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Technical Report on the Modelling of RES auctions

Key insights on the model-based analyses conducted in the course of the AURES II project

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D8.5, June 2022. Technical Report on the Modelling of RES auctions – Summary report on modelling activities undertaken in the course of AURES II

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Content

1 Introduction

This technical report summarises modelling works related to RES auctions undertaken in the course of the H2020 project AURES II. In this context, modelling related to the design and use of RES auctions aimed for facilitating the topical analyses undertaken with in-depth model-based quantitative assessments. A set of specialised models has been used, with complementary strengths and focal points, tailored to the specific research and policy questions in focus.

1.1 Structure of this report

This report is structured in accordance with the individual modelling tasks undertaken, summarising the works undertaken in topical order.

- Chapter 2 is dedicated to inform on our assessment on quantifying biases in technology-neutral auctions.
- Chapter 3 informs on the modelling works related to European RES auctions
- Chapter 4 illustrates the case study works done on Cross-Border RES auctions, exemplified by a case study analysis of Hungary and selected neighbours.
- Chapter 5 shows the work done to illustrate the impact of changes in RES financing during the last years.
- Finally, within chapter 6 we take a deep dive into the future of RES auctions, informing on the approach taken and the outcomes of a model-based assessment of long-term trends in a changing electricity system.

2 Quantifying biases in technology-neutral auctions

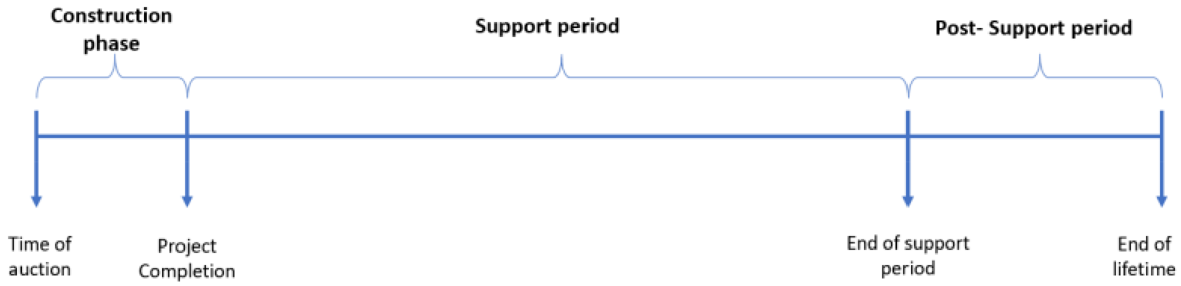
2.1 Key Objectives

The main aim of this task was to analyse how different renewable auction design elements in technology-neutral auctions favour different renewable technologies relative to each other. In a more formalised sense, to quantify technology bias between four selected technologies, which are solar PV, onshore wind, offshore wind, and biomass.

2.2 Approach

In the corresponding analysis, technology bias between two technologies was defined as the difference between the bid price of two technologies and the unit social value of two technologies. Bid prices are the values that project promoters would bid on the auction, while unit social value is the difference between the total social benefit and the total social costs of the project in per unit terms. To calculate the technology bias, an LCOE model was used. The model calculated the LCOE of different technologies, assuming various inputs, then based on the LCOE it was possible to estimate the bid prices and the unit social values, thus the technology bias as well.

Figure 2-1. Schematic summary of the operation of the applied LCOE model



The inputs of the model were based on different auction and market databases and values originating from relevant literature. It is important to highlight that the model was used for scenario analysis, which means that the input data that were used did not represent a selected country or energy system, instead the used modelling approach tried to show different types of general scenarios. In this sense the report did not provided answers to those type of question, that what is the LCOE of PV, or what is the bias between PV and wind in the German auction. It focused more on scenario comparison, like analysing the change in bias between two technologies in an assumed setup if for example the length of support period changes from 15 years to 20 years.

In the report, two types of efficiencies were analysed with respect to technology bias. These are general efficiency and allocative efficiency. Those setups were labelled more efficient based on general efficiency, where the average bias between all four technologies was lower. The average bias between all technologies were calculated as the unweighted average of pairwise technology biases. The concept of allocative efficiency is slightly different, as it is not associated with the bias between all technologies. Instead, it is about the question that when a technology neutral auction is held in an assumed setup, would the technology that is socially the most beneficial (having the largest social value), emerge victorious from the auction or not.

Three main scenarios were identified and evaluated, based on general and allocative efficiency. In all three scenarios, the same input values were used, which were labelled as reference case. The first scenario was called the "laboratory scenario" in which externalities were assumed to be zero. Additionally, all technologies faced the same market price in this setup. In this sense the laboratory scenario is to some extent artificial, however, it provided a very good basis the analysis. The second scenario was named "No externality," where externalities were also assumed to be zero, but price cannibalisation effects were introduced, which mean that if the share of PV or wind power plants increased in the energy system, then it influenced the market value factor of these technologies, mainly reducing the market price of the respective technology. Finally, the third scenario was called "Baseline," where grid integration costs and environmental harm were introduced in the model, as externalities, based on literature values. In all scenarios a huge number of sensitivity cases were also estimated, with varying inputs.

In general, the effect of several auction design elements was investigated in the study. The main point of interest was the comparison of three different remuneration schemes, one-sided sliding feed in premium (when market price is higher than bid price, producer can keep the surplus), two-sided sliding premium (when market price is higher than bid price producer must pay back the surplus) and fixed premium. These three remuneration schemes were tested for all analysed setups. In addition to the remuneration, the effect of several additional design elements was investigated on technology bias, which were the length of support period, granted realisation period, timing of the auction within the year, balancing cost payment responsibility, grid integration cost compensation payment requirement and environmental harm compensation payment requirement.

2.3 Results

First, the reference results for the three main scenarios were analysed in more detail. In the laboratory scenario solar PV was identified, as the most beneficial technology, and all three remuneration schemes were labelled as allocatively efficient, because solar PV producers were modelled with the lowest bid prices. The report identified that in the laboratory setup the ordering of technologies in terms of bias were PV > Onshore Wind > Offshore Wind > Biomass, which means that PV would enjoy advantage over all technologies in a technology neutral auction. The average differences between the biases however turned to be significantly lower in the fixed premium scheme, which also resulted in lower average bias value for all technologies for this scheme.

With the introduction of cannibalisation effect, and different prices for technologies in the "no externality scenario" several important changes occurred. First that unit social value of onshore wind became larger than solar PV. This had important consequences on the allocative efficiency as in the "no externality scenario" in the fixed premium scheme onshore wind bid the lowest, however in the sliding premium schemes solar PV. As a result, in this setup only fixed premium turned to be allocatively efficient. The reason behind this finding is that with the introduction of cannibalisation, fixed premium scheme become biased toward onshore wind, while the sliding schemes remained biased toward PV. In terms of average biases and general efficiency fixed premium outperformed sliding premium in this setup as well.

As a final point the effect of introducing grid integration costs and environmental harm as externalities were investigated in the "baseline scenario". As in this setup the bid prices remained the same, and the ordering of the unit social values as well, still only fixed premium resulted in allocative efficiency. However, by introducing externalities the ordering of the technologies, in terms of technology bias, changed drastically to biomass > offshore wind > PV > onshore wind, in all remuneration schemes, which is the exact opposite of the ordering of the "laboratory" and "no externality scenarios." As a result, the average biases between all four technologies changed drastically resulting in the fact that in the "baseline scenario" sliding premium was associated with smaller average bias (higher general efficiency) than fixed premium.

Table 2-1. Exemplary model calculation results for "baseline scenario"

	PV	Onshore Wind	Offshore Wind	Biomass
LCOE	56.03	61.78	87.46	129.50
Unit externality	18.05	12.35	36.50	58.68
Bid price 1s	62.24	62.63	91.68	138.10
Bid price 2s	62.24	62.67	91.68	138.10
Bid price fixed	23.77	14.57	43.01	82.58
Unit social value	-32.69	-22.60	-65.62	-115.83
Winning technology (1s, 2s)	yes	no	no	no
Winning technology (fixed)	no	yes	no	no

From the above results two very important conclusions can be drawn. First, there is no clear hierarchy between the technologies in terms of bias in technology neutral auction, the ordering of technologies may be very dependent on the market setup and assumptions made. By introducing externalities into the system, the relative bias that the design offered to technologies changed drastically. The second important conclusion is that allocative efficiency and general efficiency are not complementary elements. The "baseline scenario" also showed that the fixed premium design is allocatively more efficient than the sliding premium design, however the latter schemes result on average lower bias between all technologies. This is the result of the fact that in the fixed premium setup the bias between solar PV and onshore wind were very small, which are the two technologies that have a real chance to win the auction (with their current maturity level). However, if all technologies are considered, the sliding premium scheme proved to be generally more efficient. This is an important insight, as this means that, if in the future offshore wind would become cheaper, it is possible that sliding premiums would be a more efficient system in terms of minimalizing technology bias, than fixed premium. Also, in many auction implementations it is the case that only onshore wind energy and solar PV energy are combined into the technology-neutral auction pool, meaning that this insight is already relevant in these cases.

On top of the reference case, several sensitivity scenarios for different inputs variables were tested. Based on the sensitivity estimations this report concluded that in terms of general efficiency, two-sided sliding premium and fixed premium performs better than one sliding premium. In the one-sided scheme it often occurred that if one technology become mature (requires no support for operation) than its bid-price suddenly moved to 0, from a significantly higher level, resulting in very large biases in per unit terms.

By testing the robustness of all results to different input variables, it can be concluded that average bias between all technologies is relatively stable across all estimated cases. A more than 10 EUR/MWh variation in average bias only occurred for: 1) changes in discount factor in all schemes, 2) Changes in environmental harm in the sliding premium scheme only in the "baseline scenario", and 3) when the above-described maturity effect occurred in the one-sided feed in premium system. In terms of robustness, no clear conclusion can be drawn for the comparison of two-sided feed in premium and fixed premium. For some variable changes, the former was more robust, while for some other variable changes, it was the latter. The relative robustness often varied between the three main scenarios.

As a final point of the study the effect of several different auction design elements on technology bias were investigated. In terms of support period, a general pattern was identified that shorter support periods result in higher bid prices with the assumed inputs, as producers have less time to cover for the losses when the power plant on market basis after the support period ends. The results of the "laboratory scenario" showed that the average bias became lower when the support period increased in all schemes. The same dynamic was detectible in the "no externality scenario" however in this setup in the sliding premium schemes only those designs turned to be allocatively efficient when the support period was 10 or 15 years. Both in the "no externality" and "laboratory" case, the fixed premium scheme resulted in lower average bias than sliding premiums.

The results turned out to be more complicated in the "baseline scenario." In this setup long support period led to the highest average bias, which became lower for shorter support lengths, however increased again when the support period shortened form 15 years to 10 years in all remuneration schemes. So, the general dynamic was the exact opposite of the "laboratory" and "no externality," with a slightly different element when very short support period was considered. The main reason behind the opposite dynamic is the fact which were already described, that in the baseline case the ordering of technologies in terms of bias changed. The result, that 10-year support period led to higher bias comes from the fact that moving from long support period toward short, the advantage of biomass and offshore wind reduced relative to PV and onshore wind. In the 10-year case however, the latter two technologies enjoyed an advantage over the former two, which resulted in a higher on average bias. As a result of these two dynamics however in the "baseline scenario" a 15-year long support period led to allocative efficiency as well as to highest general efficiency, in all three schemes.

The results also show that the length of support period is an important determinant of technology bias, as depending on the scheme and analysed scenarios, the variation of average bias if support length is changed reached 9-11 EUR/MWh.

The analysis of the support period led to the general conclusion that "starting point" is a major determinant of how a change of the different design element affects technology bias. Assume that shorter support period would favour wind over PV within a given setup. If in the general auction design, PV enjoys an advantage over wind, then shortening the support period would decrease the bias, while in an auction setup where wind is favoured, a shorter support period would have the opposite effect. As a result, it is not possible to formulate such conclusions that a given design element would increase or decrease technology bias as it is always dependent on the starting point. This starting point effect resulted in the complete opposite dynamic in the "laboratory" and "no externality scenarios" relative to the "baseline" case.

The second analysed design element was the granted time for the completion of the project. Please note that in the model it was assumed, that producers always complete their project at the end of the granted realisation period, so there are no early finishes or delays. The results showed that bid prices are lower for shorter realisation periods, which is mainly the result of the market price assumptions used in the modelling.

As the starting point effect was explained in detail in the previous paragraphs, it shall suffice to highlight that the effect of granted realisation period on technology bias is heavily influenced by the starting point effect as well. In the "laboratory" and "no externality" scenarios, the setups that resulted in the lowest average biases were the ones in which realisation period was relatively short, for example when 24 months were allowed for all technologies, or when the fastest possible realisation was considered. On the other hand, in the "baseline scenario" in terms of general efficiency auction designs with longer realisation periods proved to be better. All the analysed cases turned out to be allocatively efficient for the fixed premium scheme, and many of the cases for the sliding premium scheme. Exceptions were the reference case, and when longer realisation period were granted for onshore wind, offshore wind, or biomass in the "no externality" and "baseline scenarios."

Despite similar dynamics, granted realisation period turned to be a less important determinant of technology bias than support period, as the variation between the different realisation setups only reached 3.5-4.5 EUR/MWh, depending on the scenario and remuneration scheme.

Also, the timing of the auction within the year was tested. The report concluded that variation in timing only marginally changed unit social value and bid prices (less than 0.1 EUR/MWh in general), and hence the average bias between all technologies. For these reasons, it can be stated that timing of the auction is not an important determinant of technology bias.

For the last three design elements, the internalisation of different cost elements was investigated such as balancing costs, grid integration costs and environmental harm. For balancing cost, two separate setups were analysed: 1) when the system bears the balancing burden, and 2) when producers are responsible for paying balancing costs. A general pattern with respect to balancing was identified, that when producers are not responsible for balancing their costs reduces, resulting in lower bid prices. In the “no externality scenario” the average bias between all technologies was lower when producers were responsible for balancing, relative to the case when no payment were required from them. The situation changed, however, in the “baseline scenario” when grid integration costs and environmental harm were introduced as externalities, as in this setup bias was lower when producers were not responsible for balancing. The reason for the change is the already described starting point effect.

Note, however, that in both scenarios the difference between the average biases for all technologies was estimated small between the two payment responsibility types, reaching only 1 EUR/MWh. The main explanation behind this small effect was the low reference values (1-2 EUR/MWh), for the balancing costs of PV and wind. Because of that, such sensitivities were also investigated, when one or all weather dependent technologies faced a balancing cost of 10 EUR/MWh. In these setups, the effect of changing the party responsible for balancing on technology bias reached 5-6 EUR/MWh. Based on these results this report concluded, that balancing cost payment responsibility only influence technology bias, if balancing costs in the system are high, but even in such case only moderately.

Similar analysis was conducted for grid integration costs and environmental harm compensation. For both variables it was investigated how a compensation payment introduced for producers would affect bias. For both variables, three separate cases were compared, when 0%, 50% or 100% of the two cost elements were required to be paid by producers. As scenarios were defined such way, these designs elements were only analysed in the “baseline scenario.” As the highest grid integration cost was associated with offshore wind, while highest environmental harm with biomass, the internalisation of grid integration costs and environmental harm would mostly reduce the advantage of those two technologies, relative to the others, in the auction, respectively.

The results showed that the sole internalisation of grid integration costs does not help allocative efficiency, as it increased the bid price difference between onshore wind and solar PV relative to the 0% case. This means that the sliding premium scheme remained allocatively inefficient and the fixed premium scheme remained allocatively efficient even in the case when 100% of the grid connection costs were internalised. In terms of general efficiency sliding premium and fixed premium reacted differently to the internalisation of grid costs. In the sliding premium scheme, if more compensations were required by the producers, the average bias between all technologies increased, while in the fixed premium a slight decrease was observable from 0% to 50% and only if 100% was internalised the bias increased drastically. Grid integration costs compensation turned to be a significant determinant of technology bias as the range of biases between 0% and 100% cases reached 7-12 EUR/MWh.

For environmental harm, larger internalisation resulted in allocatively more efficient outcomes, as (based on our inputs) the costs internalised for PV were larger than those for onshore wind. As a result, even if only a 50% payment was required, the sliding premium scheme turned to be allocatively efficient, while fixed premium was already efficient in the 0% case. The average bias for all technologies was the lowest for all remuneration schemes when a 50% compensation was required. Environmental harm compensation turned to be a significant determinant of technology bias as the range of biases between 0% and 100% case reached 12-16 EUR/MWh.

