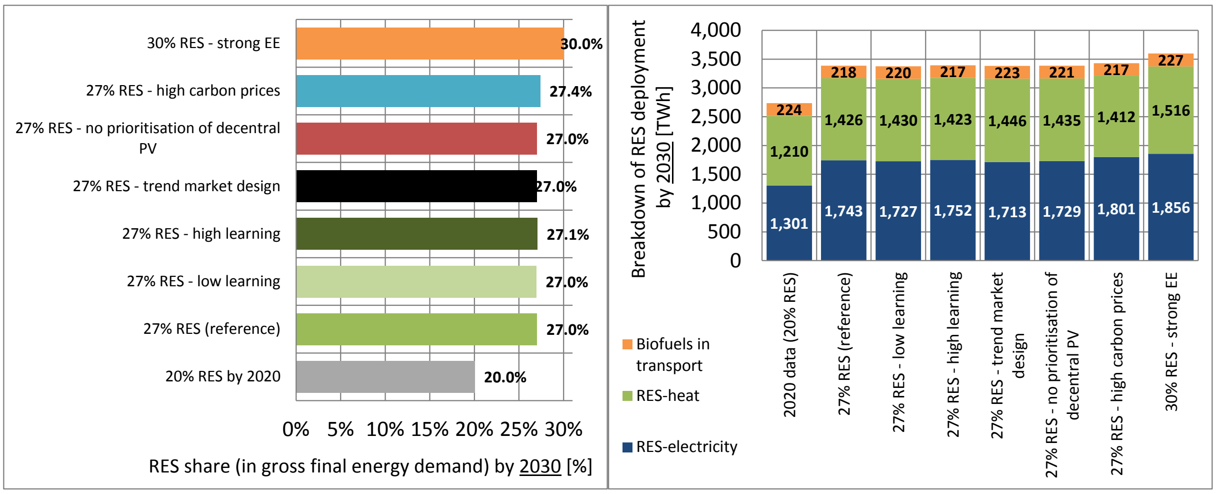

Figure 5: 2030 RES deployment: RES share in gross final energy demand (left) and sectorial decomposition of RES use in absolute terms (right) in the EU 28 according to assessed scenarios

[6] An increase of the targeted RES share from 27% to 30% (as share in gross final energy demand) corresponds to an increase by 11% of RES use in absolute terms – if the underlying demand would be the same. As a consequence of the at the same time imposed stronger efficiency (i.e. increasing the EE target from 27% to 30%) the correspondingly required RES use in absolute terms increases however only by 6%.

3.2 RES developments in the electricity sector

The optimal RES-E share in dependence of assessed determinants

Next we take a closer look at RES in the electricity sector, aiming to clarify the central question underlying this modelling case: how is the optimal RES-E share under a cross-sectorial least-cost allocation of RES use affected by assessed determinants? Similar to Figure 4, Figure 6 provides an illustration of the required RES deployment in the electricity sector at EU28 level in the period up to 2030 in relative terms, depicting the expected development of the RES share in gross electricity demand according to the assessed modelling cases. Striving for 27% RES by 2030 implies to achieve a RES-E share around 50% at the same point time – if a least-cost policy approach is followed as conditioned in this exercise. Increasing the RES ambition to 30% by 2030 would for example lead to an increase of the RES-E share to around 55%. As discussed for total RES above, energy efficiency impacts the required RES-E deployment in absolute terms – i.e. the amount of energy stemming from renewable sources (cf. Figure 5 (right)).

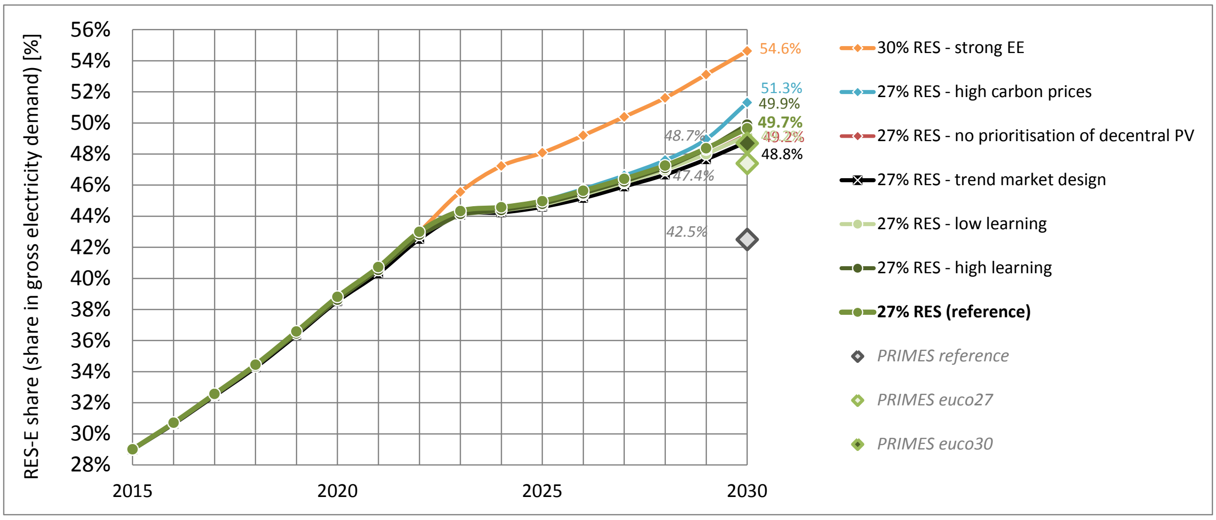

Figure 6: RES-E deployment in relative terms (i.e. as share in gross electricity demand) over time in the EU 28 for assessed scenarios

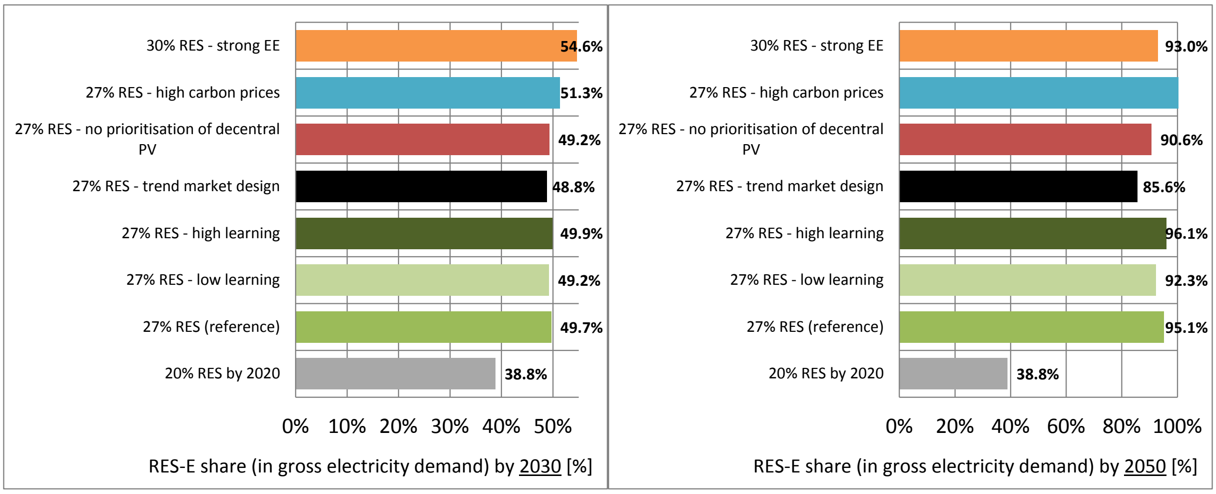

Figure 7: RES-E deployment 2030 and beyond: RES-E share in gross electricity demand by 2030 (left) and by 2050 (right) in the EU 28 according to assessed scenarios

In accordance with the central question underlying this case study (i.e. elaborating on the optimal RES-E share in dependence of assessed determinants), Figure 7 takes a closer look at the resulting RES-E deployment by 2030 and beyond. More precisely, this graph illustrates the resulting RES-E share in gross electricity demand by 2030 (left) for all assessed scenarios. The right-hand side of this graph provides also an outlook to 2050, indicating the expected RES-E share by that point in time.

Key results and findings derived from these depictions are:

- Under *default framework conditions* – i.e. moderate learning, optimal electricity market design, moderate carbon prices, and a RES policy framework that safeguard a minimum RES share of 27% RES by 2030 and beyond – as presumed in the reference scenario "27% RES" a RES-E share of 49.7% is reached in 2030. In the forthcoming years post 2030 RES-E deployment would then further increase because of expected ongoing improvements in economic viability, driven by technological progress of underlying technologies as well as by assumed increases in fossil fuel and carbon prices. In 2050 modelling indicates an impressive increase of the absolute and relative RES-E deployment, reaching a RES-E share in gross electricity demand of 95.1%.
- *Technological learning* has an impact on these developments as observable from the related scenarios where either a 20% (compared to default) lower (i.e. scenario "27% RES – low learning") or a 20% higher learning rate (i.e. scenario "27% RES – high learning") is assumed for key technologies like wind energy and photovoltaics. As a consequence of the comparatively limited time span until 2030, only a small impact on the resulting 2030 RES-E share is applicable: the default RES-E share decreases by 0.5 percentage points to 49.2% in the case of low learning, and it is expected to increase by 0.2 pp to 49.9% in the case of high learning. By 2050 effects are more pronounced: here low learning of wind and photovoltaics would cause a decline of the RES-E share by 2.8 pp (i.e. from 95.1% (reference) to 92.3% (scenario "27% - low learning"). In the contrary, in the case of high learning the resulting RES-E share would increase by 1 pp (i.e. 96.1% under scenario" 27% RES – high learning"). Summing up, effects are generally more pronounced in the case of low learning since then some wind or photovoltaic projects would not materialise whereas in the case of high learning other constraints may come into play that limit the overall diffusion of wind and PV.
- An even more pronounced impact on the optimal RES-E share is applicable for *electricity market design*, or, in other words, the capability of the system to provide flexibility to cope with high shares of variable renewables in electricity supply. Less or more flexibility of the power system and electricity market design in general, has technical and operational consequences and determines also the economic viability of RES-based electricity supply. As outlined in the methodology part of this report, specifically section 0, our modelling focusses on some core issues that impact RES-E integration, including grid development, electricity market design, and sector coupling / demand-side response. Under default optimal framework conditions / market design (i.e. scenario "27% RES (reference)) a high RES-E share (i.e. 49.7% by 2030, 95.1% by 2050) appears feasible from a technical perspective and at the same time this can be seen as economically viable. We contrast these findings with a scenario reflecting less optimal framework conditions – i.e. the so-called trend scenario (i.e. scenario "27% RES – trend market design") where for example a delayed grid development, no demand response and the implementation of capacity markets (leading to lower prices at the (energy-related) wholesale market) are postulated. It turns out that the optimal RES-E share is strongly affected: a decline of the RES-E

share by 0.9 pp in 2030 (i.e. from 49.7% to 48.8%) and by 9.5% pp in 2050 (i.e. from 95.1% to 85.6%) is getting apparent. This underpins the often called need to adapt or redesign our market framework to foster renewable integration.