The dynamics presented above lead to the conclusion that in terms of externalities, there should be an optimal level of compensation required for all schemes that would lead to the lowest average bias between the technologies. Unfortunately, this optimal level can only be determined on a case-by-case basis, and if all necessary inputs are known. It is, however, important to note that it is possible to combine these compensations. The results of the model estimations showed that the highest general efficiency of all modelled scenarios is achievable for all remuneration schemes when 50%-50% compensation was required for grid integration costs and environmental harm simultaneously.

Table 2-2 summarises the relevance of each analysed auction design elements on technology bias.

Table 2-2. Relevance of each investigated design elements on technology bias

Relevance of design elements for technology bias in auctions	1-sided sliding premium	2-sided sliding premium (CfD)	Fixed premium
Support period	moderate	moderate	high
Granted realisation period	small	small	small
Timing of the auction	marginal	marginal	marginal
Balancing cost payment responsibility[15]	small	small	marginal
Grid integration cost compensation	high	high	moderate
Enviromental harm compensation	high	high	high

2.4 Conclusions

Based on the findings of this analysis two very important conclusions can be drawn for future policy makers. First, the effect of a change in a different design element on technology bias is highly dependent on the "starting point", that is on the extent of bias in the reference case. As a result, it is not possible to formulate general rules of thumb for policy solutions, as it is possible that a certain change would increase technology bias in one case but decrease it in another. For this reason, a case-by-case analysis is required if a policymaker's aim is to reduce bias between technologies. The second important conclusion is that aiming for allocative efficiency in terms of technology bias may result in completely different designs than aiming for general efficiency. It is necessary to separately analyse these two types of efficiency when comparing different auction designs. It was also found that, remuneration scheme, internalisation of grid integration costs and environmental harm, alongside with the length of support period are those elements that possibly have the highest influence on technology bias.

3 Modelling of European and cross-border RES auctions

3.1 Policy context

Throughout last years, EU Member States (MSs) have agreed upon 2030 energy and climate targets, aiming in the field of renewables for an EU RES share of at least 32% by 2030, in accordance with the 40% target for the reduction of greenhouse gas emissions (GHG). In this context, by the end of 2019 EU MS's had to provide National Energy and Climate Plan's (NECPs) to show how to contribute to 2030 EU targets.

As part of the European Green Deal (cf. EC, 2019) the EU ambition has been raised: the European Union (EU) now aims at full climate-neutrality of all sectors by 2050 and, in accordance with that, the European Commission (EC) has proposed to revise the 2030 GHG reduction target to (at least) 55%, cf. (EC, 2020a). An adoption of this proposal is pending but it appears likely that this will revision of the overall 2030 energy and climate target framework, including renewables, cf. (EC, 2020b). As a consequence of the above, one may expect an increase in electricity demand driven by sector-coupling driven by the overall decarbonisation objective of the whole EU economy, and a further boost towards renewables across all parts of the energy sector, cf. EC, 2020c. Within the electricity sector, renewables are expected to dominate electricity supply post 2030, requiring high shares of wind and photovoltaics in the power system as well as dispatchable (RES) technologies to balance the fluctuating generation patterns of wind and PV.

Since renewable resources differ across the EU, cooperation between MS and/or at EU level is of key importance, helping to make promising RES potentials in certain parts/areas also available to neighbouring regions within the EU and facilitating overall energy and climate target achievements. Cooperation is generally characterized by shared efforts and risks, cost optimised investments over all countries instead of separate, national strategies and high shares of energy trading (physically or statistically), cf. (Boje et al., 2020). To facilitate RES cooperation, a variety of cooperation mechanisms have been defined in EU regulation in prior, cf. (EC, 2009) or (EC, 2018a). In recent years, only limited progress has been achieved concerning cooperation in the field of RES across the EU – i.e. as stated in (EC, 2020d) currently (as of October 2020) four binational agreements have been taken to collaborate on 2020 RES target achievement. Further agreements can however be expected in the 2020 context and beyond. Thus, cross-border cooperation on renewables is currently prominent on the agenda of many MSs and at aggregated level since the EC is strongly encouraging MSs to make of these cooperation mechanisms, for example by means of cross-border or EU-wide RES auctions, for achieving RES targets for 2020, 2030 and beyond in a cost-effective manner, cf. (EC, 2020d).

3.2 Scope and structure of this analysis

This analysis aimed to shed light on the above, summarising insights from our forward-looking model-based analyses referring timely to the 2030 context. Here different scenarios for meeting (and exceeding) the EU's overall 2030 RES target have been derived, aiming to illustrate the feasibility of the 2030 RES ambition in accordance with past agreements taken (i.e. to achieve at EU level an overall RES share of at least 32%) and under consideration of the needs arising from the EU Green Deal. Apart from feasibility and corresponding costs impacts, a focal point in that analysis was also to analyse the need for RES cooperation, practically implemented by use of European or Cross-Border RES auctions. Thus, this chapter provides a summary of key outcomes of our analyses performed and concludes with a summary of key findings and lessons learnt.

This summary of the corresponding model-based assessment is structured as follows:

- Section 3.3 is dedicated to inform on the approach taken and the models applied
- Section 3.4 discusses key results gained on 2030 RES deployment, providing a feasibility check of planned/required RES use and identifies the need for RES cooperation.
- Section 3.5 complements the above by taking a closer look at the impacts arising from RES cooperation. We thereby focus on the electricity sector, and shed light on the RES uptake proclaimed therein as well as on corresponding support expenditures, indicating the changes in support expenditures and cost to consumer that may arise from making broader use of RES cooperation.

- Section 3.6 concludes this analysis with a summary of key findings and lessons learnt.

3.3 Method of approach and key assumptions

3.3.1 The applied modelling system

This analysis builds on modelling works undertaken by the use of TU Wien's Green-X model, a specialised energy system model with a sound incorporation of various RES policy approaches, closely linked to two complementary power system models (REKK's EPMM model and the open-source model Balmorel). A brief characterisation all models is given in Box 3-1 below.

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) and expenditures (capital, operation and support expenditures). For assessing the interplay between RES and the future electricity market, Green-X was complemented by its power-system companions, i.e. the models EPMM and Balmorel. Thanks to a higher intertemporal resolution than in the RES investment model Green-X, EPMM and Balmorel enable 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.

Box 3-1. Brief characterisation of the applied modelling system (Green-X in combination with Balmorel & EPMM)

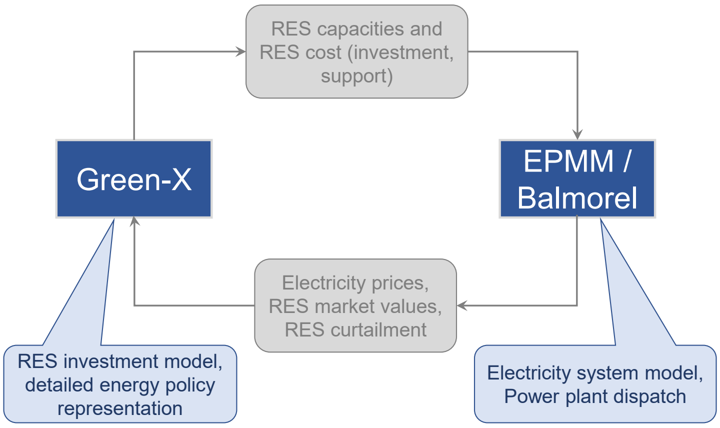
Green-X is an energy system model, developed by TU Wien, that offers a detailed representation of the potentials and the related technologies of various renewable energy sources (RES) in Europe and in neighbouring countries, including all EU Member States and all Contracting Parties of the Energy Community. It aims at indicating consequences of RES policy choices in a real-world energy policy context. 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.

Balmorel (the BALtic Model for Regional Electricity Liberalisation) is an open-source partial equilibrium model, analysing the electricity and combined heat and power sector on various geographic levels. The analysis of further sectors via sector coupling (e.g. e-mobility, individual heating) is also possible via model add-ons. The model was originally developed by DTU and is now used and further developed by a wide range of institutions within Europe and worldwide, including TU Wien who is conducting also recent extensions in the course of this project. Balmorel is a deterministic bottom-up energy system model that is able to co-optimize energy dispatch and investments via linear (and for some applications mixed-integer) programming. For this, equations on electricity and district heat balance, capacity and energy constraints, production of dispatchable and non-dispatchable units, operational constraints, storage operation, transmission constraints, emission caps, and several more are considered. As a result, the model delivers energy conversion characteristics, fuel consumption, electricity exports and imports, emissions, investments in plants and transmission lines, prices on traded energy, and total system costs.

The European Power Market Model (EPMM) is a unit commitment and economic dispatch model developed by REKK, which during the optimisation process satisfies the electricity consumption needs in the modelled countries at minimum system cost considering the different types of costs and capacity constraints of the available power plants and cross-border transmission capacities. The model minimises the production cost of power plants to satisfy demand. These costs include start-up and shut-down costs of the power plants, the costs of production (mainly fuel and CO2 costs) and the costs which occur to RES producers in the form of curtailment. The model simultaneously optimises all 168 hours of a modelled week, and as a result determines the hours of the week in which power plants will operate and at what production level. The model is executed for each week of the given year, where all 8760 hours could be modelled. EPMM endogenously models 41 electricity markets in 38 countries across the ENTSO-E network. The model runs yield the optimal generation mixes and required number of power plant start-ups for the region.

Figure 3-1 gives an overview on the interplay of both types of models. All 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 2030). 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) serves as input for the power-system analysis done with Balmorel and/or EPMM. Subsequently, the applied power system model analyses the interplay between supply, demand, and storage in the electricity sector on an hourly basis for the given years. The output of the power system model 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.

Figure 3-1. Model coupling between Green-X (energy policy analysis) and EPMM / Balmorel (power system analysis) for an assessment of RES developments in the electricity sector. (Source: own development)



3.3.2 Assessed scenarios

The modelling undertaken in the course of this assessment serves to conduct a feasibility check of planned RES use by 2030 in accordance with either current planning (National Energy Climate Plans (NECP) ambition), or with the requirements arising from an increase of the RES ambition under the European Green Deal (Green Deal needs). Under both perspectives we then aim for identifying the need for RES cooperation.

Thus, the scenarios defined had to reflect both dimensions – i.e. the underlying RES ambition (i.e. NECP ambition vs Green Deal needs) and the approach taken concerning RES cooperation (i.e. with or without RES cooperation):

(1) NECP ambition:

Two distinct scenarios were derived:

- National perspective / without RES cooperation: The default scenario reflects a so-called national perspective in accordance with NECP planning, and a 2030 RES target fulfilment using domestic renewable sources only (named as "Without Cooperation")
- European perspective / with RES cooperation: The second scenario reflects the EU perspective for meeting planned RES shares in accordance with NECPs, and, accordingly, a proactive use of cooperation mechanism (named as "With Cooperation") to allocate RES investments across the whole EU cost effectively.

(2) Green Deal needs:

Similar to above, two distinct scenarios were derived:

- National perspective / without RES cooperation: This scenario aims for reflecting the national perspective in accordance with Green Deal needs, and, similar to above, a 2030 RES target fulfilment using domestic RES only (named as "Without Cooperation").
- European perspective / with RES cooperation: The other scenario offers an EU perspective for meeting the required increase of the RES shares in accordance with the European Green Deal, and, accordingly, a proactive use of cooperation mechanism (named as "With Cooperation") to allocate RES investments across the whole EU cost effectively.

Generally, a least-cost approach is followed for allocating RES investments post 2020 cost-effectively across technologies (and partly also geographically across the whole EU): The model-based selection of RES technologies in the period post 2020 follows within all assessed scenario 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, in case of RES cooperation, also across countries (incorporating well also differences in financing conditions etc.) from a European perspective.

For the assessment of cost impacts related to the RES uptake in the electricity sector, different policy instruments have been analysed. More precisely, for providing the required financial support to RES-E technologies we made assumed either the use of umbrella policies approaches, e.g. technology-neutral quotas with certificate trading, or of targeted technology-specific policy approaches, e.g. auctions for feed-in premiums, that offer incentives tailored to individual needs.

3.3.3 Key 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. More precisely, PRIMES comes into play for energy demand developments as well as fossil energy and carbon price trends[1]. The specific PRIMES scenarios used are the latest publicly available reference scenario (European Commission, 2016) and the climate mitigation scenario PRIMES euco3232.5 that builds on the targeted use of renewables (i.e. 32% RES by 2030) and an enhanced use of energy efficiency (EE) compared to reference conditions (i.e. 32.5% EE by 2030), respectively. Please note that all PRIMES scenarios are discussed in the EC's Impact assessment of the Climate Target Plan related to the European Green Deal (EC, 2020c).

For our analysis of Green Deal needs we had to modify original demand trends in accordance with the presumed energy efficiency increases arising from the strengthening of the climate ambition. Here we assumed strong declines in the demand for heating & cooling as well as in transport, while 2030 electricity demand was kept constant – since here two diverging trends come into play: an increase due to enhanced sector-coupling, and a decline due to a strengthening of energy efficiency.

3.4 Feasibility check of meeting planned/required 2030 RES deployment – identifying the need for RES cooperation

This Chapter is dedicated to represent key results on 2030 RES deployment at EU level and by MS, providing a feasibility check of planned RES use in accordance with current planning (NECPs) as well as on the

[1] A sensitivity analysis has been performed to reflect on the uncertainty in electricity market developments, in particular concerning wholesale prices trends. For a so-called low [wholesale] price scenario we deviated from default fossil fuel price trends, using IEA works (WEO 2016) as alternative data source.

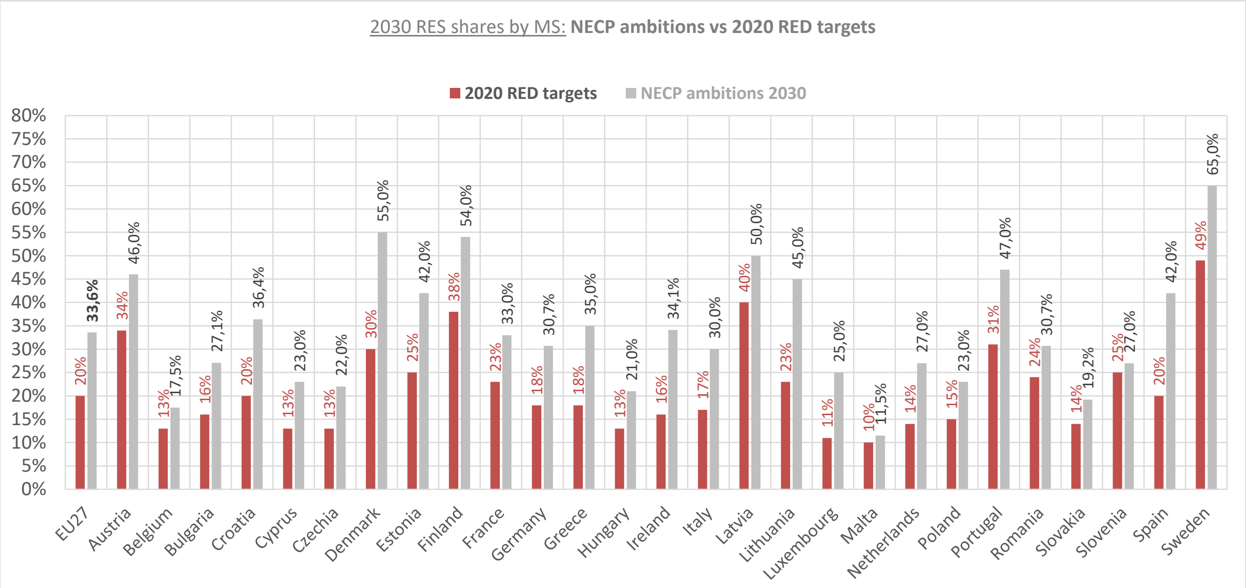
requirements arising from an increase of the RES ambition under the European Green Deal (Green Deal needs). Under both perspectives we aim for identifying the need for RES cooperation.

3.4.1 2030 RES deployment according to National Energy and Climate Plans (NECPs)

The role of RES in National Energy and Climate Plans

As stated above, throughout last years, EU Member States (MSs) have agreed upon 2030 energy and climate targets. In the field of renewables the current framework implies at EU level an increase of the RES share from 20% by 2020, as set by the original RED (EU, 2009), to (at least) 32% by 2030, in accordance with the recast of the RED (EU, 2018a). In order to facilitate this energy transition, EU MSs had to provide National Energy and Climate Plans (NECPs) by the end of 2019, indicating how to contribute to the overall 2030 EU energy and climate targets. Thus, MSs have to increase their RES shares (well) above their 2020 RED targets in order to contribute to the overall EU RES target of (at least) 32% by 2030, and, as applicable from Figure 3-2, they are aware of that: Summing up the nationally planned RES shares (and where reported demand projections) for 2030 leads to an EU RES share of approx. 33.6%. The RES ambition however differs to a large extent across MSs: at the lower end, MSs like Malta, Slovenia, Belgium and Slovakia plan for increasing their RES share until 2030 less than 6 percentage points compared to their 2020 RED RES target, which is less than half of the RES share increase imposed at EU level during the same period in time. At the upper end, Denmark, Lithuania, Spain and Ireland aim for increasing their RES share until 2030 by more than 18 percentage points which is well above the EU RES share increase (12 percentage points) agreed upon.