- Different *policy-related aspects* have been analysed within our modelling exam. For each topical subject under consideration one scenario has been defined to gain further insights on the resulting impacts as outlined below:
    - Within our analysis of how policy design may facilitate or hinder the uptake of decentral RES prosumers, we showcase the impact of whether or not a *prioritisation of decentral generation*, exemplified for the case decentral PV, will be given in future years post 2020. Under default conditions (i.e. reference scenario "27% RES") the assumption is taken that a prioritisation of decentral PV is maintained in future years, leading to a strong uptake of decentral PV in future years and, thus, affecting also total RES-E deployment. As discussed above, RES-E is expected to achieve a share of 49.7% in 2020, increasing to 95.1% by 2050. In contrast to above, in the absence of a special prioritisation of decentral PV, meaning in practical terms that under scenario "27% RES – no prioritisation of decentral PV" we treat decentral PV systems (similar to other forms of central electricity supply) as a supply option to compete in the wholesale electricity market, decentral PV is lacking behind default trends. The optimal RES-E share by 2030 is consequently also affected, amounting to 49.2% which is 0.5 percentage points below the reference. Long-term (2050) impacts are even more pronounced: in 2050 the optimal RES-E share amounts to 90.6%, corresponding to a decline by 4.5 percentage points compared to reference.
    - Pronounced impacts are also applicable for the scenario where *high carbon prices* (as a consequence of a major ETS reform) are prevailing (cf. scenario "27% RES – high carbon prices"). One scenario is consequently dedicated to assess how the (pending) reform of the EU's Emission Trading Scheme (ETS) may impact future RES developments and in particular the uptake of RES in the electricity sector (in competition to RES in other energy sectors). We assume here a strong uptake of carbon prices within the ETS in future years, building on outcomes of recent PRIMES modelling in this topical area. More precisely, we assume that carbon prices evolve as proclaimed by the PRIMES euco27 scenario, serving as a guiding scenario in line with energy and climate targets within the EC's 2016 winter package. In contrast, our default assumption used in modelling is that carbon prices increase moderately in the years up to 2050 (in accordance with the 2016 PRIMES reference scenario), cf. Figure 3. Results show that an increase in carbon prices leads to a faster uptake of renewables in the electricity sector. The scenario "27% RES – high carbon prices" shows a RES share of 51.3% by 2030, and a fully RES-based electricity supply by 2050.[7]
    - *Strong 2030 targets for RES (and energy efficiency)*: Here, we analyse how the overall policy ambition for renewables (and for energy efficiency) determines the required uptake of RES in the electricity sector, exemplified by the assumed overall 2030 target set for RES

[7] A fully RES-based electricity supply, including a large set of variable RES generation, requires also a strong uptake of storage options and other flexibility solutions, so that they are available by that point in time.

within the EU. More precisely, we take the assumption that at EU level the 2030 RES target is set at 30% (instead of 27% as default).[8] This leads to an accelerated uptake of RES electricity, reaching a demand share of 54.6% (instead of 49.7% as default) by 2030. By 2050 there is however hardly any difference in RES-E deployment compared to the reference case. Reason is that the policy-driven demand for RES (in electricity and in other sectors) is no longer the determining factor for RES use under the scenario setting. In other words, renewables are expected to be cost-competitive by then and the "minimum RES-share" imposed in the modelling takes no effect at that point in time (independent if that is set at 27% or at 30%).

The underlying technology mix

Complementary to the above, Figure 8 provides a technology breakdown of RES-E deployment at EU 28 level by 2030 (top) and by 2050 (bottom). Apart from the outlook toward 2030 and 2050 this figure also includes a comparison to the status quo (2015). Below we summarise key results:

- Apparently, onshore wind energy dominates the picture – both by 2030 and by 2050 the largest share of RES-based electricity generation will come from this particular technology, and also today (as of 2015) onshore wind plays a dominant role, achieving a slightly lower contribution as large-scale hydropower. Thus, electricity generation from onshore wind is expected grow from 258 TWh to a yearly generation potential of around 682 to 717 TWh by 2030. The trend continues towards 2050, reaching between 1,529 and 1,648 TWh by 2050.
- Large-scale hydropower (i.e. above 10 MW installed capacity) is the dominant RES source in the electricity sector by 2015. There is however only a limited potential available for further use. Normalised electricity generation from large hydro stands at 295 TWh today (2015). Scenarios indicate only a minor increase in generation to ca. 319 TWh by 2030 and to around 329 TWh by 2050. There is only a negligible variation across scenarios, indicating that the indicated increase in generation is economically viable. It also shows however that there is no additional potential available under the given economic and technical / environmental constraints.
- Offshore wind energy offers a promising potential. According to the scenarios assessed a strong increase is expected for offshore wind in the forthcoming decade – i.e. electricity generation will rise from 31 to at least 131 TWh by 2030. A strong increase is also presumed for the years post 2030. As a consequence, offshore wind is expected to reach between 798 and 884 TWh as annual generation potential by 2050.
- Apart from wind energy, photovoltaics is the other key technology in future years. Modelling indicates a significant increase in PV deployment, where electricity generation increases from 102.5 TWh in 2015 to 258 TWh under pessimistic circumstances (i.e. with no prioritisation of decentral generation) by 2030 whereas under default framework conditions a level of 294 TWh is achieved. Electricity generation from PV is expected in increase further until 2050, reaching between 487 and 795 TWh by then.

[8] We are aware that this is still below the actually agreed one (i.e. 32% - as agreed in Council and Parliament during 2018) – but since it is here combined also with a lower energy efficiency target (i.e. 30% instead of 32.5%) this causes a comparatively similar level of overall RES ambition. Thus, in other words, the RES volumes required for meeting 30% RES in combination with a 30% energy efficiency target are comparatively similar than to strive for 32% RES combined with 32.5% energy efficiency. If accounted precisely, the required RES volumes by 2030 would be less than 3% smaller under the assessed combination (i.e. 30% RES, 30% EE) than under the politically agreed one (i.e. 32% RES, 32.5% EE).

- Significant increases in deployment can be expected also for bioenergy under presumed “least cost” conditions. Electricity generation from bioenergy, comprising biogas, biowaste and solid biomass is expected to increase from ca. 171 TWh in 2015 to at least 235 TWh by 2030. That trend is prolonged in the years post 2030 and bioenergy will contribute to electricity generation with 500 to ca. 720 TWh by 2050 according to Green-X least-cost modelling.
- Other technologies like small-scale hydropower, geothermal electricity, tidal stream and wave power as well as CSP show only a minor contribution by 2030 and by 2050 under the underlying framework conditions where least-cost options are prioritised in modelling.

A comparison of the changes in deployment across scenarios shows that apart from specific non-prioritisation / discrimination – e.g. the scenario of “no prioritisation of decentral PV” where PV deployment is lowest among all assessed scenarios – in general terms the scenario of “27% RES – trend market design” leads to the lowest deployment of RES technologies in the electricity sector. In contrast to above, RES deployment generally peaks in the scenario “30% RES – strong EE” by 2030, and in the scenario of high carbon prices by 2050.

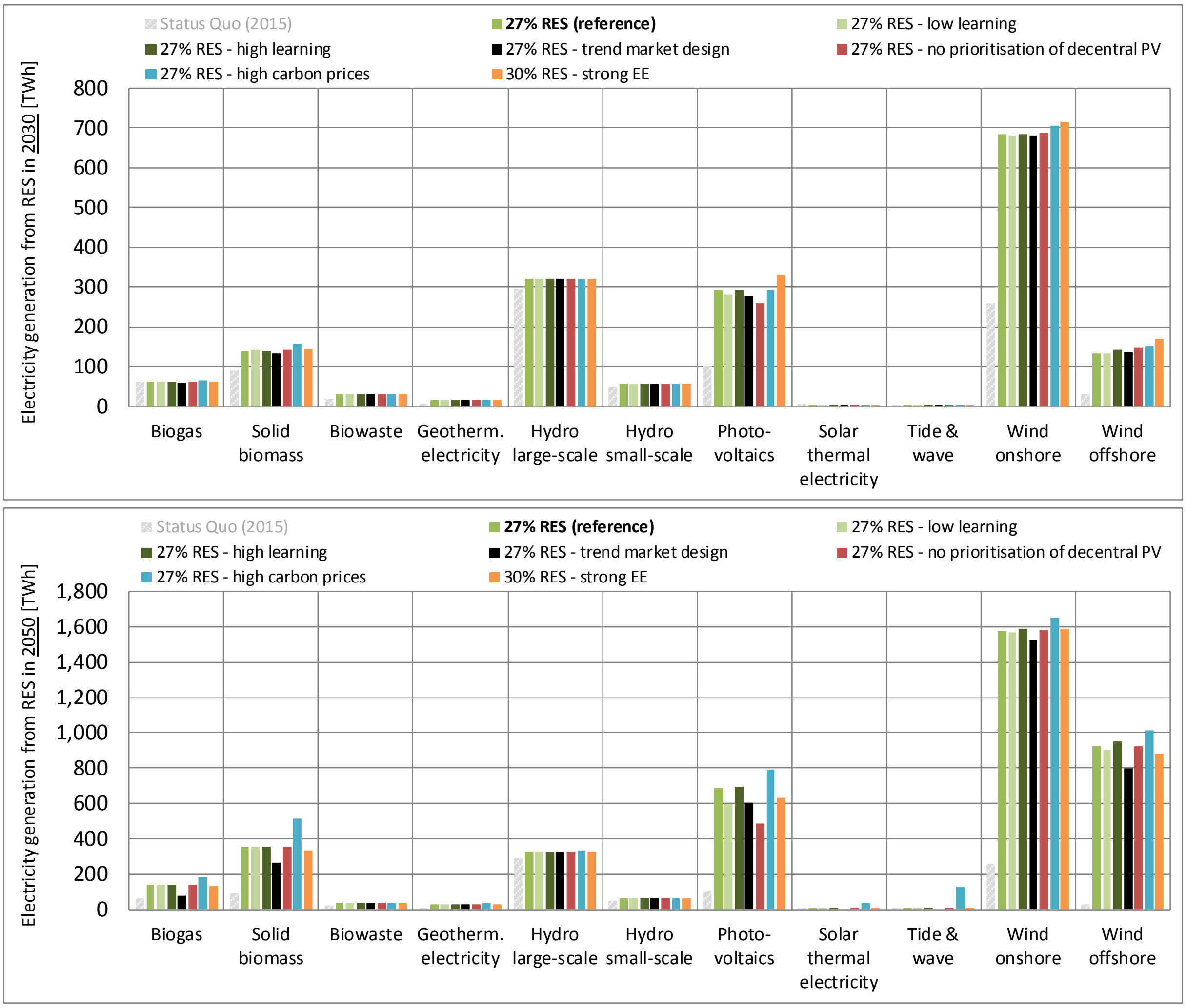

Figure 8. Technology-specific breakdown of RES-E generation by 2030 (top) and by 2050 (bottom) at EU 28 level for all assessed scenarios.

3.3 Direct impacts of future RES deployment: Costs, expenditures and benefits

Indicators on costs, expenditures and benefits of RES

The outcomes of Green-X modelling related to capital, O&M, and fuel expenditures of RES as well as to additional generation costs, support expenditures and savings related to fossil fuel (imports) are presented in this section. The results are complemented by a qualitative discussion based on key indicators.

Figure 9 summarises the assessed costs, expenditures and benefits arising from future RES deployment in the focal period 2021 to 2030. More precisely, this graphs shows the required capital and operational (O&M and fuel) expenditures and the resulting costs – i.e. additional generation cost, and support expenditures[9] for the assessed RES-E policy pathways (all on average per year throughout the assessed period). Moreover, they indicate the accompanying benefits in terms of supply security (avoided fossil fuels expressed in monetary terms – with impact on a country's trade balance) and climate protection (avoided CO_2 emissions –expressed in monetary terms as avoided expenses for emission allowances). This comparative depiction refers to total RES in the electricity sector and includes all plants – i.e. new plants installed post 2020 as well as the large stock of RES-E plants installed in the years up to 2020.

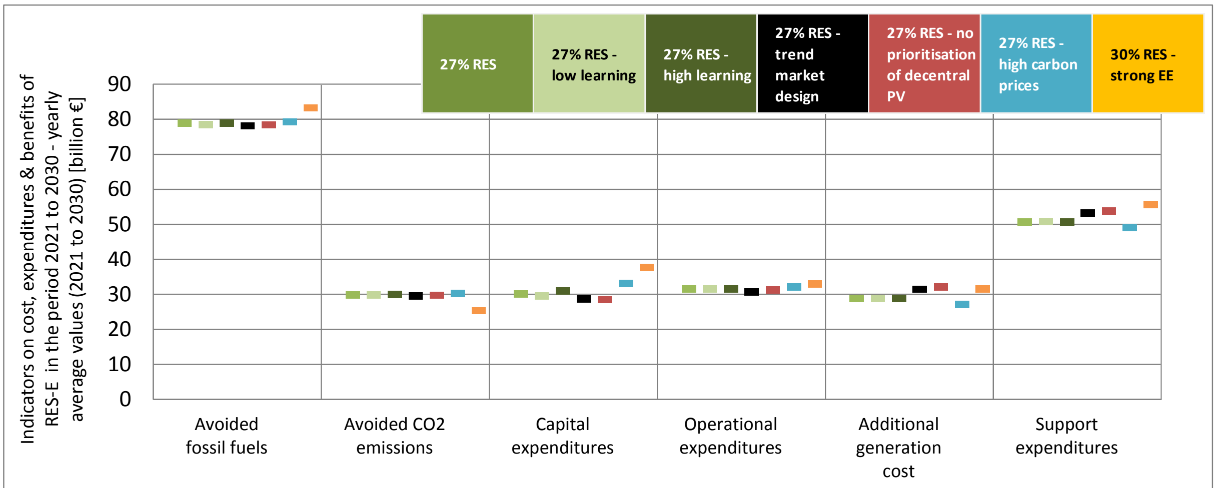

Figure 9. Indicators on yearly average cost, expenditures and benefits of RES at EU 28 level for all assessed cases, monetary expressed in absolute terms (billion €) per decade (2021 to 2030)

Some key observations can be made from Figure 9:

- Benefits, and here in particular the monetary expression of fossil fuel avoidance, are across all scenarios higher than the required investments or the necessary support if we include in our aggregation in addition to new installations also the stock of existing plants (installed up to 2020).

[9] *Support expenditures* - i.e. the transfer costs for consumers (society) due to RES support – are defined as the financial transfer payments from the consumer to the RES producer compared to the reference case of consumers purchasing conventional electricity on the power market. This means that these costs do not consider any indirect costs or externalities (environmental benefits, change of employment, etc.)

- In general terms, there is a valid correlation between RES-E deployment and the benefits like fossil fuel or carbon avoidance. The same dependency can be observed between RES-E deployment and
- Not so surprisingly, scenarios that reach a 27% RES target lead to overall costs and benefits in a comparable order of magnitude. The strongest differences between analysed scenarios are however applicable if we look at capital expenditures, additional generation cost and support expenditures. The reason for this is that all assessed scenarios affect only investments in new RES-E plants installed post 2020. Consequently, differences between assessed scenarios are strongest if we look at the investments triggered by the presumed policy intervention, or, as it is for example the case with the scenario "27% RES – trend market design", if the underlying market framework (i.e. carbon prices, wholesale prices, or, generally, flexibility provision) is different to the other analysed scenarios.

Moreover, a significant difference between *additional generation costs* and *support expenditures* for RES can be observed. The following aspects are important to consider in this respect:

- The expressed additional generation costs are calculated by summarising the average additional generation costs at technology level by country. Hence, some averaging trend occurs which underestimates the actual costs specifically if costs differ substantially between feedstock subcategories or sites. This becomes more important in the case of an accelerated RES deployment where the marginal plant possesses significantly higher cost than the average.
- Additional generation costs are risk-neutral while for support costs the country-, policy- and technology-inherent investor's risk is taken into consideration.
- Additional generation costs shall mean the levelised cost of energy minus the reference price for conventional energy supply whereby the levellising is done over the lifetime. In contrast to this, investors typically insist on a shorter depreciation time which needs to be taken into account in policy design. This is consequently reflected in the resulting support costs.

Indicators on support expenditures for RES

Figure 10 complements the above depictions of RES deployment and overall economic impacts, indicating the resulting support expenditures for RES-electricity. More precisely, Figure 10 compares the required support expenditures (on average per year for the period 2021 to 2030) for all assessed scenarios.

Of highlight, these graphs clearly indicate that the bulk of support expenditures in the forthcoming decade is dedicated to RES installations that have been erected in the years up to 2020: under a 27% RES target generally around 8% of total RES-E support in the forthcoming decade will be for new installations being built in the years 2021 to 2030.[10] That share increases for example to about 16% if a 30% RES target is pursued for 2030 instead of 27%.

As outlined above, we can see that overall policy costs are in comparatively similar magnitude for all cases and that, generally, they match with RES-E deployment. An exception from that general trend is the

[10] The expressed ranges indicate the variations observable among the different RES-E policy pathways. We have excluded from this comparison the "ETS only" pathway since here no dedicated support will be paid for new RES installations and also since the EU would fail to achieve the given 2030 RES target under this policy path.

scenario of "27% RES under high carbon prices" – here costs are lower despite the increase in RES-E deployment in the 2030 timeframe. Reason for that are the higher carbon prices that lead to an increase in wholesale prices and, consequently, reduce the need for additional support (on top of the electricity market revenues). The impact of carbon prices on the wholesale market is also getting apparent if we look at the support dedicated to existing plants (installed up to 2020). Despite similar generation volumes for existing plants, support expenditures are significantly lower in the case of high carbon prices.

Learning positively affects RES-E deployment as well as corresponding costs (e.g. support expenditures). However, due to the short time in which differences in learning rates are presumed in modelling, the impact on overall support expenditures for (new) RES-electricity is comparatively small in the forthcoming decade. The improved viability will however also positively impact the cost burden post 2030.