Figure 3-2. 2020 RED targets vs. 2030 RES shares by EU MS according to NECPs (Target Scenario)
Source: AURES2 – own analysis

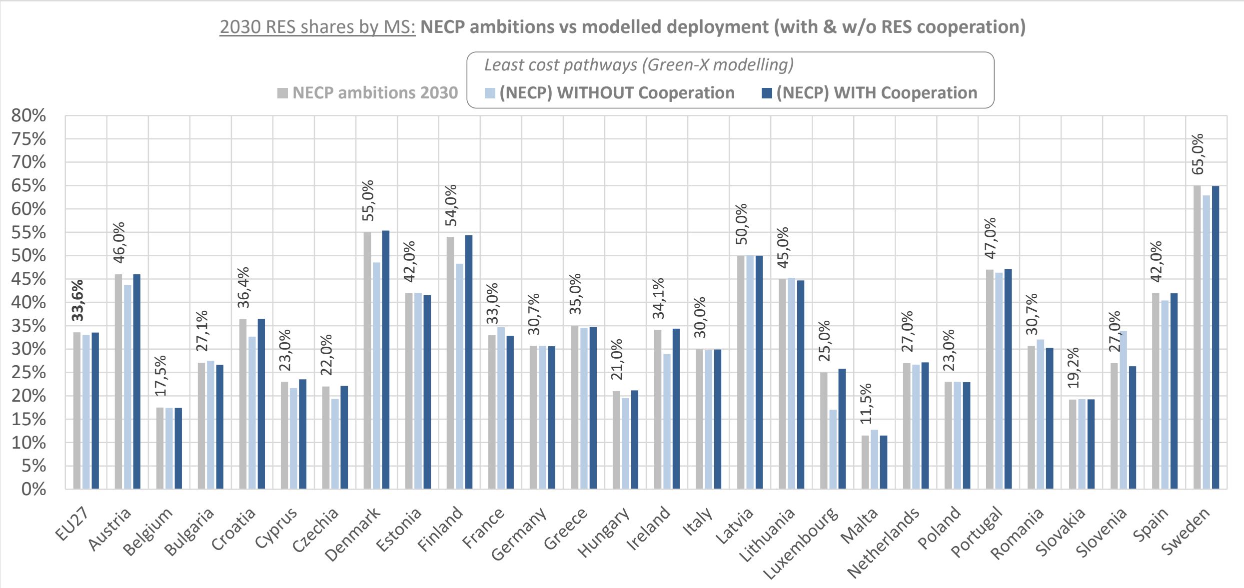


Feasibility check – identifying the need for RES cooperation in accordance with NECP planning

By use of TU Wien's Green-X model, in combination with the models EPMM and Balmorel for a complementary power system analysis, a feasibility check-up of planned 2030 RES deployment (NECP ambition) was undertaken. As explained in chapter 2 of this report, two distinct least-cost scenarios were derived: one reflecting the national perspective in accordance with NECP planning, and a 2030 RES target fulfilment using domestic renewable sources only (named as "Without Cooperation"), and the other scenario reflecting the EU perspective for meeting planned RES shares in accordance with NECPs, and, accordingly, a proactive use of cooperation mechanism (named as "With Cooperation") to allocate RES investments across the whole EU cost effectively.

In this context, Figure 3-3 informs on the outcomes of our modelling, comparing planned 2030 RES shares (NECP ambitions 2030) with modelled RES deployment according to the two scenarios assessed, i.e. with and without RES cooperation. Modelling shows that without RES cooperation only an EU RES share of 33.0% appears feasible since some MSs would fail to achieve their planned RES share using only domestic resources. The highest gap (in percentage points, comparing planned and modelled RES deployment) is here applicable for Luxembourg, Denmark, Finland and Ireland, maybe a consequence of the high domestic RES ambition and the difficulties in mobilising domestic resources well in time given the underlying (linear) target trajectory. In contrast to above, with RES cooperation the planned deployment (33.6%) can be reached across the whole EU but several MSs would require RES cooperation to reach their planned 2030 RES share.

Figure 3-3. 2030 RES shares by EU MS according to NECP planning (Target scenario) vs modelled RES deployment (with & w/o RES cooperation) (Source: Own analysis and Green-X modelling)



3.4.2 The necessary increase of the RES ambition in accordance with the European Green Deal

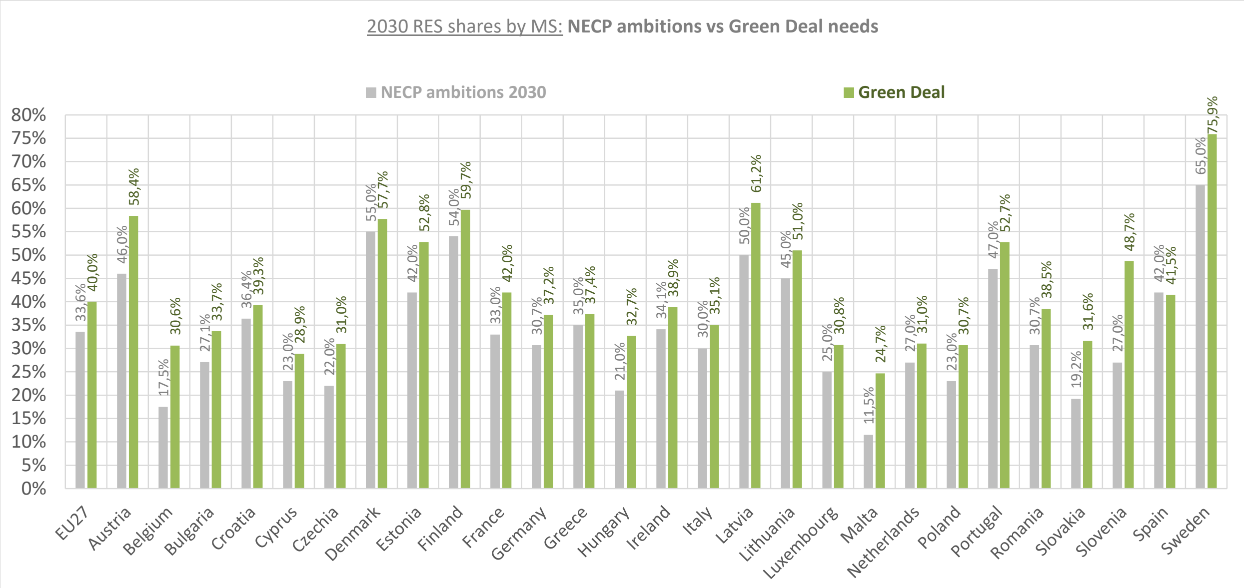
Comparing planned RES deployment (NECPs) with "Green Deal needs"

The EU Green Deal and the corresponding increase in the 2030 climate ambition (approximately 55% instead of 40% GHG reduction) raises the need for a stronger uptake of renewables. Within the underlying model-based analysis the assumption was taken that the EU 2030 RES target would consequently be increased from (at least) 32% to (at least) 40%. Subsequently, a fair effort sharing across MSs was calculated, expressing national contributions for the EU RES target in accordance with an approach for doing so as described in the EU Governance Directive (EU, 2018b)[2], cf. Figure 3-4. With the exception of Spain where national planning shows a higher RES ambition, this implies in general a strong increase of the RES ambition in the forthcoming decade. Following that approach would imply highest increases of the 2030 RES share (above 10 percentage points) for Slovenia, Malta, Belgium, Austria, Slovenia, Latvia, Hungary, Sweden and Slovakia, whereas a comparatively small increase (below 3 percentage points) would result for Greece,

[2] The question arose how to distribute the increased overall RES effort at EU level across individual MSs. Annex II of the EU Governance Directive (EU, 2018b) introduces for that purpose a methodology for establishing benchmarks concerning the national contributions for the RES share in gross final energy consumption in the 2030 context at EU level. This approach follows an integrated concept that takes into account the differences in economic development, the potential for cost-effective RES deployment and the interconnection level in the European Network of Transmission System Operators for Electricity (ENTSO-E) across the EU and its MSs, respectively.

Denmark and Croatia.

Figure 3-4. 2030 RES shares by EU MS according to NECP planning (Target Scenario) vs Green Deal needs (Source: NCEP and own analysis)



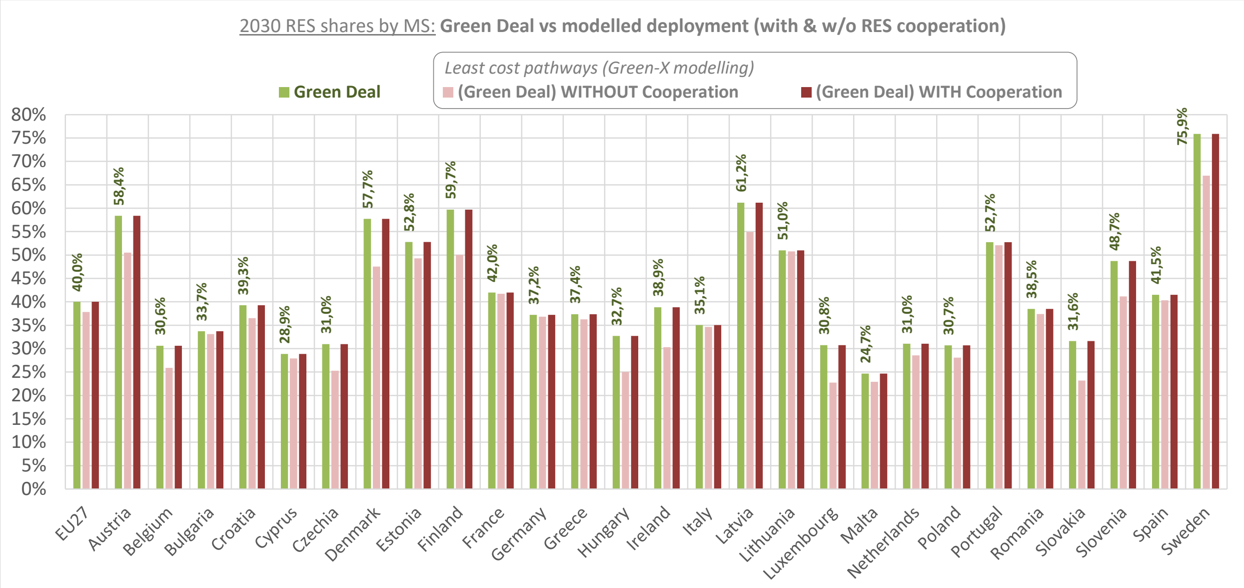
Feasibility check of the necessary increase of the RES ambition – identifying the need for RES cooperation in accordance with European Green Deal needs

Again, by use of TU Wien's Green-X model in combination with the power system models EPMM and Balmorel a feasibility check-up was undertaken. More precisely, as described in section 3.3.2, two distinct least-cost scenarios were derived: Similar to above, one scenario aims for reflecting the national perspective in accordance with Green Deal needs, and a 2030 RES target fulfilment using domestic RES only (named as "Without Cooperation"). The other scenario offers an EU perspective for meeting the required increase of the RES shares in accordance with the European Green Deal, and, accordingly, a proactive use of cooperation mechanism (named as "With Cooperation") to allocate RES investments across the whole EU cost effectively.

Figure 3-5 shows the outcomes of our modelling, comparing required 2030 RES shares (Green Deal needs) with modelled RES deployment according to the two scenarios assessed, i.e. with and without RES cooperation. Modelling reveals that without RES cooperation only an EU RES share of 37.8% appears feasible – but with RES cooperation the planned deployment (40%) can be reached (cf. Figure 3-5). Taking a closer look at the national perspective scenario, i.e. without RES cooperation, indicates that the highest gap (in percentage points, comparing required and modelled RES deployment) is here applicable for Denmark, Finland, Sweden, Ireland, Slovakia and Luxembourg, again as a consequence of the high domestic RES ambition and the difficulties (or, in the case of Luxembourg, lack) in mobilising domestic resources well in time given the underlying (linear) target trajectory.

Thus, the conclusion can be drawn that EU-wide RES cooperation appears under these new framework conditions essential for achieving a stronger RES uptake at short notice (i.e. by 2030). Apart from these needs, there are several benefits of RES cooperation: Firstly, RES cooperation facilitates a levelling of country-specific risk for RES investors. Secondly, a (more) fair effort sharing can then be triggered by RES cooperation and, thirdly, it can be expected that this lowers the overall cost for reaching ambitious future RES targets (as analysed subsequently in section 3.5 of this report)

Figure 3-5. 2030 RES shares by EU MS according to Green Deal needs vs modelled RES deployment (with & w/o RES cooperation) (Source: Own analysis & Green-X modelling)



3.4.3 Gap analysis on the need for RES cooperation

Complementary to and partly also as summary of the above, a gap analysis on the need for RES cooperation has been undertaken in the course of our analysis. More precisely, the gap analysis has been conducted from two angles:

(1) Firstly, from a desk research perspective by comparing planned RES use (in accordance with the current 2030 target framework) with required RES deployment, in accordance with Green Deal needs.
(2) Secondly, by indicating the gap that may still occur under revised national planning whilst proclaiming no use of cooperation mechanisms post 2020. For that we directly built on our modelled-based analysis in accordance with Green Deal needs as discussed in the previous section.

In accordance with (1), a gap in the 2030 RES share in size of 6.4 percentage points occurs if we compare NECP planning (33.6%) with Green Deal needs (40%). Since our model-based analysis has shown that even under NECP ambition there is a comparatively small need for RES cooperation, accounting for 0.6 percentage points of the RES share at EU level[3], the overall need for RES cooperation would then stand at 7.0 percentage points (of the EU RES share in gross final energy demand). Under these circumstances, a top-down approach needs to be followed for triggering the additional RES deployment required for increasing the EU's RES ambition in line with Green Deal needs. This implies that there is no revision of national RES planning and, consequently, for example EU wide auctions may serve to close that high gap.

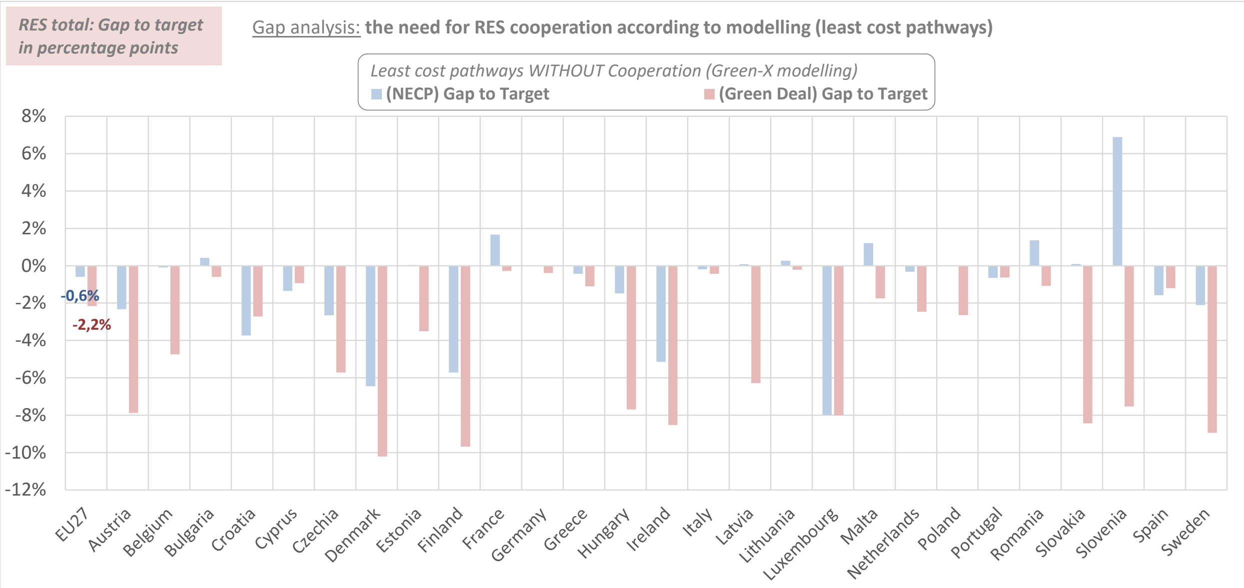
In accordance with (2), a smaller gap can be identified if we assume that MSs will revise their planning in accordance with the Green Deal needs: 2.2 percentage points (of the EU RES share in gross final energy demand) would then be the need for RES cooperation.