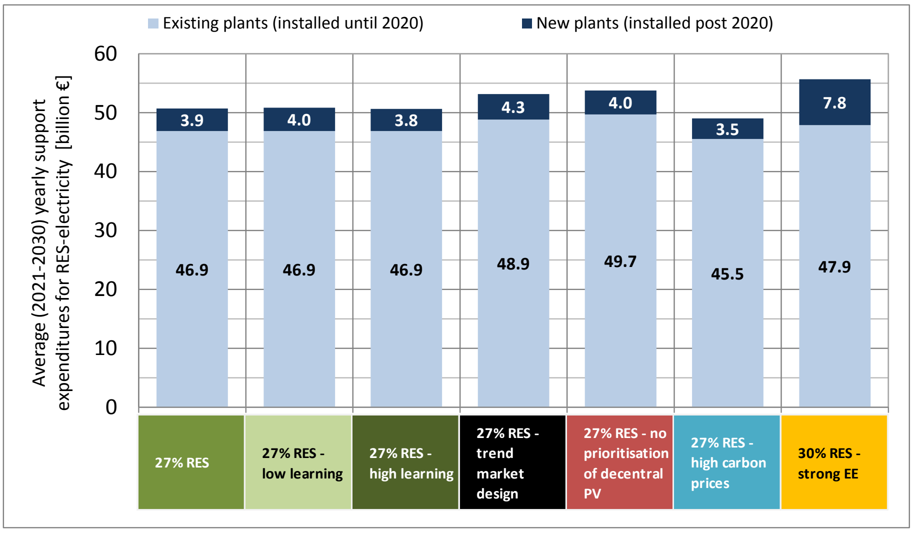

Figure 10. Comparison of the required average (2021-2030) yearly support expenditures for RES (left) and RES-E (right) in the EU 28 for all assessed RES-E policy pathways.

4 Synthesis and conclusions

This case study is dedicated to elaborate on *the diffusion of renewable electricity generation, aiming to gain insights on the suitable/optimal share renewables may take in Europe's future electricity supply.* Generally, renewable electricity generation (RES-E) is estimated to cover a high share of the future electricity demand in the EU. The possible diffusion of RES-E generation depends on the overall policy ambition in our combat against climate change, the relative costs of RES-E to its (low-carbon) alternatives, and the capability of the system to accommodate volatile generation. All these determinants are dynamic and therefore can change over time, and, most important, their impact on the optimal RES-E share has been analysed in the course of this case study. Below we report on some key findings.

Under assessed *default framework conditions* (i.e. 27% RES by 2030, optimal market design, etc.) a RES-E share of 49.7% is reached in 2030.

Technological learning has an impact on these developments as observable from the related scenarios where either a 20% (compared to default) lower (i.e. scenario "27% RES – low learning") or a 20% higher learning rate (i.e. scenario "27% RES – high learning") is assumed for key technologies like wind energy and photovoltaics. As a consequence of the comparatively limited time span until 2030, only a small impact on the resulting 2030 RES-E share and on corresponding cost, analysed here through e.g. the resulting support expenditures, is applicable. The default RES-E share would for example decline by 0.5 percentage points by 2030 in the case of low learning, and the share increases by 0.2 pp in the case of high learning. By 2050 these effects are getting more pronounced: here low learning of wind and photovoltaics would cause a decline of the RES-E share by 2.8 pp.

An even more pronounced impact on the optimal RES-E share is applicable for *electricity market design*, or, in other words, the capability of the system to provide flexibility to cope with high shares of variable renewables in electricity supply. Less or more flexibility of the power system and electricity market design in general, has technical and operational consequences and determines also the economic viability of RES-based electricity supply. Our modelling focusses here on some core issues that impact RES-E integration, including grid development, electricity market design, and sector coupling / demand-side response. In a scenario reflecting less optimal framework conditions on these aspects it turns out that the optimal RES-E share is strongly affected: a decline of the RES-E share by 0.9 pp in 2030 (i.e. from 49.7% to 48.8%) and by 9.5% pp in 2050 (i.e. from 95.1% to 85.6%). This underpins the often called need to adapt or redesign our market framework to foster renewable integration.

Different *policy-related aspects* have been analysed within our modelling exam. For each topical subject under consideration one scenario has been defined to gain further insights on the resulting impacts as outlined below:

- Within our analysis of how policy design may facilitate or hinder the uptake of decentral RES prosumers, we showcase the impact of whether or not a *prioritisation of decentral generation*, exemplified for the case decentral PV, will be given in future years post 2020. Under default conditions (i.e. reference scenario "27% RES") the assumption is taken that a prioritisation of decentral PV is maintained in future years, leading to a strong uptake of decentral PV in future years and, thus, affecting also total RES-E deployment. In the absence of a special prioritisation of decentral PV, we treat decentral PV systems (similar to other forms of central electricity supply) as a supply option to compete in the wholesale electricity market. Consequently, decentral PV is then lacking behind default trends. The optimal RES-E share by 2030 is consequently also affected, amounting to 49.2% which is 0.5 percentage points below the reference. Long-term (2050) impacts are even more pronounced: in 2050 the optimal RES-E share amounts to 90.6%, corresponding to a decline by 4.5 percentage points compared to reference.

- Pronounced impacts are also applicable for the scenario where *high carbon prices* (as a consequence of a major ETS reform) are prevailing (cf. scenario "27% RES – high carbon prices"). We assume here a strong uptake of carbon prices within the ETS in future years, building on outcomes of recent PRIMES modelling in this topical area. Results show that a stronger increase in carbon prices leads to a faster uptake of renewables in the electricity sector. The scenario "27% RES – high carbon prices" shows a RES share of 51.3% by 2030, and a fully RES-based electricity supply by 2050.[11]
- *Strong 2030 targets for RES (and energy efficiency)*: Here, we analyse how the overall policy ambition for renewables (and for energy efficiency) determines the required uptake of RES in the electricity sector, exemplified by the assumed overall 2030 target set for RES within the EU. More precisely, we take the assumption that at EU level the 2030 RES target is set at 30% (instead of 27% as default).[12] This leads to an accelerated uptake of RES electricity, reaching a demand share of 54.6% (instead of 49.7% as default) by 2030. As recent modelling proves the optimal RES-electricity share would increase further to around 58%-60% if an overall RES share of 32% is aimed for by 2030.

[11] A fully RES-based electricity supply, including a large set of variable RES generation, requires also a strong uptake of storage options and other flexibility solutions, so that they are available by that point in time.

[12] We are aware that this is still below the actually agreed one (i.e. 32% - as agreed in Council and Parliament during 2018) – but since it is here combined also with a lower energy efficiency target (i.e. 30% instead of 32.5%) this causes a comparatively similar level of overall RES ambition. Thus, in other words, the RES volumes required for meeting 30% RES in combination with a 30% energy efficiency target are comparatively similar than to strive for 32% RES combined with 32.5% energy efficiency. If accounted precisely, the required RES volumes by 2030 would be less than 3% smaller under the assessed combination (i.e. 30% RES, 30% EE) than under the politically agreed one (i.e. 32% RES, 32.5% EE).

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6 Annex A: Key assumptions used in modelling

In order to ensure maximum consistency with existing EU scenarios and projections the key input parameters of the scenarios presented in this report are derived from PRIMES modelling and from the Green-X database (www.green-x.at) with respect to the potentials and cost of RES technologies. Table 5 shows which parameters are based on PRIMES, on the Green-X database and which have been defined for this study. The PRIMES scenarios used for are the latest publicly available reference scenario (European Commission, 2016f) and the climate mitigation scenarios PRIMES euco27 and PRIMES euco30 that build on the targeted use of renewables (i.e. 27% RES by 2030) and an enhanced use of energy efficiency compared to reference conditions – i.e. 27% (euco27) or 30% EE (euco30) by 2030, respectively. Please note that all PRIMES scenarios are intensively discussed in the EC's winter package, cf. the Impact assessment of the recasted RED (SWD (2016) 410 final) (European Commission, 2016g).

Table 5. Main input sources for scenario parameters

Based on PRIMES	Based on Green-X database	Defined for this assessment
Primary energy prices	Renewable energy technology cost (investment, fuel, O&M)	Renewable energy policy framework
Conventional supply portfolio and conversion efficiencies	Renewable energy potentials	Reference electricity prices
CO_2 intensity of sectors	Biomass trade specification	
Energy demand by sector	Technology diffusion / Non-economic barriers	
	Learning rates	
	Market values for variable renewables	

The following subsections provide further details on the assumptions used for key parameter.

6.1 Energy demand

Figure 11 depicts the projected energy demand development at EU 28 level according to the PRIMES scenarios used in this study with regard to gross final energy demand (left) as well as gross electricity demand (right).

A comparison of the different PRIMES demand projections at EU 28 levels shows the following trends: The *PRIMES reference case* as of 2016 (EC, 2016) draws a modified picture of future demand patterns compared to previous baseline and reference cases. The impacts of the global financial crisis are better reflected, leading to a reduction of overall gross final energy demand in the short term, and moderate growth in later years towards 2020. Beyond 2020, according to the *PRIMES reference case* (where the achievement of climate and RES targets for 2020 is assumed) gross final energy demand is expected to moderately decrease. The decrease of gross final energy demand is even more pronounced in the *PRIMES euco27* as well as in the *PRIMES euco30* where in addition to short-term (2020) also mid- (2030) to long-term (2050) EU climate targets have to be met. In these cases, policy measures supporting RES and energy efficiency were assumed to accompany purely climate policies (i.e. the ETS) – and both are regarded as key options for mitigating climate change.

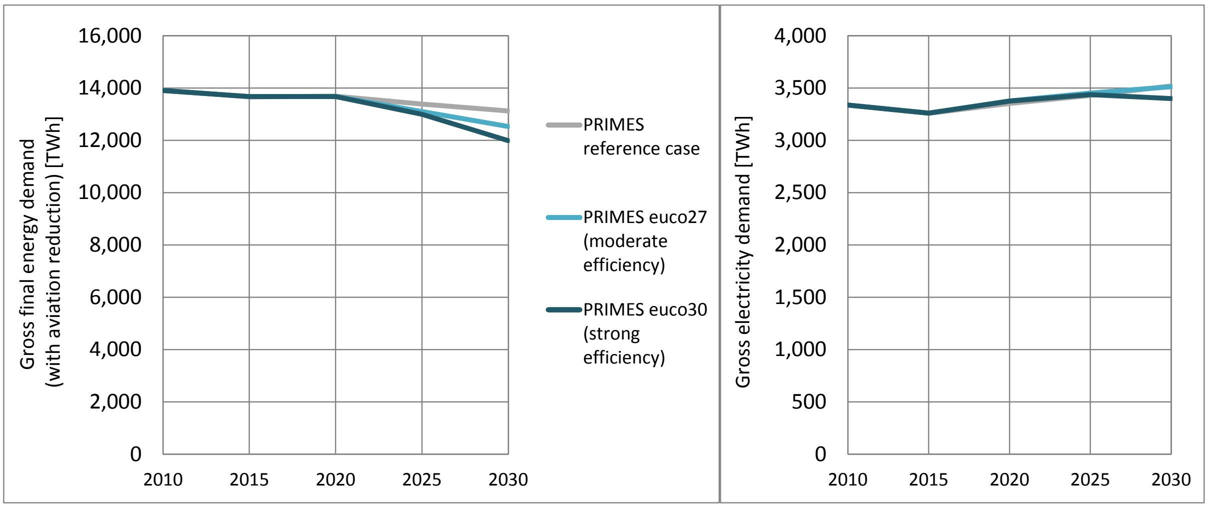


Figure 11: Comparison of projected energy demand development at European (EU-28) level – gross final energy demand (left) and gross electricity demand (right). Source: PRIMES scenarios (EC, 2016)

For the electricity sector, demand growth is generally more pronounced. The distinct PRIMES cases follow a similar pattern and differences between them are moderate – i.e. all cases expect electricity consumption to rise strongly in later years because of cross-sectoral substitutions: electricity is expected to make a stronger contribution to meeting the demand for heat in the future, and similar substitution effects are assumed for the transport sector as well. In the final years closer to 2050 this trend is even more pronounced in the cases where long-term (2050) climate targets are considered (*PRIMES euco27* and *euco30*), leading to a higher electricity demand than under reference conditions.

6.2 Conventional supply portfolio

The conventional supply portfolio, i.e. the share of the different conventional conversion technologies in each sector, is based on PRIMES forecasts on a country-specific basis. These projections of the portfolio of conventional technologies particularly influence the calculations done within this study on the avoidance of fossil fuels and related CO_2 emissions. As it is beyond the scope of this study to analyse in detail which conventional power plants would actually be replaced, for instance, by a wind farm installed in the year 2023 in a certain country (i.e. either a less efficient existing coal-fired plant or possibly a new highly-efficient combined cycle gas turbine), the following assumptions are made:

- Bearing in mind that fossil energy represents the marginal generation option that determines the prices on energy markets, it was decided to stick to the sector-specific conventional supply portfolio projections on a country level provided by PRIMES. Sector- and country-specific conversion efficiencies derived on a yearly basis are used to calculate the amount of avoided primary energy based on the renewable generation figures obtained. Assuming that the fuel mix is unaffected, avoidance can be expressed in units of coal or gas replaced.
- A similar approach is chosen with regard to the avoidance of CO_2 emissions, where the basis is the fossil-based conventional supply portfolio and its average country- and sector-specific CO_2 intensities that may change over time.

In the following, the derived data on aggregated conventional conversion efficiencies and the CO2 intensities characterising the conventional reference system (excl. nuclear energy) are presented.

Figure 12 shows the dynamic development of the average conversion efficiencies as projected by PRIMES for conventional electricity generation as well as for grid-connected heat production. Conversion efficiencies are shown exemplarily for the PRIMES reference scenario (EC, 2016). Error bars indicate the range of country-specific average efficiencies among EU Member States. For the transport sector, where efficiencies are not explicitly expressed in PRIMES' results, the average efficiency of the refinery process used to derive fossil diesel and gasoline was assumed to be 95%.

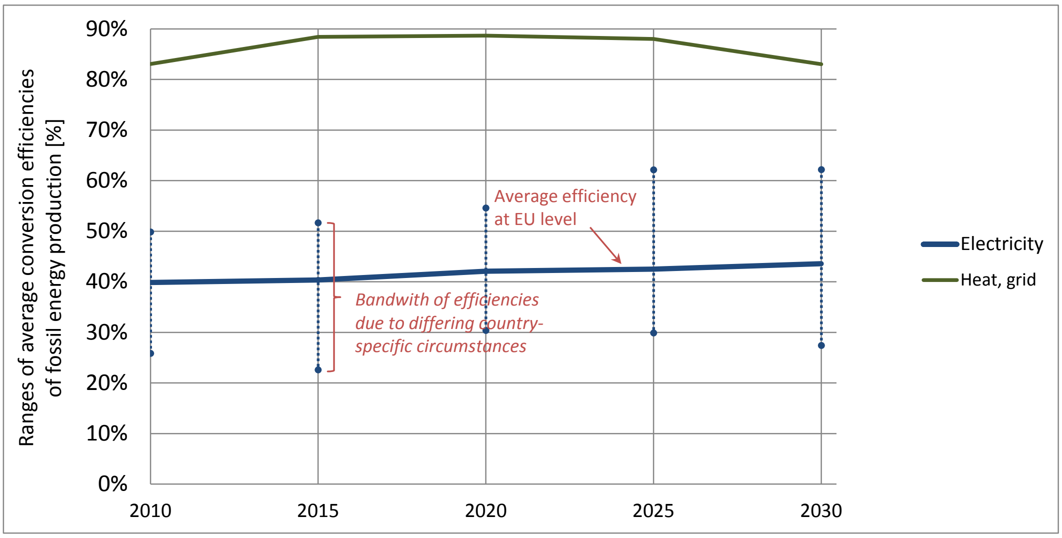


Figure 12: Country-specific average conversion efficiencies of conventional (fossil-based) electricity and grid-connected heat production in the EU28. Source: PRIMES scenarios (EC, 2016)

The corresponding data on country- and sector-specific CO_2 intensities of the conventional energy conversion system according to the PRIMES reference scenario are shown in Figure 13. Error bars again illustrate the variation across countries.

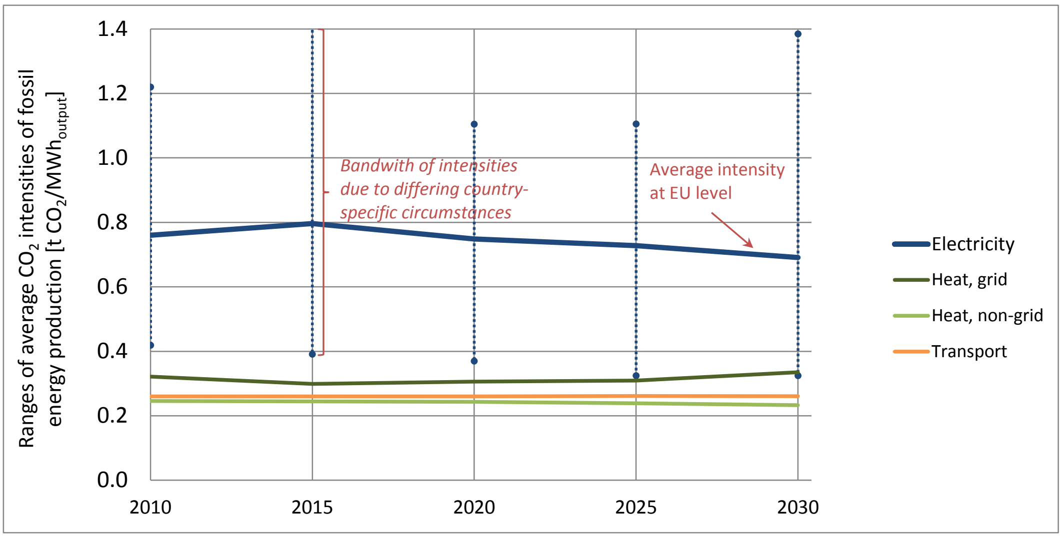


Figure 13: Country-specific average sectorial CO_2 intensities of the conventional (fossil-based) energy system in the EU28. Source: PRIMES scenarios (EC, 2016)

6.3 Fossil fuel and carbon prices

The country- and sector-specific reference energy prices used in this analysis are based on the primary energy price assumptions applied in the latest PRIMES scenarios, e.g. within the reference scenario as of 2016 (see EC (2016)). As shown in Figure 14 (left) generally only one price trend is considered – i.e. a default case of moderate energy prices that represents the price trends of recent PRIMES modelling (i.e. PRIMES reference, PRIMES euco27 and PRIMES euco30 scenarios).

It can be seen that the latest PRIMES scenarios incorporate in a suitable manner recent energy price developments – i.e. the steep rise of energy prices up to 2011, and later on (by 2015) the rapid decline. For the years to come an increase of oil, coal and gas prices is expected but compared to the energy prices as observed in 2011, all the price assumptions appear comparatively low, even for the final years close to 2050.