Figure 3-6 complements the above, indicating the need for RES cooperation identified from our model-based

[3] As discussed in section 3.4.1, the modelled 2030 EU RES share stands at 33.0% without, and at 33.6% with RES cooperation.

analysis at MS level. Here the blue bars illustrate the gap in RES use to be covered by RES cooperation from an NECP perspective, comparing planned 2030 RES deployment with the modelled one proclaiming no use of RES cooperation. In accordance with section 3.4.1, at EU level a gap in size of 0.6 percentage points occurs under these circumstances.[4] The red bars reveal the outcomes of our modelling on Green Deal impacts (cf. section 3.4.2), and presume a revision of national NECP planning in forthcoming year(s). Under these circumstances, as postulated above, a gap of 2.2 percentage points (of the RES share in gross final energy demand) can be identified.

Figure 3-6. Gap analysis: the need for RES cooperation by EU MS according to modelling (NCEP & Green Deal perspective). (Source: Green-X modelling & own analysis)



3.5 Impacts of RES cooperation exemplified for the electricity sector

This section complements the above by taking a closer look at the impacts arising from RES cooperation. We thereby focus on the electricity sector, and shed light on the RES uptake proclaimed therein as well as on corresponding support expenditures, indicating the changes in support expenditures and cost-to-consumer that may arise from making broader use of RES cooperation mechanisms.

3.5.1 The future uptake of renewables in the electricity sector

As a starting point for analysing the impact of RES cooperation, exemplified for the electricity sector, we shed light on the RES uptake proclaimed therein. Here our modelling provides a sound basis for that since derived least cost pathways of RES deployment provide, on the one hand, insights on the planned RES uptake within the electricity sector in accordance with NECP planning as well as on likelihood of that. On the other hand, modelling also allows for identifying the needs arising from the Green Deal for a stronger increase of RES overall, and, a focal point within this section, on the contribution of RES electricity to that. Under both perspectives, similar to the overall identification of the required RES cooperation, we can then subsequently illustrate the impacts arising from the use of RES cooperation mechanisms.

A distinct approach is followed while conceptualising the RES uptake in the electricity sector in the underlying scenarios:

[4] Please note that this however ignores any increase of the RES ambition arising from the Green Deal.

- For the NECP perspective we modelled the deployment of RES-electricity (RES-E) in accordance with planning.
- For the Green Deal perspective, a cross-sectoral least cost allocation of RES deployment is derived by the applied (Green-X) model endogenously.

Figure 3-7. Development of the RES-E share at EU level over time (NECP ambition vs Green Deal – according to scenarios with RES cooperation). (Source: Green-X modelling)

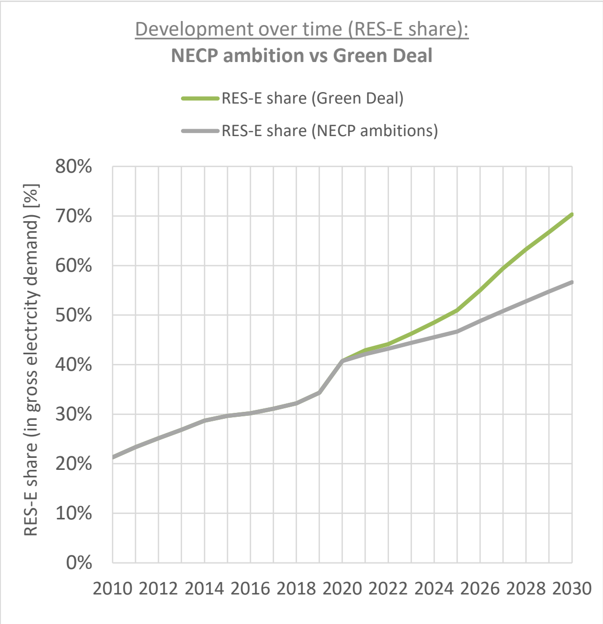


Figure 3-8: Electricity generation from RES at EU level over time (NECP ambition – according to scenario with RES cooperation). (Source: Green-X modelling)

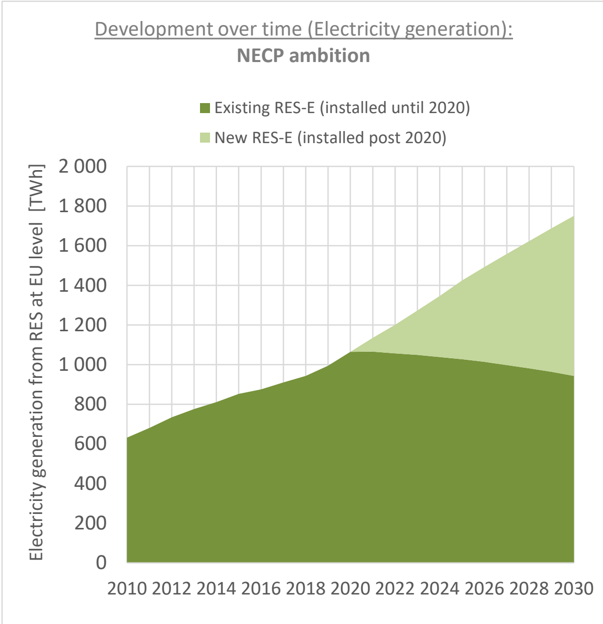


Table 3-1. 2030 share of RES & RES-E at EU level: NECP ambitions vs. modelled deployment of Green Deal needs. (Source: Green-X modelling)

RES & RES-E shares 2030 at EU level: NECP ambitions vs modelled deployment of Green Deal needs		RES	RES-E
NECP ambitions	%	**33.6%**	**56.7%**
(NECP) L.c. scenario WITHOUT Coop	%	33.0%	57.0%
(NECP) L.c. scenario WITH Coop	%	**33.6%**	**56.9%**
Green Deal needs	%	**40.0%**	
(Green Deal) L.c. scenario WITHOUT Coop	%	37.8%	64.7%
(Green Deal) L.c. scenario WITH Coop	%	**40.2%**	**70.3%**

Figure 3-7 and Figure 3-8 illustrate the proclaimed uptake of RES in the electricity sector at EU level. More precisely, Figure 3-7 shows the development of the RES-E share at EU level over time according to distinct scenarios (with RES cooperation), reflecting, on the one hand, the NECP ambition in corresponding planning and, on the other hand, the Green Deal needs. Figure 3-8 provides a graphical illustration of the development of electricity generation from RES at EU level under NECP planning over time, indicating the required uptake of new RES installations within this decade (up to 2030). Table 3-1 complements the above by taking a closer look at 2030, listing 2030 EU RES and RES-E shares for all scenarios assessed.

Key results are:

- At EU level we see a moderate RES uptake in the electricity sector if NECP planning is considered (56.9-57.0% RES-E share 2030), and
- a strong increase of RES deployment in the electricity sector if the Green Deal perspective is followed (ranging from 64.7 to 70.3% by 2030);
- New RES installations within this decade (up to 2030) will by 2030 have to provide slightly less than half of total electricity generation from RES (i.e. 46% of total) under NECP planning. The required contribution of new installations has to increase to 57% of the total RES-E volumes considering Green Deal needs.

3.5.2 The need for dedicated RES support post 2020 & the impacts of RES cooperation on that

Next, we take a closer look at the need for dedicated RES support in the electricity sector post 2020.

Within modelling different policy instruments for providing the required financial support to RES-E technologies have been assessed, ranging from umbrella policies approaches, e.g. technology-neutral quotas with certificate trading, on to targeted technology-specific policy approaches, e.g. auctions for feed-in premiums, that offer incentives tailored to individual needs.

The other dimension taken up in the model-based analysis was the impact of RES cooperation: In accordance with above (cf. section 3.3), we presumed the use of European / Cross-Border RES auctions – i.e. from a modelling perspective these two options are identical if modelled simultaneously for all MSs – in one set of scenarios (i.e. scenarios with RES cooperation), whilst in the other scenario group no RES cooperation was presumed (i.e. scenarios without RES cooperation).

We exemplify this for all assessed policy options under the NECP ambition, reflecting current national RES planning (NECP ambition). Two graphs provide a sound summary of the key results derived: On the one hand, Figure 3-9 shows the development of the required support expenditures for RES at EU level over time – more precisely, according to a scenario with targeted technology-specific policies (RES auctions), with RES cooperation. To inform on the impact of the underlying policy approach as well as of RES cooperation, Figure 3-10 complements with a comparison of average (2021-2030) yearly support expenditures for new RES-E (installed post 2020) for all assessed policy options, with and with use of RES cooperation.

As applicable from Figure 3-9, within in the forthcoming decade, the bulk of support expenditures for RES in the electricity will be dedicated to those RES systems installed until 2020. New RES installations being deployed in forthcoming years are expected to come at lower cost (compared to past RES installations) and consequently require less financial support, thanks to technological progress achieved and expected in forthcoming years.

RES cooperation and a selection of an appropriate policy approach can then help to lower the policy cost further, cf. Figure 3-10. As applicable from this graph:

- RES cooperation can help to lower the cost burden significantly. By the assumed full use of RES cooperation (done e.g. via EU wide or Cross-Border RES auctions) at EU level, support expenditures for new RES installations (i.e. installed post 2020) can be reduced by 23% to 38% percentage points compared to default case where no such cooperation was presumed.
- The other key parameter is the selection of an appropriate policy framework: Here our modelling reveals that targeted policies offering technology-specific incentives tailored to individual needs, done e.g. by use of auctions for feed-in premiums, appear highly beneficial for triggering a cost-effective uptake of RES in the electricity sector. Modelling results show cost savings ranging from 28% to 42% when comparing average support under targeted RES policy approaches (e.g. RES auctions) with umbrella policy approaches (e.g. technology-neutral quotas with certificate trading).

Figure 3-9. Development of the required support expenditures for RES at EU level over time (NECP ambition – according to a scenario with targeted technology-specific policies (RES auctions), with RES cooperation). (Source: Green-X modelling)

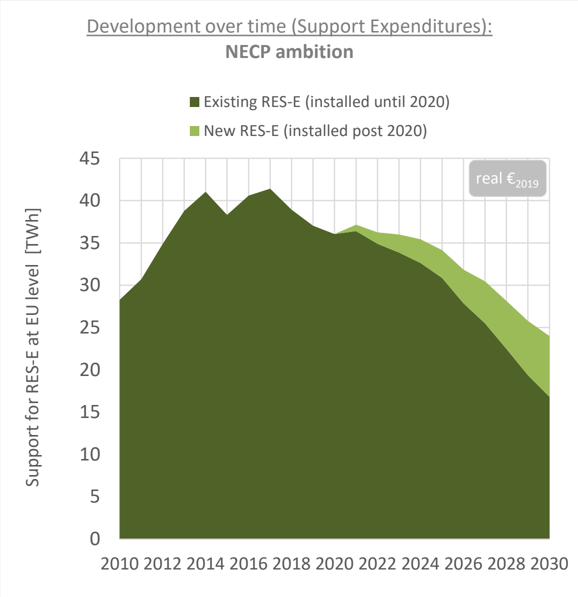
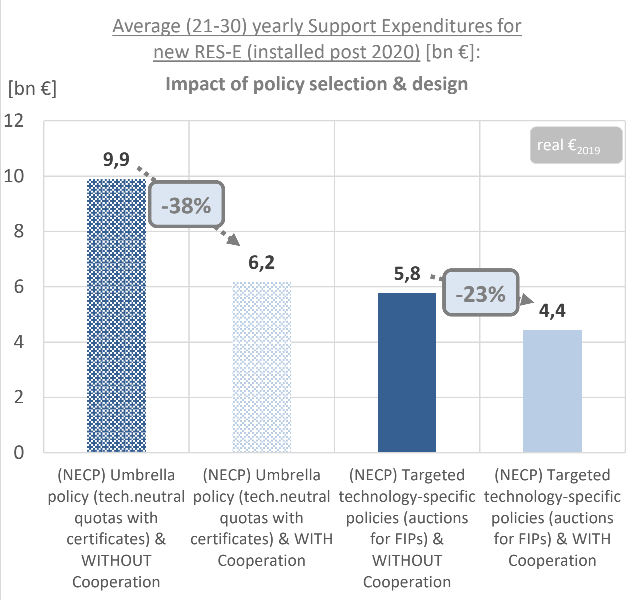


Figure 3-10. Comparison of average (2021-2030) yearly support expenditures for new RES-E (installed post 2020) (NECP ambition – according to all assessed policy options). (Source: Green-X modelling)



3.5.3 Sensitivity analysis on the impact of wholesale price trends

A sensitivity analysis has been performed to reflect on the uncertainty in electricity market developments, in particular concerning wholesale prices trends. For a so-called low (wholesale) price scenario we deviated from default (high) fossil fuel price trends, using IEA works (WEO 2016) as alternative data source, combined with the assumptions that the full potential of system flexibility offered by sector-coupling is not yet used by 2030, and that there is still significant overcapacity in the European power system as a consequence of limited policy emphasis of proactively phasing-out coal and lignite. This section is dedicated to summarise briefly corresponding outcomes, exemplified for the scenarios with RES cooperation following the NECP ambition.

Underlying wholesale price trends are depicted by Figure 3-11, indicating the development of at EU level yearly average wholesale prices for the default case of high prices, and for the alternative case of low prices in the period 2020 to 2030. The impacts of a low wholesale price trend are then shown in Figure 3-12 and can be summarised as follows: a 33% (compared to default, i.e. high prices) reduction of average (2021 to 2030) wholesale prices in the period up to 2030 would firstly lead to a strong increase of RES support – i.e. by 36% (compared to default). Thanks to the two opposing developments, i.e. the decline in wholesale electricity prices, and the increase in RES support, the cost to consumer are however lower compared to default – i.e. by 22% (compared to default). A negative impact can however be expected for the contribution of RES-E technologies to overall RES target achievement: with the assumed cross-sectoral competition of available RES options, the RES-E share is expected to decline by 7% (compared to default high prices), mainly a consequence of an earlier phase-out of existing RES installations (due to declining competitiveness once guaranteed RES support has ended).

Figure 3-11. Development of wholesale prices on average at EU level (NECP ambition – according to scenarios with RES cooperation and different price trends).
(Source: Balmorel / EPMM modelling)

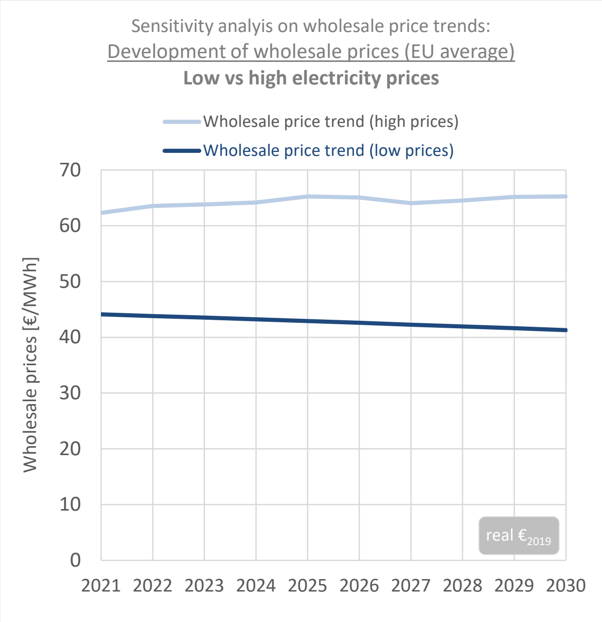
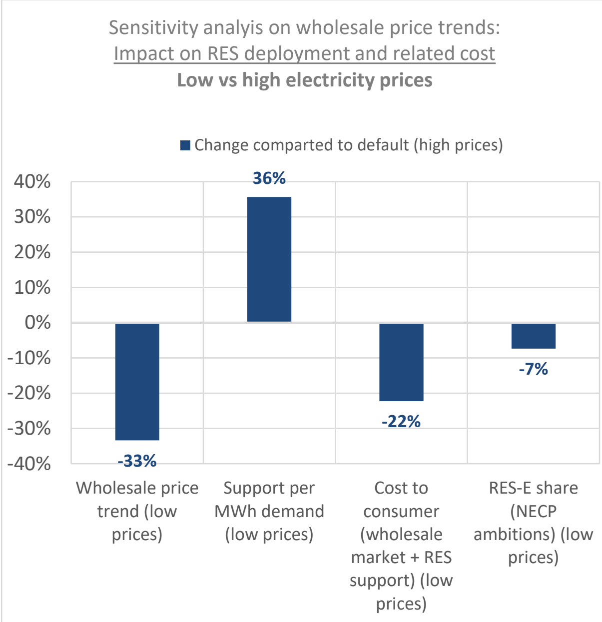


Figure 3-12. Summary of impacts of low wholesale prices: Change in RES deployment and related cost (NECP ambition – according to scenarios with RES cooperation).
(Source: Green-X modelling)



3.6 Conclusions

This analysis aimed to shed light on the need for and impact of RES cooperation across the EU in the 2030 context, practically done by means of establishing European and/or Cross-Border RES auctions. For doing so we relied on insights gained from our forward-looking model-based analyses where different scenarios for meeting (and exceeding) the EU's overall 2030 RES target have been derived, serving as a feasibility of the 2030 RES ambition in accordance with past agreements taken (i.e. NECP ambition to achieve an EU RES share of at least 32%) and under consideration of the needs arising from the European Green Deal.