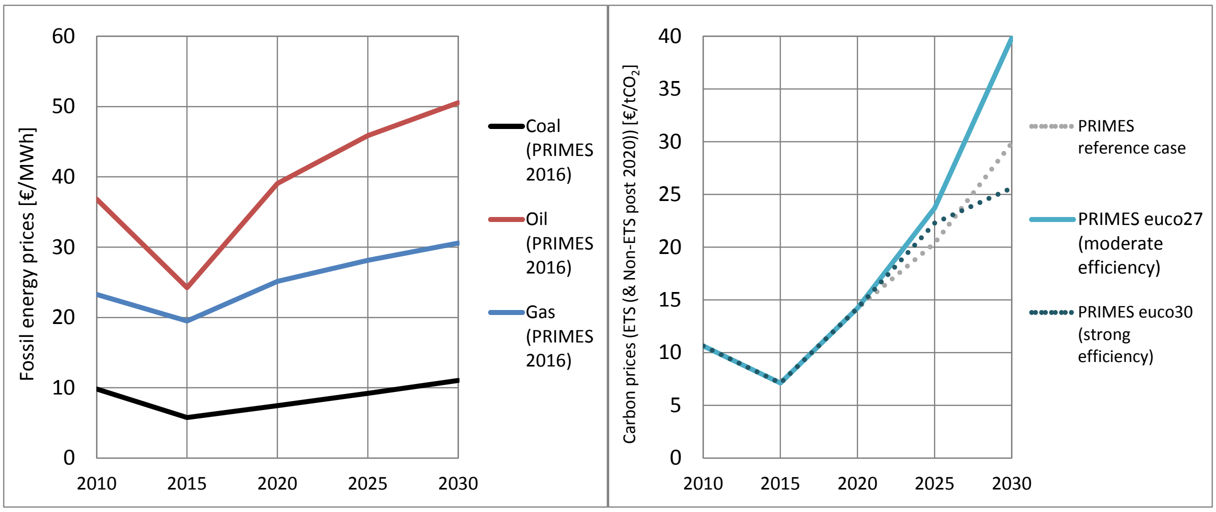


Figure 14: Assumptions on future primary energy prices (left) and on prices for CO_2 emission allowances in the EU ETS (right) (in €$_{2010}$/MWh or €$_{2010}$/t CO_2, respectively). Source: PRIMES scenarios (EC, 2016)

The CO_2 price in the scenarios presented in this report is also based on recent PRIMES modelling, see Figure 14 (right). Actual market prices for EU Allowances have fluctuated between 6 and 30 €/t since 2005 but remained on a low level with averages between 6 and 8 €/t in 2015. In the model, it is assumed that CO_2 prices are directly passed through to electricity prices as well as to prices for grid-connected heat supply.

Increased RES-deployment has the effect of reducing CO_2 prices since it reduces the demand to cut CO_2 via alternative measures, for example dedicated financial support for renewables or energy efficiency. Generally, this effect appears to be well covered in the PRIMES euco27 and PRIMES euco30 scenarios in the years up to 2030. Here carbon prices are partly even below the reference trend – despite the fact that 2030 GHG reduction targets are met under these scenarios whereas under reference conditions this is not the case.

6.4 Assumptions for simulated support schemes

A number of key input parameters were defined for each of the model runs referring to the specific design of the support instruments as described below.

Consumer expenditures related to RES support schemes are heavily dependent on the design of policy instruments. In the policy variants investigated, it is obvious that the design options of the various instruments were chosen in such a way that expenditure is low. Accordingly, it is assumed that investigated RES policy schemes are characterized by:

- A stable planning horizon;

- A continuous RES-E policy / long-term RES-E targets and;
- A clear and well defined tariff structure / yearly targets for RES(-E) deployment.

In addition, for all investigated scenarios, the following design options are assumed:

- Financial support is restricted to new capacity only;[13]
- The guaranteed duration of financial support is limited.[14]

With respect to model parameters reflecting dynamic aspects such as technology diffusion or technological change, the following settings are applied:

- *Removal of non-financial barriers and high public acceptance in the long term:* In all derived scenario runs it is assumed that the existing social, market and technical barriers (e.g. grid integration) can be overcome in time. More precisely, the assumption is taken that their impact is still relevant at least in the short-term as is reflected in the "business-as-usual" settings compared to, e.g. the more optimistic view assumed for reaching an accelerated RES deployment. Further details on the modelling approach to reflect the impact of non-economic barriers are provided in the subsequent section of this report;
- A stimulation of technological learning is considered – leading to reduced investment and O&M costs for RES over time: Thereby, generally moderate technological learning is assumed for all assessed cases.

6.5 RES technology diffusion – the impact of non-economic RES barriers

In several countries financial support appears sufficiently high to stimulate deployment of a RES technology, in practice actual deployment lacks however far behind expectations. This is a consequence of several deficits not directly linked to the financial support offered which in literature are frequently named "non-economic /non-cost barriers". These barriers refer to administrative deficiencies (e.g. a high level of bureaucracy), diminishing spatial planning, problems associated with grid access, possibly missing local acceptance, or even the non-existence of proper market structures.

In the Green-X model dynamic diffusion constraints are used to describe the impact of such non-economic barriers. Details on the applied modelling approach are explained subsequently.

Within Green-X dynamic diffusion constraints are used to describe the impact of such non-economic barriers. They represent the key element to derive the feasible dynamic potential for a certain year from the overall remaining additional realisable mid- / long-term potential for a specific RES technology at country level. The application of such a constraint in the model calculations results in a technology penetration following an "S-curve" pattern – obviously, only if financial incentives are set sufficiently high to allow a positive investment decision.

In accordance with general diffusion theory, penetration of a market by any new commodity typically follows an "S-curve" pattern. The evolution is characterised by a growth, which is nearly exponential at the start and linear at half penetration before it saturates at the maximum penetration level. With regards to the technical estimate of the logistic curve, a novel method has been employed by a simple

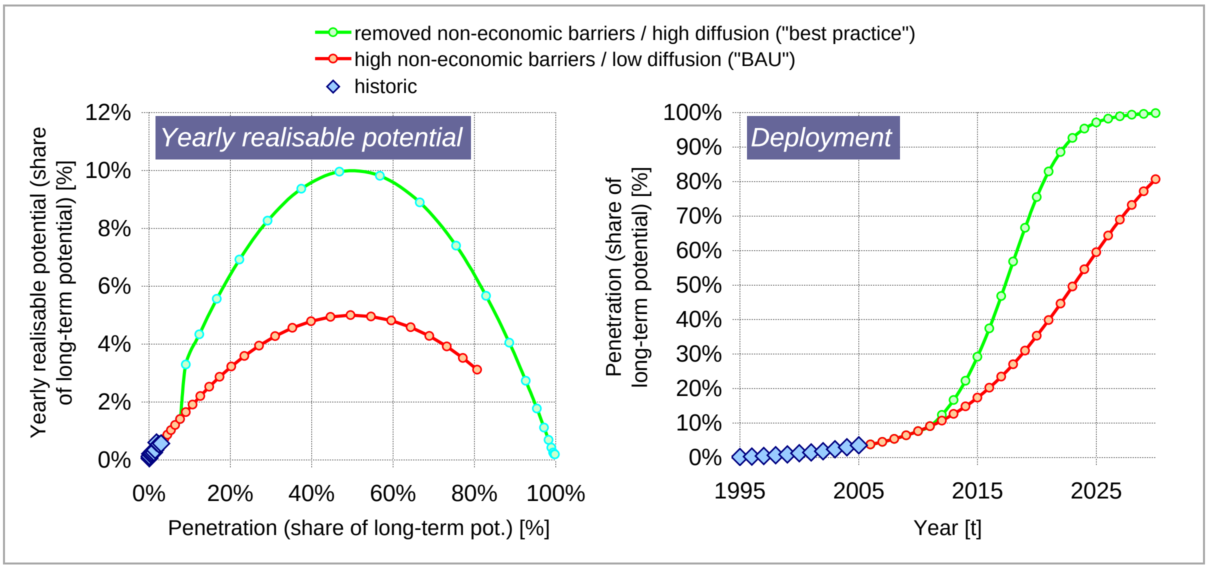
[13] This means that only plants constructed in the period 2021 to 2030 are eligible to receive support from the new schemes. Existing plants (constructed before 2021) remain in their old scheme.

[14] In the model runs, it is assumed that the time frame in which investors can receive (additional) financial support is restricted to 15 years for all instruments providing generation-based support.

transformation of the logistic curve from a temporal evolution of the market penetration of a technology to a linear relation between annual penetration and growth rates. This novel procedure for estimating the precise form of the logistic curve is more robust against uncertainties in the historic data. Furthermore, this method allows the determination of the independent parameters of the logistic function by means of simple linear regression instead of nonlinear fits involving the problem of local minima, etc.

Generally two different variants of settings with respect to the non-economic barriers of individual RES technologies are used:

- High non-economic barriers / low diffusion ("business-as-usual settings")
  This case aims to reflect the current situation (business-as-usual (BAU) conditions) where non-economic barriers are of relevance for most RES technologies. The applied technology-specific parameters have been derived by an econometric assessment of past deployment of the individual RES technologies within the assessed country.
- Removed non-economic barriers / high diffusion ("Best practice")
  This case represents the other extreme where the assumption is taken that non-economic barriers will be mitigated in time.[15] Applied technology-specific settings refer to the "best practice" situation as identified by a cross-country comparison. Accordingly, an enhanced RES deployment can be expected – if financial support is also provided in an adequate manner.



Note: In accordance with the analytical model as described in Annex A of this report (cf. section 6.1), key parameter have been set in this schematic depiction as follows: A = (-B) = -0.4; b_M was varied from 2 (high barriers / low diffusion) to 4 (removed barriers / high diffusion)

Figure 15: Schematic depiction of the impact of non-economic barriers on the feasible diffusion at technology and country level: Yearly realisable potential (left) and corresponding resulting feasible deployment (right) in dependence of the barrier level

[15] More precisely, a stepwise removal of non-economic barriers is preconditioned which allows an accelerated RES technology diffusion. Thereby, the assumption is taken that this process has been launched in 2016.