Below we summarise the key findings and lessons learnt, sorted in a topical manner.

NECP ambition: a limited set of MSs requires RES cooperation to meet their 2030 planned RES deployment

Under current agreements taken at EU level, MSs have to increase their RES shares (well) above their 2020 RED targets in order to contribute to the overall EU RES target of (at least) 32% by 2030, and, as discussed in section 3.4.1, generally they are aware of that: Summing up the nationally planned RES shares for 2030 leads to an EU RES share of approx. 33.6% - but we observe strong differences in the RES ambition of individual MSs. Modelling shows that without RES cooperation only an EU RES share of 33.0% appears feasible since some MSs would fail to achieve their planned RES share using only domestic resources. Allowing for RES cooperation would, in turn, assure that the planned deployment (33.6%) can be reached across the whole EU.

Green Deal needs: a strong increase of the RES ambition at short notice (by 2030) causes a strong demand for RES cooperation across the whole EU

The EU Green Deal and the corresponding increase in the 2030 climate ambition will require a significantly stronger RES uptake at short notice. In accordance with (EC, 2020c) we presumed in modelling an increase of the 2030 EU RES target to (at least) 40%. Modelling revealed that without RES cooperation however only an EU RES share of 37.8% appears feasible – whereas with RES cooperation the planned deployment (40%)

can be reached. Thus, the conclusion can be drawn that under these new framework conditions EU-wide RES cooperation appears essential for achieving a stronger RES uptake at short notice (i.e. by 2030).

Impacts of RES cooperation: facilitating the (renewable) energy transition and lowering related cost

Apart from above identified needs for RES cooperation, there are several benefits of RES cooperation: Firstly, RES cooperation facilitates a levelling of country-specific risk for RES investors. Secondly, a (more) fair effort sharing can then be triggered by RES cooperation and, thirdly, it can be expected that this lowers the overall cost for reaching ambitious future RES targets – this was confirmed by our modelling: In modelling a closer look was taken at the need for dedicated RES support in the electricity sector post 2020, exemplified for current national RES planning (NECP ambition), and on the impacts on that arising from RES cooperation.

Modelling revealed that, firstly, within this decade (up to 2030), the bulk of support expenditures for RES in the electricity sector will be dedicated to those RES systems installed until 2020. New RES installations being deployed in forthcoming years are expected to come at lower cost (compared to past RES installations) and consequently require less financial support, thanks to technological progress achieved and expected in forthcoming years. RES cooperation and a selection of an appropriate policy approach can then help to lower the policy cost further:

- RES cooperation can help to lower the cost burden significantly. By the assumed full use of RES cooperation (done e.g. via EU wide or Cross-Border RES auctions) at EU level, support expenditures for new RES installations (i.e. installed post 2020) can be reduced by 23% to 38% percentage points compared to default case where no such cooperation was presumed.
- The other key parameter is the selection of an appropriate policy framework: Here our modelling reveals that targeted policies offering technology-specific incentives tailored to individual needs, done e.g. by use of dedicated RES auctions for feed-in premiums, appear highly beneficial for triggering a cost-effective uptake of RES in the electricity sector. Cost savings in the range of 28% to 42% have been identified when comparing average support under targeted RES policy approaches (e.g. RES auctions) with umbrella policy approaches (e.g. technology-neutral RES quotas with certificate trading).

4 Modelling of cross-border RES auctions – a case study analysis of Hungary and selected neighbors

As example for the modelling activities undertaken with respect to cross-border RES cooperation we shed light within this chapter on the approach taken and the results gained from our modelling exercise dedicated to cross-border RES auctions between Hungary with selected neighbouring countries. The modelling undertaken thereby complemented an in-depth qualitative analysis of Hungary's plans for a possible future cross-border auction design and related considerations, cf. Bartek-Lesi (2020). That analysis was performed in the course of the Hungarian cooperation case study undertaken within the AURES II project.

For the modelling part, as presented in this chapter, the main tool used for that purpose was TU Wien's Green-X model, a specialised energy system model offering a sound coverage of support instruments for renewables as well as on the available resources and corresponding cost of individual RES technologies within Europe.

In general terms, RES cooperation, and specifically a cross-border auction, aims for allocating RES investments across affected countries and technologies where they are from an economic perspective most beneficial. If such a least cost pathway is followed for the future RES expansion, this may then allow for meeting given RES or decarbonisation targets in, from an aggregated perspective, cost effective manner. In practical terms this requires collaboration in RES planning, RES policy design and the corresponding policy implementation. Support instruments for RES like auctions could also be opened up beyond national boundaries as already prescribed by the revised RES directive 2018/2001/EU concerning cross-border auctions as well as in other parts of this report.

4.1 Applied approach

The modelling is done in the 2030 context, analysing by use of TU Wien's Green-X model how cross-border auctions may facilitate the achievement of targeted RES deployment in the electricity sector up to 2030 as postulated in National Energy and Climate Plans (NECPs) by the assessed EU Member States. Geographically we put Hungary in the centre of our analysis, and include all neighbouring countries as possible cooperation partners within this case study.

Two steps are taken in modelling for identifying most promising cooperation candidates and for assessing the impacts that may arise from cross-border cooperation.

- More precisely, in a first step, we take the assumptions that all assessed countries form a joint region – a so-called "bubble" – where postulated national 2030 RES targets shall be met jointly. That implies that a regional policy approach would be agreed upon and implemented to allocate RES investments where economically most beneficial in future years. As reference case we assume the continuation of current practices where RES policies are designed and implemented to meet given national RES targets using only domestic resources. From a policy perspective this "bubble exercise" can be classified as unrealistic but it allows for identifying most interesting cross-border collaboration partners for Hungary.
- Thus, building on the lessons learnt from the "bubble exercise", we analyse under step two three different subcases of bilateral RES cooperation between Hungary and a neighbouring country – the so-called "pairing cases". Neighbouring countries are selected for exemplifying distinct circumstances: one where it can be expected that Hungary acts as host, one where the opposite situation is likely to occur (i.e. Hungary as off-taker), and a third subcase where it remains unclear at the start how cross-border cooperation may affect future RES investments.

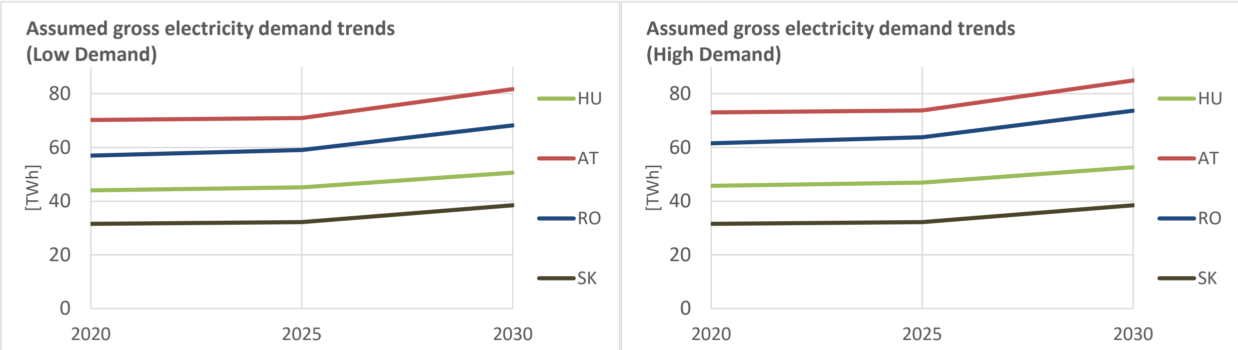
The whole assessment is undertaken twice, assuming two distinct energy demand trends, i.e. a low and high demand trend scenario.[5] This aims for acknowledging the uncertainty in future demand growth due to distinct underlying drivers – i.e. on the one hand energy efficiency measures as well as economic degrowth

5

or stagnation may cause a decline in consumption for default electricity uses, and, on the other hand, a strong growth can be expected due to increased sector coupling where e-mobility is assumed to increase as well as the use of electricity in heating and cooling and for industrial purposes. Assumed gross electricity demand trends for selected assessed countries are shown in Figure 4-1 below. As applicable from this graph, in the low demand case we assume for the whole period 2015 to 2030 an average yearly growth of gross electricity consumption by 1.1% for the whole region and by 1.4% for Hungary. That leads to a gross electricity consumption of about 275 TWh by 2030 (compared to 233 TWh in 2015) for the whole region. The corresponding average yearly growth rate for the high demand case is 1.4% for the whole region and 1.6% for Hungary, leading to a regional gross electricity consumption in size of 287 TWh in 2030.

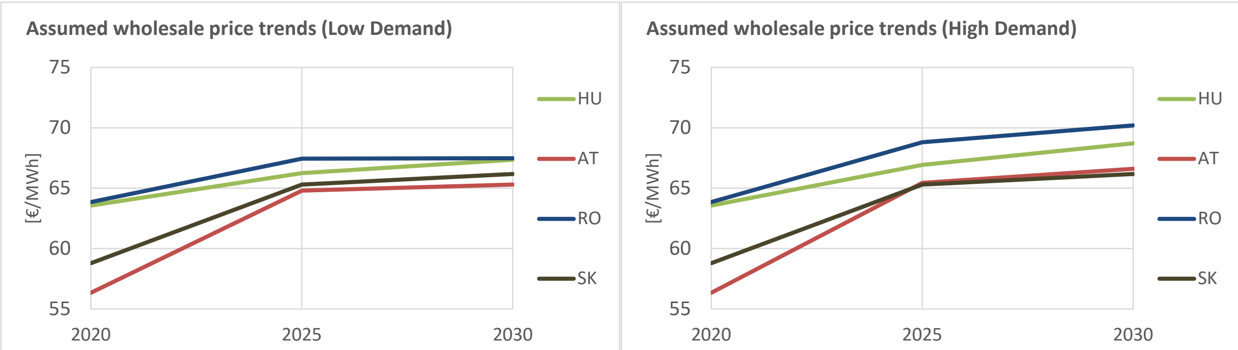
The differences in electricity demand between both cases affect also the price developments in the wholesale electricity market. Here Figure 4-2 illustrates our assumptions taken in that respect, building on analyses performed by use of REKK's EEMM model in the course of a recently completed study focussing on the electricity sector under a comparable geographical scope (Szabo et al. (2020)).

Figure 4-1: Assumed gross electricity demand trends: Low Demand (left) vs High Demand case (right).



Source: Own assessment based on PRIMES reference (EC, 2016).

Figure 4-2: Assumed wholesale price trends: Low Demand (left) vs High Demand case (right).



Source: Own assessment based on Szabo et al. (2020).

4.2 Results from the model-based analysis

This section is dedicated to discuss the results of our model-based analysis concerning the possible implementation of cross-border RES auctions between Hungary and selected neighbours.

4.2.1 Step 1: "Bubble exercise" – a joint regional RES market of Hungary and its neighbours

We start with results derived from the first of our two-step approach. Under this "bubble exercise" a joint regional RES market of Hungary and its neighbours is conditioned, assuming that postulated national 2030

RES targets shall be met jointly across the whole focal region. As outlined above, complementary to these Cooperation scenarios we assume under reference conditions the continuation of current practices where RES policies are designed and implemented to meet given national RES targets using only domestic resources. Key results on the expected use of renewables under both distinct policy cases are shown in Table 4-1 for both underlying demand trends (Low vs High Demand case). Under both demand trends an identical picture arises concerning the impact of RES cooperation. Croatia and Romania act as host countries, meaning they achieve a surplus in RES-E generation compared to their own targeted 2030 RES-E deployment whereas the remainder of countries, including Austria, Hungary, Slovakia and Slovenia, act as off-taker, counting on (virtual) RES-E imports to achieve a match with planned 2030 RES use.

Table 4-1. Key results on 2030 RES-E deployment from the "bubble exercise" (i.e. a joint regional RES market of Hungary and its neighbours)

Comparison of results: (Cross-border RES) **Coooperation vs. Reference** (national RES-E target fulfillment)		Bubble analysis						
		Austria	Croatia	Hungary	Romania	Slovakia	Slovenia	Region
	Unit	AT	HR	HU	RO	SK	SI	Region
Targeted RES-E share 2030 (according to NECPs)		92.0%	63.8%	20.0%	49.4%	27.3%	43.3%	
		Low Demand case (i.e. low demand growth due to limited economic growth and/or strong energy efficiency)						
Generation balance								
RES-E share 2030								
Reference	%	92.0%	65.0%	20.0%	52.7%	27.3%	43.3%	55.1%
Cooperation	%	89.0%	69.9%	15.2%	56.0%	25.6%	42.8%	54.1%
Deviation (Coop minus Ref) +...Export, -...Import (both virtual)	%	-3.0%	4.9%	-4.8%	3.2%	-1.8%	-0.4%	-0.9%
RES-E generation 2030								
Reference	TWh	75.20	12.00	10.13	35.96	10.52	7.34	151.16
Cooperation	TWh	72.76	12.90	7.70	38.16	9.85	7.27	148.64
Deviation (Coop minus Ref) +...Export, -...Import (both virtual)	TWh	-2.44	0.90	-2.43	2.20	-0.68	-0.07	-2.52
	Exchange volumes:		3.1 TWh					
		High Demand case (i.e. high demand growth due to strong sector coupling and enhanced electrification)						
Generation balance								
RES-E share 2030								
Reference	%	92.0%	65.2%	20.0%	50.9%	27.3%	43.3%	54.7%
Cooperation	%	87.8%	70.1%	16.6%	56.0%	25.8%	42.7%	54.3%
Deviation (Coop minus Ref) +...Export, -...Import (both virtual)	%	-4.2%	4.9%	-3.4%	5.1%	-1.6%	-0.6%	-0.5%
RES-E generation 2030								
Reference	TWh	78.14	13.00	10.55	37.46	10.52	7.56	157.24
Cooperation	TWh	74.57	13.98	8.75	41.22	9.92	7.46	155.91
Deviation (Coop minus Ref) +...Export, -...Import (both virtual)	TWh	-3.58	0.98	-1.80	3.76	-0.60	-0.10	-1.33
	Exchange volumes:		4.7 TWh					
Evaluation: Cooperation characteristics		AT	HR	HU	RO	SK	SI	
Low Demand case								
High Demand case								

Source: Own analyses (Green-X modelling)

The "bubble exercise" allows for identifying most interesting bilateral cooperation cases from a Hungarian perspective. The analyses performed and results derived within this subsequent step are discussed in the follow-up section.

4.2.2 Step 2: "Pairing cases" – assessment of bilateral cross-border auctions between Hungary and selected neighbours

Building on the lessons learnt from the "bubble exercise", we analyse under this step three different subcases of bilateral RES cooperation between Hungary and a neighbouring country. Neighbouring countries are selected for exemplifying distinct circumstances: one where it can be expected that Hungary acts as host, one where the opposite situation is likely to occur (i.e. Hungary as off-taker), and a third subcase where it remains unclear at the start how cross-border cooperation may affect future RES investments.

Table 4-2: Key results on 2030 RES-E deployment from the "pairing cases" (i.e. bilateral cross-border auctions between Hungary and selected neighbours)

Comparison of results: (Cross-border RES) Coooperation vs. Reference	Unit	Pairing cases								
		Hungary HU	Austria AT	Region	Hungary HU	Romania RO	Region	Hungary HU	Slovakia SK	Region
Targeted RES-E share 2030 (according to NECPs)		20.0%	92.0%		20.0%	49.4%		20.0%	27.3%	
Low Demand case (i.e. low demand growth due to limited economic growth and/or strong energy efficiency)										
Generation balance										
RES-E share 2030										
Reference	%	20.0%	92.0%	64.5%	20.0%	52.7%	65.9%	20.0%	27.3%	23.2%
Cooperation	%	21.1%	91.3%	64.5%	13.8%	53.0%	63.9%	19.5%	27.9%	23.2%
Deviation (Coop minus Ref) +...Export, -...Import (both virtual)	%	1.0%	-0.7%	0.0%	-6.2%	0.2%	-2.0%	-0.5%	0.6%	0.0%
RES-E generation 2030										
Reference	TWh	10.13	75.20	85.33	10.13	35.96	46.09	10.13	10.52	20.66
Cooperation	TWh	10.66	74.63	85.29	7.51	37.18	44.68	9.89	10.76	20.66
Deviation (Coop minus Ref) +...Export, -...Import (both virtual)	TWh	0.53	-0.57	-0.04	-2.63	1.22	-1.41	-0.24	0.24	0.00
High Demand case (i.e. high demand growth due to strong sector coupling and enhanced electrification)										
Generation balance										
RES-E share 2030										
Reference	%	20.0%	92.0%	64.4%	20.0%	50.9%	67.3%	20.0%	27.3%	54.7%
Cooperation	%	22.1%	90.7%	64.4%	15.2%	52.9%	65.8%	19.9%	27.5%	23.1%
Deviation (Coop minus Ref) +...Export, -...Import (both virtual)	%	2.1%	-1.3%	0.0%	-4.9%	2.0%	-1.5%	-0.1%	0.2%	-31.6%
RES-E generation 2030										
Reference	TWh	10.55	78.14	88.69	10.55	37.46	48.01	10.55	10.52	21.07
Cooperation	TWh	11.65	77.04	88.69	7.98	38.94	46.92	10.47	10.60	21.07
Deviation (Coop minus Ref) +...Export, -...Import (both virtual)	TWh	1.11	-1.11	0.00	-2.56	1.47	-1.09	-0.07	0.07	0.00

Evaluation: Cooperation characteristics	HU	AT	HU	RO	HU	SK
Low Demand case						
High Demand case						

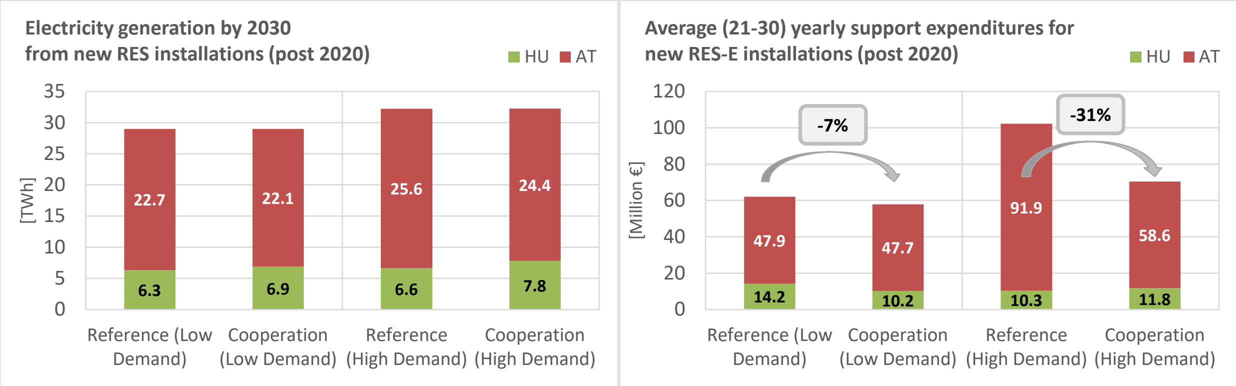
Source: Own analyses (Green-X modelling)

Key results on the expected use of renewables in 2030 under both distinct policy cases are shown in Table 4-2 for both underlying demand trends (Low vs High Demand case). Similar to the "bubble exercise", under both demand trends an identical picture arises concerning the impact of RES cooperation, here analysed at bilateral and not multilateral level. Three pairing cases are modelled and discussed in further detail below.

Case 1: Cross-border RES auctions between Hungary and Austria: Hungary acting as host

Thus, as applicable from Table 4-2, a bilateral RES cooperation between Hungary and Austria by means of implementing cross-border RES auctions for meeting planned 2030 RES-E deployment jointly reveals that Hungary would then act as host country while Austria is becoming an off-taker for parts of the planned RES uptake in the forthcoming decade. Details on the impacts of this bilateral RES cooperation on the deployment of new RES installations in the electricity sector within the years up to 2030 and on the corresponding policy cost, here exemplified by means of support expenditures, are shown in Figure 4-3 below.

Figure 4-3: Impacts of cross-border RES auctions between Hungary and Austria on the deployment of new RES-E installations (post 2020) (left) and on the corresponding support expenditures (right)



Source: Own analyses (Green-X modelling)

Thus, the results indicate that only a minor part of the RES uptake in the electricity sector within the forthcoming decade is affected by cross-border RES cooperation, and that the impact is stronger if a high demand growth may arise:

- In the Low Demand case 2030 RES-E generation from new installations (post 2020) increases from 6.3 to 6.9 TWh in Hungary, implying a rise by 0.6 TWh. Accordingly, RES-E generation from new plants declines from 22.7 to 22.1 TWh in Austria.
- Under the High Demand case the changes in country-specific RES-E generation are stronger – i.e. 1.2 TWh instead of 0.6 TWh (according to the Low Demand case).

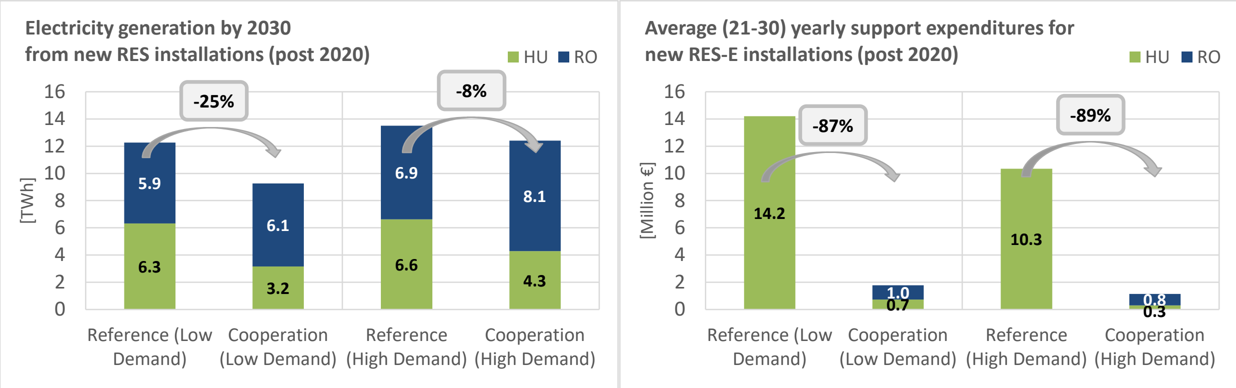
When comparing the policy cost, i.e. support expenditures to refinance the uptake of renewables in both countries until 2030, between the Cooperation and the Reference scenarios, it is getting clear that RES cooperation leads to savings, cf. Figure 5-3 (right). Similar to RES-E deployment, also these savings in terms of policy cost, are significantly stronger under a high demand growth: cost savings at the aggregated level[6] amount to 7% in the Low Demand case and to 31% in the High Demand case.[7] A closer look at the distribution of cost among both countries indicates that specifically Austria would largely benefit from the assessed cross-border cooperation.

[6] Aggregated level means here the two assessed countries together.
[7] Cost savings shall mean here the decline in average (2021-2030) yearly support expenditures dedicated to new RES (installed post 2020) when comparing the Cooperation and the corresponding Reference scenario.

Case 2: Cross-border RES auctions between Hungary and Romania: Hungary acting as off-taker

Similar to above, Table 4-2 provides an overview on the impacts on RES-E deployment of a bilateral RES cooperation between Hungary and Romania. Implementing cross-border RES auctions for meeting planned 2030 RES-E deployment jointly would lead here to a strong reallocation of investments in renewables across the border. Thanks to the low RES-related policy ambition of Romania, causing that under Reference conditions 2030 RES-E deployment would be above the planned/targeted one, Romania can now offer parts of its surplus in renewable electricity to Hungary, acting as off-taker under both assessed demand cases. Figure 4-4 informs on the impacts of this bilateral RES cooperation, specifically on the deployment of new RES installations in the electricity sector within the years up to 2030 (left) and on the corresponding policy cost, here exemplified by means of support expenditures (right).

Figure 4-4: Impacts of cross-border RES auctions between Hungary and Romania on the deployment of new RES-E installations (post 2020) (left) and on the corresponding support expenditures (right)



Source: Own analyses (Green-X modelling)

As outlined above, the results reveal that the forthcoming RES uptake in the electricity sector of both countries is stronger affected by cross-border RES cooperation compared to the previous case 1:

- In the Low Demand case 2030 RES-E generation from new installations (post 2020) declines from 6.3 to 3.2 TWh in Hungary, implying a significant drop by 3.1 TWh. The increase of RES-E generation from new plants in Romania is however less pronounced – i.e. one can see a rise from 5.9 to 6.1 TWh, indicating that Romania can expect a strong surplus in RES-E generation under Reference conditions. This shows the low policy ambition of Romania when postulating 2030 RES-E deployment targets in its NECP.
- Under the High Demand case a similar trend is observable but the changes in country-specific RES-E generation are generally less pronounced. As shown in Figure 4-4 (left), the decline in domestic RES-E generation in Hungary is now smaller – i.e. 2.3 TWh instead of 3.1 TWh (under Low Demand). Due to the lower surplus in RES-E generation under Reference conditions one can see now however a stronger increase in RES-E generation in Romania – i.e. according to the High Demand case 2030 RES-E generation is 1.2 TWh higher in the Cooperation scenario (compared to Reference) whereas in the Low Demand case that increase amounts to only 0.2 TWh.

A comparison of the impact on policy cost, i.e. support expenditures to refinance the uptake of renewables in both countries until 2030, between the Cooperation and the Reference scenarios indicates strong savings that may arise from cross-border RES cooperation. At the aggregated level of both countries together these cost savings amount to 87% in the Low Demand case and to 89% in the High Demand case. [8] A closer look at the distribution of cost among both countries indicates that now Hungary would largely benefit from the assessed cross-border cooperation. Romania would, in turn, face higher policy cost compared to Reference but the Romanian economy may benefit largely from the increase in RES-related investments as well as the

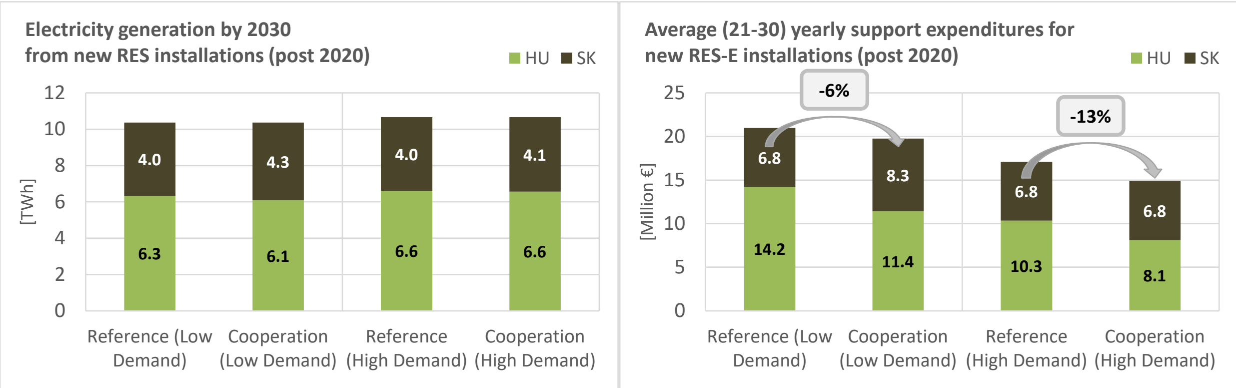
[8] Cost savings shall mean here the decline in average (2021-2030) yearly support expenditures dedicated to new RES (installed post 2020) when comparing the Cooperation and the corresponding Reference scenario.

additional income for domestic RES-E producers.

Case 3: Cross-border RES auctions between Hungary and Slovakia: negligible impacts on RES-E deployment accompanied by moderate savings in policy cost

Similar to above, also for the third cooperation case Table 4-2 offers an overview on the impacts on RES-E deployment of a bilateral RES cooperation, now between Hungary and Slovakia. Implementing cross-border RES auctions for meeting planned 2030 RES-E deployment jointly would cause here only a negligible reallocation of investments in renewables across the border when looking at 2030 deployment of new RES installations (post 2020). There are however savings in policy cost that come along with cross-border RES auctions as outlined below. Figure 4-5 indicates the impacts of this bilateral RES cooperation, specifically on the deployment of new RES installations in the electricity sector within the years up to 2030 (left) and on the corresponding policy cost by means of support expenditures (right).

Figure 4-5: Impacts of cross-border RES auctions between Hungary and Slovakia on the deployment of new RES-E installations (post 2020) (left) and on the corresponding support expenditures (right)



Source: Own analyses (Green-X modelling)

As outlined above, the results reveal that the forthcoming RES uptake in the electricity sector of both countries is only to a negligible extent affected by cross-border RES cooperation:

- In the Low Demand case 2030 RES-E generation from new installations (post 2020) declines from 6.3 to 6.1 TWh in Hungary, implying a small drop by 0.2 TWh. In turn, RES-E generation increase from 4.0 to 4.3 TWh in Slovakia.
- Under the High Demand case the changes are significantly smaller in magnitude when looking at 2030 RES-E generation as shown in Figure 4-5 (right). The reallocation of RES-E deployment amounts by then to only 0.05 TWh, causing a negligible increase in Slovakia and the corresponding decline in Hungary.

A comparison of the impact on support expenditures to refinance the uptake of renewables in both countries until 2030 between the Cooperation and the Reference scenarios reveals however moderate savings that may arise from cross-border RES cooperation. At the aggregated level of both countries together these cost savings amount to 6% in the Low Demand case and to 13% in the High Demand case. [9] A closer look at the default distribution of cost among both countries indicates that Hungary would strongly benefit from the assessed cross-border cooperation. For Slovakia policy cost are not affected in the High Demand case whereas in the Low Demand case a moderate cost increase is applicable. This calls for additional measures/agreements to be taken between both countries to achieve a fair distribution of the resulting overall cost savings.

[9] Cost savings shall mean here the decline in average (2021-2030) yearly support expenditures dedicated to new RES (installed post 2020) when comparing the Cooperation and the corresponding Reference scenario.

4.2.3 Summary of results and findings

Summing up, the modelling works performed indicate that cross-border RES cooperation between Hungary and its neighbours may lead to a reallocation of RES-E investments across national territories accompanied by partly significant savings in terms of policy cost.

As the pairing case analysis has shown, whether Hungary acts as host or off-taker depends on the partner country chosen:

- If Austria acts as the pairing twin for cross-border RES auctions it can be expected that Hungary will become a host, and both countries may benefit from the policy cooperation.
- In the case of Romania the opposite trend is observable: thanks to the low policy ambition postulated in its NECP Romania would become now the host for the forthcoming RES-E uptake, causing, in turn, a significant decline of RES-E investments in Hungary. Overall policy cost savings at the aggregated level are under this cooperation case strong in magnitude.
- A cross-border cooperation with Slovakia would cause negligible changes in RES-E deployment accompanied by moderate savings in terms of policy cost at the aggregated level, calling for further agreements to be taken to end up with a win-win situation for both participating countries.

5 Model-based assessment of financing aspects in RES auctions

This chapter informs on the modelling works undertaken to illustrate the impacts of recent changes in RES financing conditions across Europe. Within the AURES II project a detailed survey has been undertaken concerning the cost of capital for renewable energy projects as described in Roth et al. (2021). This brief model-based assessment complements the above, aiming to showcase the impacts of related changes in RES financing on RES support and on the future market uptake of renewables.

Below we start we a brief summary of key outcomes and findings of the detailed survey undertaken. Next to that we inform on the steps taken to incorporate the financing data into our modelling, describe the approach taken for the impact indication and, finally, present the outcomes of our modelling works.