6.6 Interest rate / weighted average cost of capital - the role of (investor's) risk

The model-based assessment incorporates the impact of risks to investors on RES deployment and corresponding (capital / support) expenditures. In contrast to the complementary detailed bottom-up analysis of illustrative financing cases as conducted e.g. in the RE-Shaping study (see e.g. Ragwitz et al, 2012), Green-X modelling aims to provide an aggregated view at the national and European level with fewer details on individual direct financing instruments. More precisely, the debt and equity conditions resulting from specific financing instruments are incorporated by applying different weighted average cost of capital (WACC) levels.

Determining the necessary rate of return is based on the weighted average cost of capital (WACC) methodology. WACC is often used as an estimate of the internal discount rate of a project or the overall rate of return desired by all investors (equity and debt providers). This means that the WACC formula[16] determines the required rate of return on a company's total asset base and is determined by the Capital Asset Pricing Model (CAPM) and the return on debt.

Formally, the pre-tax cost of capital is given by:

$$WACC^{pre\text{-}tax} = g_d \cdot r_d + g_e \cdot r_e = g_d \cdot [r_{fd} + r_{pd}] \cdot (1 - r_{td}) / (1 - r_{tc}) + g_e \cdot [r_{fe} + \beta \cdot r_{pe}] / (1 - r_{tc})$$

Table 6 explains how to determine the WACC for two examples – a default and a high risk assessment.

Table 6: Example of value setting for WACC calculation

WACC methodology	Abbreviation/ Calculation	*Default* risk assessment		*High* risk assessment	
		Debt (d)	*Equity (e)*	*Debt (d)*	*Equity (e)*
Share equity / debt	g	70.0%	30.0%	65.0%	35.0%
Nominal risk free rate	r_n	4.1%	4.1%	4.1%	4.1%
Inflation rate	i	1.25%	1.25%	1.25%	1.25%
Real risk free rate	$r_f = r_n - i$	2.85%	2.85%	2.85%	2.85%
Expected market rate of return	r_m	4.3%	6.5%	5.0%	8.0%
Risk premium	$r_p = r_m - r_f$	1.45%	3.65%	2.15%	5.15%
Equity beta	b		1.6		1.6
Tax rate (tax deduction)	r_{td}	25%		25.0%	
Tax rate (corporate income tax)	r_{tc}		25.0%		25.0%
Weighted average cost of capital (pre-tax)		**6.5%**		**8.4%**	

Within the model-based analysis, a range of settings is applied to accurately reflect the risks to investors. Risk refers to three different issues:

- A "policy risk" is related to the uncertainty about future earnings caused by the support scheme itself – e.g. refers to the uncertain development of certificate prices within a RES trading system and / or uncertainty related to earnings from selling electricity on the spot market. As shown in

[16] The WACC represents the necessary rate a prospective investor requires for investment in a new plant.

Table 6, the range of settings used in the analysis with respect to policy risks varies from 6.5% (default risk) up to 8.4% (high risk). The different values are based on a different risk assessment, a standard risk level and a set of risk levels characterised by a higher expected / required market rate of return. 6.5% is used as the default value for stable planning conditions as given, e.g. under advanced fixed feed-in tariffs. The higher value is applied in scenarios with less stable planning conditions, i.e. in the cases where support schemes cause a higher risk for investors as associated with e.g. RES trading (and related uncertainty about future earnings on the certificate market). An overview of the settings used by the type of policy instrument or pathway, respectively, is given in Table 7.

- A "technology risk" refers to uncertainty about future energy production due to unexpected production breaks, technical problems, etc... Such problems may cause (unexpected) additional operational and maintenance costs or require substantial reinvestments which (after a phase-out of operational guarantees) typically have to be borne by the investors themselves. In the case of biomass, this also includes risks associated with the future development of feedstock prices. Table 8 (below) illustrates the default assumptions applied to consider investors' technology risks. The expressed technology-specific risk factors are used as a multiplier of the default WACC figure. The ranges indicated for several RES categories reflect the fact that risk profiles are expected to change over time and that specific RES categories cover a range of technologies (and for instance also a range of different feedstocks in the case of biomass) and unit sizes. The lower boundary for PV or for several RES heat options also indicates a different risk profile of small-scale investors who may show a certain "willingness to invest", requiring a lower rate of return than commercial investors.
- The third risk component is named as "country risk". At present differences across Member States with respect to financing conditions are commonly acknowledged, see e.g. Boje et al. (2016). This leads to a higher risk profiling of investments in countries more strongly affected by the financial and economic crisis compared to more stable economies within Europe. In modelling we assume that an alignment of these conditions might take place, depending on the chosen policy framework: On the one hand, this might be driven by a further "Europeanisation" of RES policy making, e.g. through a market opening of national policy schemes, enhanced RES cooperation between Member States or at the ultimate extent via harmonisation. The assumptions taken concerning country-specific risks are shown in Figure 16, distinguishing between the default risk profiling for the year 2020 and the alternative profiling where a smoothening / alignment of risk factors will take place driven by e.g. "Europeanisation". Default risk profiling used in our modelling builds on statistical data concerning current (2016) financing conditions as specified in Table 9. Here we specifically take into account indicators on long-term governmental bonds and national credit rating. Please note further that country risk settings are assumed to change over time, aligned to general GDP/capita trends taken from PRIMES modelling.

Please note that all risk components are considered as default in the assessment, leading to a different – typically higher – WACC than the default level of 6.5%.

Table 7: Policy risk: Instrument-specific risk factor (Green-X modelling)

Policy risk: Instrument-specific risk factor (i.e. multiplier of default WACC)	
FIT (feed-in tariff)	1.00
FIP (feed-in premium – specifically a sliding feed-in premium scheme)	1.05
QUO (quota system with uniform TGC) & Cross-sectoral quota ("Least cost approach")	1.20
QUO banding (quota system with banded TGC)	1.15
ETS (no dedicated RES support)	1.30
TEN (tenders for sliding premium at RES-E technology level)	1.15

Table 8: Technology-specific risk factor (Green-X modelling)

Technology-specific risk factor (i.e. multiplier of default WACC)			
RES-electricity		*RES-heat*	
Biogas	1.00-1.05	Biogas (grid)	1.05
Solid biomass	1.05	Solid biomass (grid)	1.05
Biowaste	1.05	Biowaste (grid)	1.05
Geothermal electricity	1.1	Geothermal heat (grid)	1.05
Hydro large-scale	0.95	Solid biomass (non-grid)	0.95-1.00
Hydro small-scale	0.95	Solar thermal heat. & water	0.90
Photovoltaics	0.85-0.90	Heat pumps	0.90
Solar thermal electricity	1.1	*RES-transport / biofuels*	
Tide & wave	1.20	Traditional biofuels	1.05
Wind onshore	0.9-0.95	Advanced biofuels	1.05
Wind offshore	0.9-1.0	Biofuel imports	-

Table 9: Country-risk profiling: Statistics on financing conditions used for deriving default and alternative risk profiling

Country risk profiling		Austria	Belgium	Bulgaria	Croatia	Cyprus	Czech Republic	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland	Italy
Statistics on financing parameter (2016 data)	weighting factor															
Eurostat - long term government bond yields	10%	0.36	0.47	2.42	3.64	3.87	0.41	0.33	0.00	0.37	0.43	0.07	8.64	3.12	0.74	1.40
RES deployment times risk ranking		19.2	9.1	46.9	30.1	8.7	11.2	12.7	0.0	26.2	111.9	18.2	279.6	64.6	14.2	160.9
National Credit Rating	90%	0.89	0.89	0.56	0.56	0.56	0.89	1.00	0.89	0.89	0.89	1.00	0.44	0.67	0.78	0.67
RES deployment times risk ranking		47.0	17.1	10.7	4.6	1.2	24.2	37.9	9.2	62.7	232.3	255.6	14.4	13.8	14.9	76.7
Ease of getting credit	0%	0.60	0.45	0.70	0.55	0.60	0.70	0.70	0.70	0.65	0.50	0.70	0.50	0.75	0.70	0.45
RES deployment times risk ranking		31.7	8.7	13.5	4.5	1.3	19.1	26.5	7.2	45.9	130.8	178.9	16.2	15.5	13.5	51.9
Average risk rating																
Default (moderate smoothening)		91%	92%	143%	150%	152%	91%	84%	89%	91%	91%	82%	208%	130%	103%	119%
Risk smoothening due to Europeanisation		94%	95%	128%	134%	135%	94%	89%	93%	94%	94%	88%	172%	120%	102%	113%

Country risk profiling		Latvia	Lithuania	Luxem-bourg	Malta	Nether-lands	Poland	Portugal	Romania	Slovakia	Slovenia	Spain	Sweden	United Kingdom	**EU28**
Statistics on financing parameter (2016 data)	weighting factor														
Eurostat - long term government bond yields	10%	0.53	1.09	0.26	0.93	0.28	2.94	3.05	3.30	0.49	1.26	1.42	0.58	1.20	**1.17**
RES deployment times risk ranking		7.2	15.8	0.6	0.5	14.6	293.0	120.2	196.9	5.8	10.4	210.6	52.1	237.5	**1978.5**
National Credit Rating	90%	0.78	0.78	1.00	0.78	1.00	0.78	0.56	0.67	0.78	0.78	0.67	1.00	0.89	**0.84**
RES deployment times risk ranking		10.5	11.2	2.3	0.4	52.1	77.4	21.8	39.8	9.3	6.4	98.8	90.3	176.2	**1418.8**
Ease of getting credit	0%	0.85	0.70	0.15	0.70	0.50	0.75	0.45	0.85	0.65	0.35	0.60	0.55	0.75	**0.62**
RES deployment times risk ranking		11.5	10.1	0.4	0.4	26.0	74.7	17.7	50.8	7.8	2.9	89.0	49.6	148.8	**1054.9**
Average risk rating															
Default (moderate smoothening)		101%	105%	83%	104%	83%	117%	147%	131%	101%	106%	119%	85%	96%	100%
Risk smoothening due to Europeanisation		101%	103%	89%	103%	89%	111%	131%	121%	101%	104%	113%	90%	98%	100%

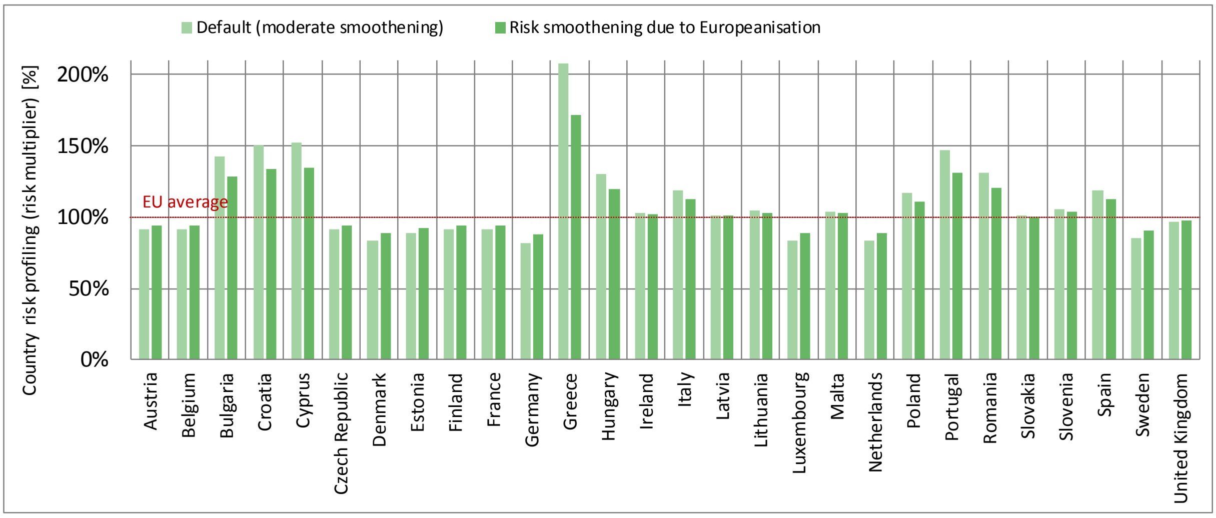


Figure 16: Country risk profiling used for the period post 2020 (specifically for the year 2021) (Green-X modelling)

6.7 Potentials and costs for RES in the European Union

Nowadays, a broad set of different renewable energy technologies exists. Obviously, for a comprehensive investigation of the future development of RES it is of crucial importance to provide a detailed investigation of the country-specific situation – e.g. with respect to the potential of the certain RES technologies in general as well as their regional distribution and the corresponding generation cost.

This section illustrates the consolidated outcomes on RES potentials and accompanying costs of an intensive assessment process conducted within several studies in this topical area. The derived data on realisable long-term (2050) potentials for RES in the European Union and assessed neighbouring countries fits to the requirements of the model Green-X and serves as sound basis for the subsequently depicted policy assessment of RES cooperation between the EU and its neighbours.

Please note that within this illustration the future potential for considered biomass feedstock is pre-allocated to feasible technologies and sectors based on simple rules of thumb. In contrast to this, within the Green-X model no pre-allocation to the sectors of electricity, heat or transport is undertaken as technology competition within and across sectors (as well as between countries) is appropriately reflected in the applied modelling approach.

The Green-X database on potentials and cost for RES – background information

The input database of the Green-X model offers a detailed depiction of the achieved and feasible future deployment of the individual RES technologies, initially constraint to the European Union (EU28) but within the course of recent projects extended to neighbouring countries / regions (i.e. Western Balkans, North Africa and Turkey). This comprises in particular information on costs and penetration in terms of installed capacities or actual & potential generation. Realisable future potentials (up to 2050) are included by technology and by country. In addition, data describing the technological progress such as learning rates are available. Both serve as crucial input for the model-based assessment of future RES deployment.

Note that an overview on the method of approach used for the assessment of this comprehensive data set is given in Box 6 (below).

Box 6: About the Green-X potentials and cost for RES

The Green X database on potentials and cost for RES technologies provides detailed information on current cost (i.e. investment -, operation & maintenance -, fuel and generation cost) and potentials for all RES technologies at country level. Geographically the scope of the database has been extended within this project from the EU28 to the assessed neighbouring countries / regions (i.e. Western Balkans, Turkey and North Africa).

The assessment of the economic parameter and accompanying technical specifications for the various RES technologies builds on a long track record of European and global studies in this topical area. From a historical perspective the starting point for the assessment of realisable mid-term potentials was geographically the European Union as of 2001 (EU-15), where corresponding data was derived for all Member States initially in 2001 based on a detailed literature survey and an expert consultation. In the following, within the framework of the study "Analysis of the Renewable Energy Sources' evolution up to 2020 (FORRES 2020)" comprehensive revisions and updates have been undertaken, taking into account recent market developments. Consolidated outcomes of this process were presented in the European Commission's Communication "The share of renewable energy" (European Commission, 2004). Later on throughout the course of the futures-e project (see Resch et al., 2009) an intensive feedback process at the national and regional level was established. A series of six regional workshops was hosted by the futures-e consortium around the EU within 2008. The active involvement of key stakeholders and their direct feedback on data and scenario outcomes helped to reshape, validate and complement the previously assessed information.

Within the Re-Shaping project (see e.g. Ragwitz et al., 2012) and parallel activities such as the RES-Financing study done on behalf of the EC, DG ENER again a comprehensive update of cost parameter was undertaken, incorporating recent developments – i.e. the past cost increase mainly caused by high oil and raw material prices, and, later on, the significant cost decline as observed for various energy technologies throughout 2008 and 2009. The process included besides a survey of related studies (e.g. also more recently Wiser (2016)) also data gathering with respect to recent RES projects in different countries.

Within this study and parallel activities the database has been extended geographically. The extended version comprises in addition to EU member states also all Contracting Parties of the Energy Community (i.e. Western Balkans), Turkey and selected North African countries. Within the case study work in the BETTER project a literature survey has been conducted, complemented by gathering of statistical information on land use, etc. Finally, a GIS-based assessment of wind and solar potentials was undertaken to derive an up-to-date data set following a harmonised approach for these important renewable energy technologies.

Within the Green-X model, supply potentials of all main technologies for RES-E, RES-H and RES-T are described in detail.

- RES-E technologies include biogas, biomass, biowaste, onshore wind, offshore wind, small-scale hydropower, large-scale hydropower, solar thermal electricity, photovoltaics, tidal & wave energy, and geothermal electricity
- RES-H technologies include heat from biomass – subdivided into log wood, wood chips, pellets, and district heating -, geothermal heat and solar heat
- RES-T options include first generation biofuels such as biodiesel and bioethanol, second generation biofuels as well as the impact of biofuel imports

The potential supply of energy from each technology is described for each country analysed by means of dynamic cost-resource curves. Dynamic cost curves are characterised by the fact that the costs as well as the potential for electricity generation / demand reduction can change each year. The magnitude of these changes is given endogenously in the model, i.e. the difference in the values compared to the previous year depends on the outcome of this year and the (policy) framework conditions set for the simulation year.

Moreover, the availability of biomass is crucial as the contribution to energy supply is significant today and its future potentials is faced with high expectations as well as concerns related to sustainability. At EU28 level the total domestic availability of solid and gaseous biomass (incl. energy crops e.g. for transport purposes) was assessed at 349 Mtoe/a by 2030, increasing to 398 Mtoe/a by 2050 – mainly because of higher yields assumed for the production of energy crops. Biomass data has been cross-checked throughout various detailed topical assessments done for DG ENER, e.g. the recently completed BioSustain study. As biomass may play a role in all sectors, also the allocation of biomass resources is a key issue. Within the Green-X model, the allocation of biomass feedstock to feasible technologies and sectors is fully internalised into the overall calculation procedure. For each feedstock category, technology options (and their corresponding demands) are ranked based on the feasible revenue streams as applicable for a possible investor under the conditioned scenario-specific energy policy framework, which obviously may change year by year. In other words, the supporting framework may have a significant impact on the sector- and country-specific bioenergy supply and demand.

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About the project

SET-Nav aims for supporting strategic decision making in Europe's energy sector, enhancing innovation towards a clean, secure and efficient energy system. Our research will enable the European Commission, national governments and regulators to facilitate the development of optimal technology portfolios by market actors. We will comprehensively address critical uncertainties facing technology developers and investors, and derive appropriate policy and market responses. Our findings will support the further development of the SET-Plan and its implementation by continuous stakeholder engagement.

These contributions of the SET-Nav project rest on three pillars: modelling, policy and pathway analysis, and dissemination. The call for proposals sets out a wide range of objectives and analytical challenges that can only be met by developing a broad and technically-advanced modelling portfolio. Advancing this portfolio is our first pillar. The EU's energy, innovation and climate challenges define the direction of a future EU energy system, but the specific technology pathways are policy sensitive and need careful comparative evaluation. This is our second pillar. Ensuring our research is policy-relevant while meeting the needs of diverse actors with their particular perspectives requires continuous engagement with stakeholder community. This is our third pillar.

Who we are?

The project is coordinated by Technische Universität Wien (TU Wien) and being implemented by a multinational consortium of European organisations, with partners from Austria, Germany, Norway, Greece, France, Switzerland, the United Kingdom, France, Hungary, Spain and Belgium.

The project partners come from both the research and the industrial sectors. They represent the wide range of expertise necessary for the implementation of the project: policy research, energy technology, systems modelling, and simulation.