5.1 Brief summary of the survey of renewable energy financing conditions in Europe.

The AURES II report on renewable energy financing conditions in Europe (cf. Roth et al., 2021) was framed within the discussions on the costs of capital for renewable energy projects and the implementation of auctions for renewable energy sources in Europe. The report includes qualitative and quantitative insights intended to contribute to a better understanding of renewable energy financing and energy and climate policy in the EU. Concerning the approach taken and the observed changes in RES financing conditions Roth et al. (2021) states:

> *"Several interviews were conducted between September 2019 and April 2020 and the results show that there is still a considerable gap between EU Member States regarding their Weighted Average Cost of Capital (WACC) for wind and PV projects, where some countries as Germany and Denmark present low WACC values and countries as Greece and Latvia have instead higher costs of capital. However, compared to 2014 levels, most of EU countries reduced their WACC dramatically, which is a positive sign for a further deployment of RE projects. The analyses showed that multiple reasons are behind the observed WACC decreased. Not only lower interest rates, technology improvements and lower country risks explain the downward trend, but other surprising reasons are also part of the picture. Interviewed experts pointed out to three phenomena. First, capital is not only raised from EU sources, but it is also flowing from international sources, such as North America and Asia markets, which could generate spill over effects in EU countries where the costs of capital are higher than the costs of international investments. Second, the non-standard monetary policy of the European Central Bank after the 2008 crisis has resulted in abundant capital which triggered lower loan fees and increased competition for business cases. Third, new market players, such as energy intensive companies, are under policy and regulatory pressure to green their portfolios and are consequently shifting to RE through, for example, corporate Power Purchase Agreements, which could add more competitive pressure on the market."*

Below we illustrate observed changes in RES financing conditions at the example of onshore wind. Here, as stated above, a significant decline in weighted average cost of capital (WACC) was observable when comparing the outcomes of the survey undertaken throughout 2019 to 2020 with a previous one, done in 2014. In this context, Figure 5-1 provides an overview on current (2019) WACC trends for wind onshore projects across MSs whereas Figure 5-2 illustrates the changes in WACC figures over time, i.e. from 2014 to 2019, for the EU and at MS level.

Figure 5-1. Overview on WACC for wind onshore in 2019 (Source: Roth et al., 2021)

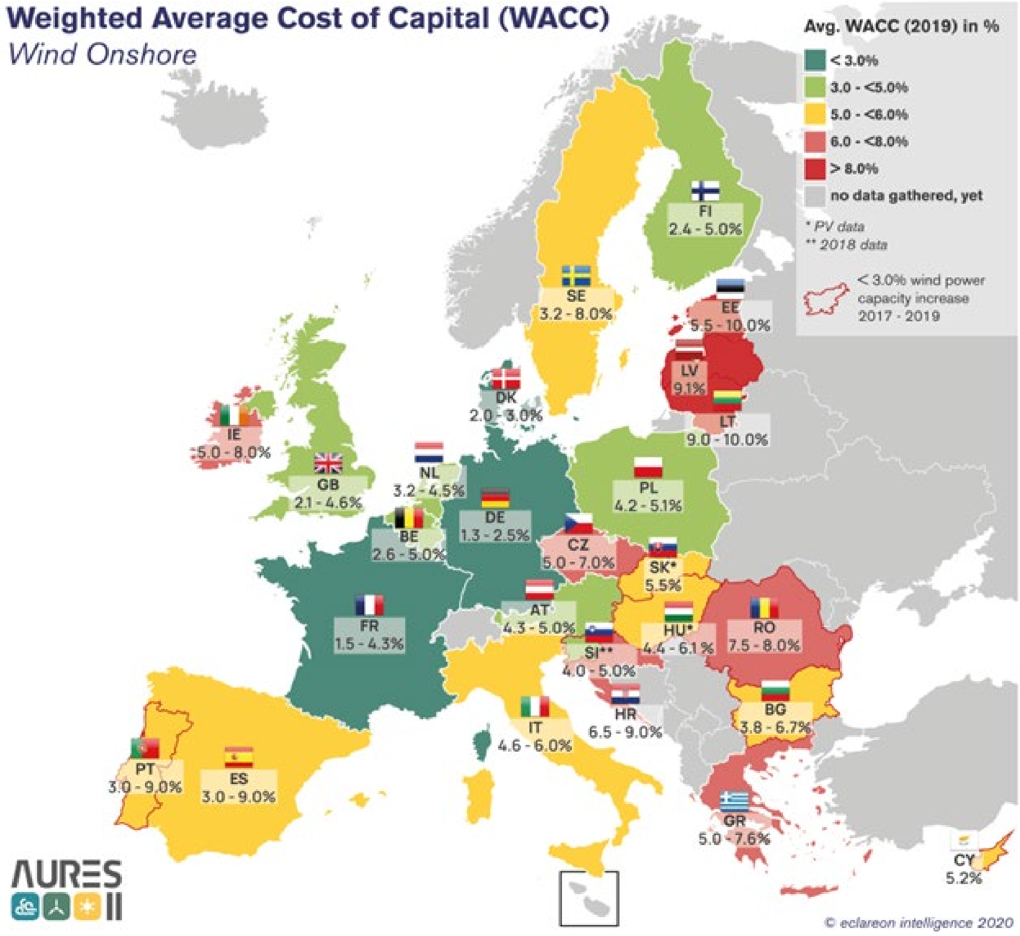
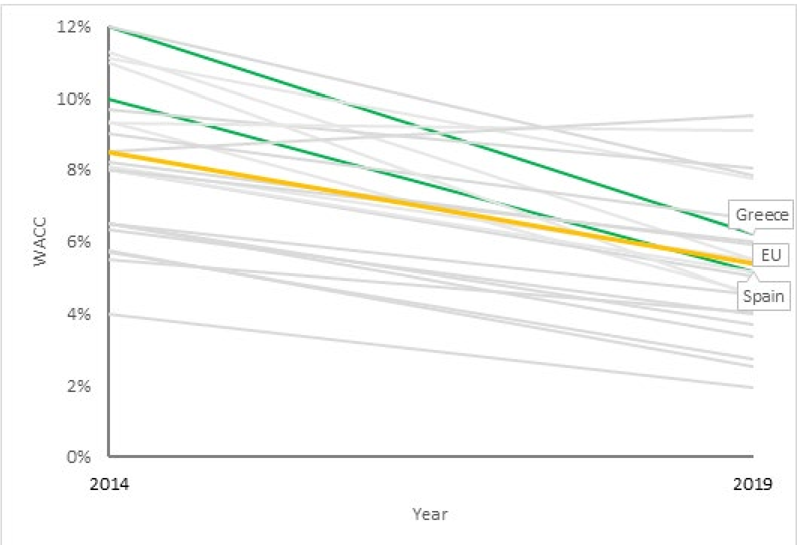


Figure 5-2. WACC historic trend for onshore wind (2014-2019) (Source: Roth et al. (2021))



5.2 Approach and assumptions taken for this model-based assessment

5.2.1 The applied model: the RES policy tool Green-X

This analysis builds on modelling works undertaken by use of TU Wien's Green-X model, a specialised energy system model with a sound incorporation of various RES policy approaches and of underlying framework conditions, incl. various aspects related to RES financing.

More precisely, *Green-X* is an energy system model, developed by TU Wien, that offers a detailed representation of the potentials and the related technologies of various renewable energy sources (RES) in Europe and in neighbouring countries, including all EU Member States and all Contracting Parties of the Energy Community. It aims at indicating consequences of RES policy choices in a real-world energy policy context. 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.

5.2.2 Concept and assumptions

The modelling concept applied was to build on previous analysis concerning the planned RES uptake within Europe's electricity sector until 2030, specifically the analysis related to European and cross-border RES auctions as presented in chapter 3 of this report.

The approach and assumptions taken is described in further detail below.

- As first preparatory step we then incorporated assessed changes in financing conditions across EU MS's (cf. Roth et al., 2021) into the model's database, using WACC data for wind onshore – a key technology for Europe's electricity supply today and in future. The WACC's identified for wind onshore served to define the country-specific risk and the changes in average cost of capital at EU level. Doing so allowed us to rebuild in the model the outcomes of the WACC survey in accordance with the model's logic.
- For illustrating the impact of identified changes in RES financing conditions we modelled two distinct cases related to financing conditions: One case using the *new WACC data* (in accordance with Roth et al., 2021) and a sort of reference case that built on *prior WACC data* as identified in the DIACORE study during 2014, cf. Held et al. (2014).
- Since prior modelling works within this project have shown that a key parameter that determines the future RES uptake and related costs are electricity market prices, we applied for sensitivity purposes two trend scenarios of future electricity price developments, i.e. a high and low energy price case, as discussed in chapter 3 of this report.

Figure 5-3 complements the above, informing the scenarios defined and related assumptions taken

The outcomes of the modelling undertaken served to showcase the impact of (improved) financing conditions on the financial support needed to finance the required RES uptake from a top-down perspective as shown in the subsequent section of this report.

Figure 5-3. Overview on the applied scenarios definition

- **Policy concept / RES ambition**:

  Assessing the feasibility of **planned RES use by 2030** in accordance **with current national planning** (2019/20-edition of National Energy Climate Plans (NECP). We thereby reflect a "European perspective" implying a proactive use of RES cooperation mechanism, serving to allocate RES investments across the whole EU cost effectively.

- Sensitivity analysis on **future wholesale price trends**:
  - High price case
  - Low price case
- Two distinct cases on **RES financing conditions**:
  - **New WACC data**
  - Prior WACC data
    (as reference to illustrate the impact of identified changes)

5.3 Results and conclusions

Below we exemplify the impact of identified changes in RES financing conditions across Europe on RES-related support expenditures and corresponding impacts on consumer cost as well as on the expectable RES uptake if current national energy and climate planning is followed.

Figure 5-4. Comparison of average (21-30) support expenditures for RES electricity, expressed in specific terms as premium per MWh electricity consumed (left), and of expected RES shares in gross electricity demand by 2030 (right) according to analysed scenarios (Source: Green- X modelling)

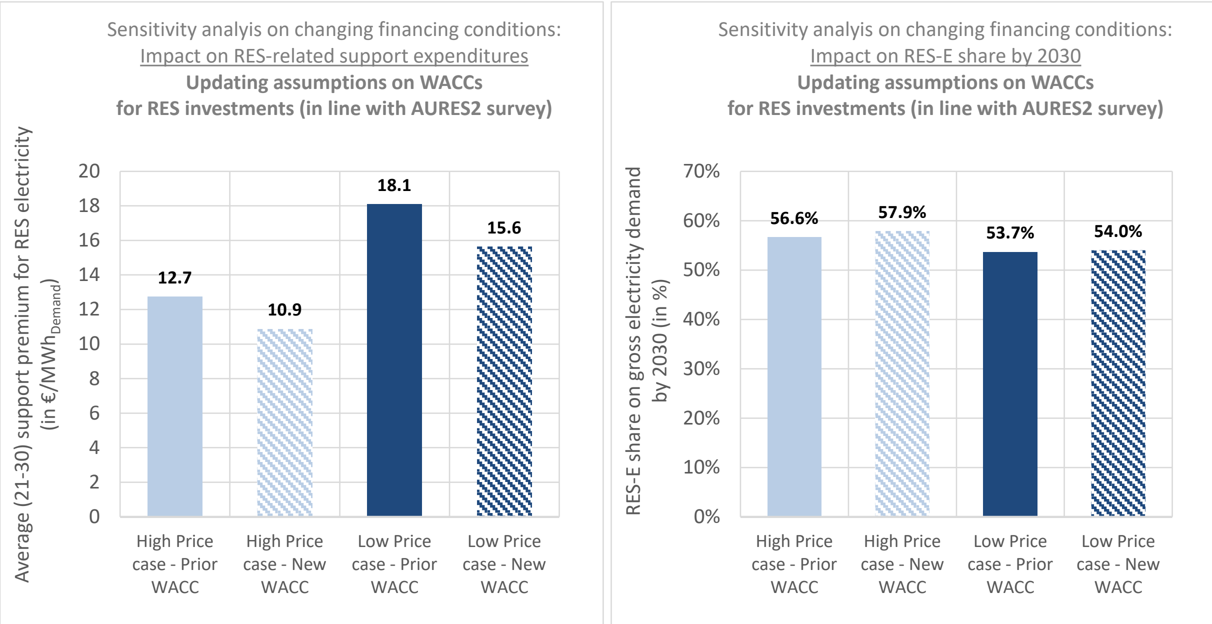
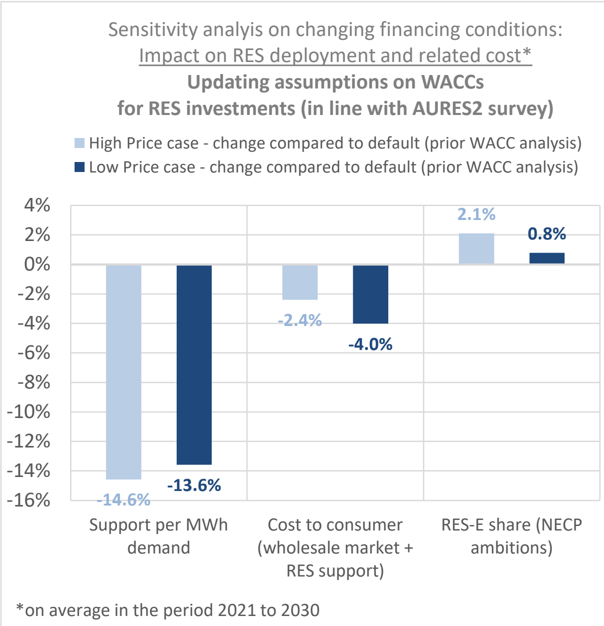


Figure 5-5. Identified changes in RES support expenditures (left), cost-to-consumer (middle) and the stipulated RES uptake (RES-electricity demand shares – right) caused by the change in RES financing conditions (Source: Green- X modelling)



As starting point, Figure 5-4 shows at EU level the impact of new WACC data on the future development of RES-related support expenditures (left) and on the 2030 RES uptake in the electricity sector (right – in accordance with national planning concerning the underlying RES ambition). Next to that, Figure 5-5 summarises identified changes from using new WACC data (compared to prior WACC data), expressing the changes in percentage points concerning RES support expenditures, RES-related cost-to-consumer[10] and the stipulated RES uptake in the electricity sector by 2030. This is then complemented by Figure 6-24, indicating the price-driven changes in RES-related support expenditures and in cost-to-consumer at EU level on average throughout the whole assessment period 2021 to 2050.

Results of this brief model-based analysis show that the analysed change in financing conditions has a strong impact on RES-related support expenditures – here a decline by 13.6% to 14.6% is observable across the whole assessment period 2021 to 2030. Consumer can benefit from that since the decline of the height of RES-related support payments reduces also their electricity bills. According to our modelling the direct impact on cost-to-consumer is a reduction of these in range of 2.4% to 4%. The improvements in financing conditions for RES may increase and simplify future RES investments and lead to a further stipulation of future RES deployment.

Final remark: The current crisis across Europe driven by the Russian invasion of the Ukraine may counteract identified recent improvements in financing conditions. Within Europe but also globally an increase in interest rates is currently discussed and, thus, can be expected in the near to mid future, as a reaction to the political and economic crisis and as a way to combat inflation.

[10] Our comparison of cost impacts on electricity consumer does however not provide the "full picture" since network charges as well as energy-related or general taxes are not taken into consideration. This would however not add value to the scope of our analysis where we aim to assess impacts from electricity market developments and RES-related support requirements, and the overall consequences of these from a consumer perspective.

6 The future of RES auctions – a model-based assessment of long-term trends in a changing electricity system

6.1 Scope and structure of this analysis

It is still uncertain whether the current trend of a market-based RES expansion will continue and whether zero-subsidy auctions and/or PPAs will make a significant contribution to the RES increase needed to meet future European RES targets. One critical factor opposing this trend is the limited ability of the electricity system to integrate variable RES leading to a reduction in market values and thus a reduction in incentives for market-based expansion. The model-based analysis of long-term trends in Europe's changing electricity system as presented in this chapter aimed for shedding light on the above, informing on the need for dedicated RES support in forthcoming years. In practical terms, the quantitative analysis builds on qualitative scenario developments on the future of RES auctions in a changing electricity system (cf. Woodman and Fitch-Roy, 2020), prescribing different electricity market trends related to the future of auctions carried out within AURES II and the accompanying modelling activities as presented in further detail below.

The forward-looking model-based analysis on the need for dedicated RES support also acknowledges recent energy and policy developments, incorporating currently observable high energy prices as a sensitivity analysis to the default modelling that was built using price trends from the latest EU reference scenario as basis. Additionally, the assessment reflects the uncertainty related to the future cost of key options for meeting system flexibility needs, done by modelling wholesale price impacts of high or low prices for green gas in future. Another sensitivity assessment is conducted on the design of RES support and how that may affect RES-related support expenditures and consumer cost.

In terms of structure we start after a brief recap of the policy context with a description of the approach taken, the scenarios defined and key assumptions applied. Results are then presented for the two complementary elements of the assessment: the power system analysis reflecting predefined long-term trends in a changing electricity system, done by use of the open-source energy system model Balmorel, and the RES policy analysis, done by use of TU Wien's Green-X model. This chapter concludes with a recap of the lessons learned and the recommendations on the way forward.

6.2 Policy context

In the last few years, auctions have become the predominant policy instrument for securing and managing RES deployment in Europe. Auctions simultaneously address a number of market failures, including wholesale electricity remuneration rates that are often lower than production costs and prohibitive risk premia associated with volatile wholesale electricity markets. Auctions also protect society from the immediate costs of over-rewarding renewable generators and system costs of uncontrolled RES expansion.

However, the role played by RES technologies is determined by the broader context in which they are embedded, which is likely to change in the coming decades. The value that renewable generators can realise through participating in markets will influence whether RES auctions are appropriate and, if they are, the most suitable design. The value of RES output and therefore the role of auctions may be subject to significant change between today and 2030 and beyond.

In particular, evolutions in market design and network regulation will have a profound effect on the cost of producing and integrating renewable electricity in the future electricity system. The 'routes to market' available to producers of renewable electricity will be determined by the products that can be exchanged and by how costs are allocated among generators, network operators, consumers, taxpayers and others.

For example, the future status of issues such as degree of market liberalisation, grid congestion and constrained output, balancing charges and trading arrangements, as well as the system value of renewables generation, will together define whether or not renewable electricity production can be conducted profitably. The future condition of markets and networks is therefore central to the issue of whether subsidies awarded through auctions (or otherwise) can or should be removed, changed or reduced over time.

At all levels of policymaking discussions about future developments such as the emergence of more local energy markets and a more active management of low-voltage distribution networks have started throughout last years. A newly designed electricity market of the future could be more supportive of renewable technologies than the current, more centralised model, reducing overall system costs and reshaping routes to market for renewable energy. As a result, there are many uncertainties about how future electricity systems may look, and many possible trajectories for the co-evolution of markets, networks and renewable technologies. This task has generated qualitative scenarios described in Woodman and Fitch-Roy (2020) as a way of thinking about the future using these drivers to think about future electricity system development. The aim was to inform debates about what the implications of market and network design and operation might be for the future viability of renewables, and therefore how auctions might evolve over time.

Moreover, a look at this year's (2022) and last year's economic and political developments shows that price increases or price turbulence can currently (as of Spring 2022) be observed worldwide in raw material and energy markets, affecting the energy sector and the whole economy significantly, specifically within Europe. Under current high energy prices, even in the absence of dedicated RES support, investments in RES technologies appear cost-competitive and highly attractive for investors despite of the increase of investment cost triggered by the above. The question remains however how long the period of high energy prices may last and how the trend will continue in forthcoming years. The Russian invasion of the Ukraine and the political, economic and societal crisis driven by that is currently triggering policy debates related to the energy sector at various angles.

- Europe's energy supply vulnerability is seen as a major concern given the strong dependency on energy imports, in particular of natural gas and oil from Russia;
- A social and economic crisis driven by the tremendous increase of energy prices, in particular in gas markets and in the electricity sector, is emerging, triggering policy debates also on aspects like the price setting mechanism in the wholesale power market.

As a consequence of the above, at EU level an increase of the overall RES ambition towards 2030 appears likely, cf. EC (2022), given that renewables together with energy efficiency are key for combating climate change as well as for safeguarding supply security in future. Thus, an increase in the RES ambition may, in turn, affect the need for dedicated RES support, since RES potentials that can be mobilized at short notice appear generally limited.

6.3 Approach and assumptions

6.3.1 The applied modelling system

This analysis builds on modelling works undertaken by the use of TU Wien's Green-X model, a specialised energy system model with a sound incorporation of various RES policy approaches, closely linked to the complementary power system models and the open-source model Balmorel. A brief characterisation of both models is provided in Box 1 below.

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) and expenditures (capital, operation and support expenditures). For assessing the interplay between RES and the future electricity market, Green-X was complemented by its power-system companion, i.e. the model Balmorel. Thanks to a higher intertemporal resolution than in the RES investment model Green-X, Balmorel 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.

Box 6-1. Brief characterisation of the applied modelling system (Green-X in combination with Balmorel)

Green-X is an energy system model, developed by TU Wien, that offers a detailed representation of the potentials and the related technologies of various renewable energy sources (RES) in Europe and in neighbouring countries, including all EU Member States and all Contracting Parties of the Energy Community. It aims at indicating consequences of RES policy choices in a real-world energy policy context. 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.

Balmorel (the BALtic Model for Regional Electricity Liberalisation) is an open-source partial equilibrium model, analysing the electricity and combined heat and power sector on various geographic levels. The analysis of further sectors via sector coupling (e.g. e-mobility, individual heating) is also possible via model add-ons. The model was originally developed by DTU and is now used and further developed by a wide range of institutions within Europe and worldwide, including TU Wien who is conducting also recent extensions in the course of this project. Balmorel is a deterministic bottom-up energy system model that is able to co-optimize energy dispatch and investments via linear (and for some applications mixed-integer) programming. For this, equations on electricity and district heat balance, capacity and energy constraints, production of dispatchable and non-dispatchable units, operational constraints, storage operation, transmission constraints, emission caps, and several more are considered. As a result, the model delivers energy conversion characteristics, fuel consumption, electricity exports and imports, emissions, investments in plants and transmission lines, prices on traded energy, and total system costs.

Figure 6-1. Model coupling between Green-X (energy policy analysis) and Balmorel (power system analysis) for an assessment of RES developments in the electricity sector. (Source: own development)

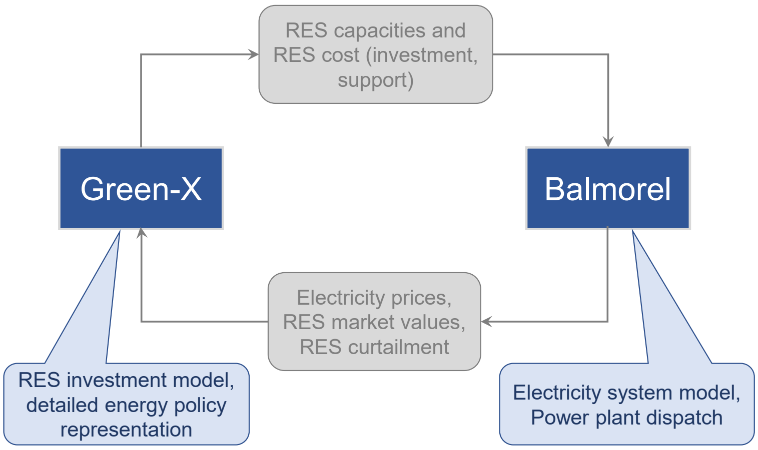


Figure gives an overview on the interplay of both types of models. All models are operated with the same set of general input parameters, however in different spatial and temporal resolution. Green-X delivers a first picture of renewables deployment and related costs, expenditures and benefits by country on a yearly basis (2030 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 (2030, 2040, 2050) serves as input for the power-system analysis done with Balmorel. Subsequently, the applied power system model analyses the interplay between supply, demand, and storage in the electricity sector on an hourly basis for the given years. The output of the power system model Balmorel 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. This feedback loop constitutes the soft model linking between Balmorel and Green X and enables us to combine the strengths of both models: Obtaining RES deployment values that respect existing European and national energy policies, specifically dedicated RES support instruments, as well as the optimization of the dispatch of generation technologies and available flexibilities.

The feedback loop sketched above is run until the results of both models converge. For the calculations of the scenarios carried out in this task, each model run had to undergo two successive iterations of the combined modelling framework.

In its default configuration and described in (Ravn et al., 2001) the partial equilibrium model Balmorel incorporates the power sectors and its interplay with the district heating sector. However, for forward looking scenario analysis of the power sector until 2050, other forms of sector coupling and flexibility options to integrate volatile renewable energy sources will become relevant. Three major trends are expected to rise in prominence until 2050 and are incorporated in our modelling framework via the inclusions of the following Add-Ons:

- Electric vehicles (EV) add-on: Gunkel et al. (2020) It enables to depict the interactions of the power sector with the growing fleet of electric vehicles. Different degrees of flexibility can be provided by the batteries in the EVs via different charging patterns. Under the regime of '*dumb charging*', the EVs simply constitute an additional electricity consumer with a static load profile. With *'smart charging'*, the battery of electric vehicle is charged in times of low electricity prices. Under the *'vehicle to grid'* regime, the batteries can additionally feed in electricity back into the grid in times of low supply.
- Demand Response (DR) add-on: Helistö et al. (2018). It enables to depict the interactions between the power sector and consumers that are able to react flexibly towards times of high and low prices and to shift or curtail their demand accordingly. The two type of consumers that can provide this flexibility and that are incorporated in our scenario assessments are industrial consumers as well as operators of large scale heat pumps for district heating.
- Hydrogen (H2) Add-on: Bermúdez et al. (2021) Given a load profile for hydrogen demand, this add-on enables the optimal investment and dispatch of electrolysis capacities and hydrogen storage facilities. By shifting hydrogen production in times of low electricity prices, the coupling of the power sector with the hydrogen and the derived synthetic fuel market allows for a greater integration of variable renewable energy. The add-on also enables the storage of energy via the intermedium of hydrogen and the consequent recovery of the electric energy via the fuel cell technology.

The specific extent to which these flexibility options are actually deployed, varies in the modelled scenarios as described in section 5.3.2.

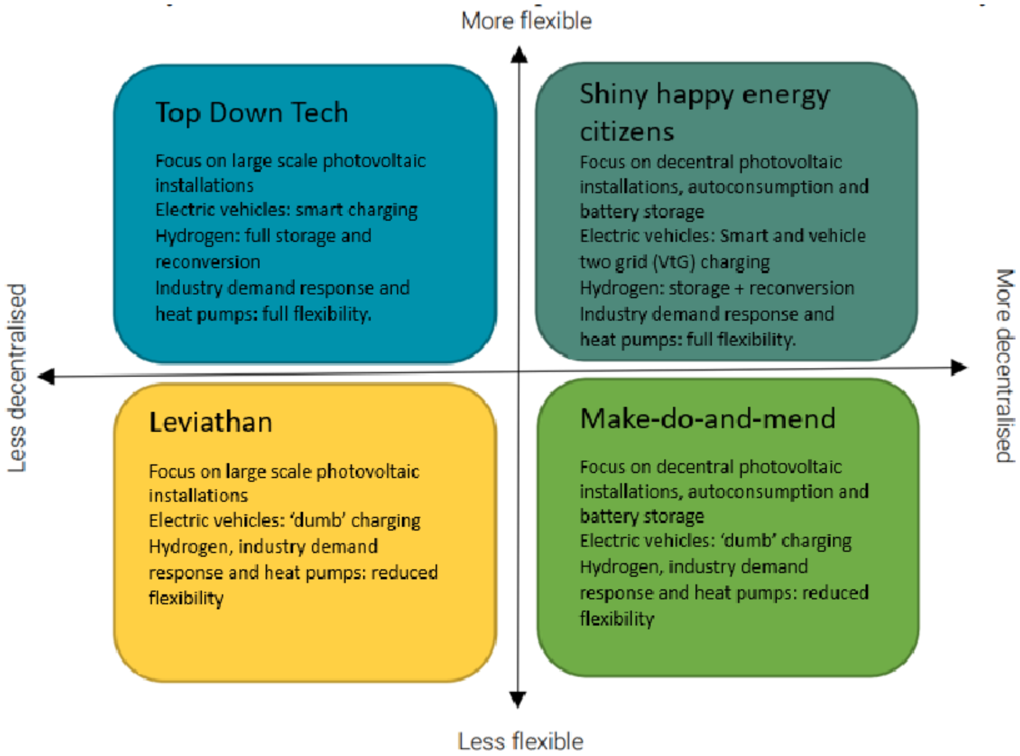
6.3.2 Scenario definition

As mentioned above, this quantitative analysis builds on qualitative scenario developments on the future of renewable energy auctions in a changing electricity system – in particular on the qualitative scenarios and pathways derived by Woodman and Fitch-Roy (2020).

Those qualitative scenarios developed describe plausible visions of EU electricity markets and networks in the period 2030 to 2050 based on the variation of two key trend parameters, i.e., the level of flexibility available in the system as well as the level of decentralization. In the course of this analysis, the possible future socio-economic and –political conditions from the four qualitative scenarios, namely "Top Down Tech", "Shiny happy energy citizens", "Leviathan" and "Make-do-and-mend", were translated into quantifiable scenarios characterized by specific assumptions and technical parameters. This enables us to assess in a consistent manner long-term trends in a changing electricity system and related impacts on the need for dedicated RES support, specifically the role of auctions for RES.

The outcomes of our translation of the qualitative scenarios derived by Woodman and Fitch-Roy (2020) into quantifiable ones to be incorporated into our modelling are illustrated in Figure and described below.

Figure 6-2. Scenarios of a changing electricity system across Europe. (Source: own development based on Woodman and Fitch-Roy (2020))



"Top Down Tech": The narrative for this scenario contains "*the top-down planning at the national and European levels allows significant flexibility through sector coupling, e-mobility and electrification of heat services. Smart consumer appliance technology and advanced data analytics allows significant demand-side response and large-scale markets are able to accurately value a range of system services" (***Woodman and Fitch-Roy, (2020)). We translated this narrative by setting a strong emphasis on large-scale photovoltaic installations. This is done by limiting the self-consumption privilege that some decentralised and small-scale PV producers currently benefit from. Electric vehicles are able to charge their batteries in times of low electricity prices yet do not feed electricity back into the grid. For the hydrogen market, industrial demand response and heat pumps, we enable our model to optimise in the full range of the derived potentials.**

Shiny happy energy citizens: The narrative for this scenario contains that "*technological innovation is accompanied by a shift in governance as participation by consumers and citizens increases towards the ideals of 'energy democracy'. The boundaries between the supply-side and the demand-side of the electricity market are blurred by the rise of widespread prosumerism, with domestic participation across storage, transport, heat and generation." (***Woodman and Fitch-Roy, (2020)). We translated this narrative by setting a strong emphasis on prosumage and thereby on decentralised PV. This is done by expanding the self-consumption privilege for small scale PV installations to all EU countries. Prosumers thus see a much higher value of their self-produced electricity, e.g. the retail price instead the wholesale price. Furthermore, the expanded deployment of decentral photovoltaic is coupled with an equivalent amount of electric storage capacity. This reflects the current trend that more and more prosumers combine their PV installation with a battery storage, not only to increase the share of auto-consumption but also in a spirit of autarky to increase their independence from the large suppliers. Analogical to the "Top Down Tech" scenario, electric vehicles are able to charge their batteries in times of low electricity prices. However, here they can also feed electricity back into the grid. For the hydrogen market, industrial demand response and heat pumps, we enable our model to optimise in the full range of the derived potentials.**

"Leviathan": The narrative for this scenario contains that "*contemporary trends towards energy system decentralisation and greater flexibility stall or are reversed. Governance of (and participation in) the electricity system is dominated by central public and private actors, most likely at the scale of the nation-state."*

(Woodman and Fitch-Roy, (2020)). We translated this narrative by setting a strong emphasis on large scale photovoltaic installations. This is done by limiting the self-consumption privilege that some decentralised and small-scale PV producers currently benefit from. The amount of system flexibility is strongly reduced: Electric vehicles users proceed in 'dumb charging' by simply following a static load profile independent of the actual wholesale price. For the hydrogen market, industrial demand response and heat pumps, the available flexibility is also reduced and we enable our model to optimise only up to 25% of the derived potentials for heat pumps and only up to 10% for industrial demand.

"Make-do-and-mend"*:* The narrative for this scenario contains that "*there is a strong divergence between stuttering technical innovation and very active social innovation. Failure to commercialise key flexibility technologies in the heat, transport and large-scale battery storage sectors, and wide-spread rejection of in-home technologies for enhanced energy management due to concerns about privacy and autonomy constrains the degree of technical system flexibility." (*Woodman and Fitch-Roy, (2020)). We translated this narrative by setting a strong emphasis on prosumage and thereby on decentralised PV. This is done by expanding the self-consumption privilege for small scale PV installations to all EU countries. Prosumers thus see a much higher value of their self-produced electricity, e.g. the retail price instead the wholesale price. Analogously to the "Shiny happy energy citizens" scenario and in order to emphasise the decentral character, the expansion of decentral PV is hard coupled to a battery storage expansion. That implies the availability of small-scale battery storages as an option to store solar energy. Those battery storages are however not optimized from a system perspective but instead from the point of view of the prosumer. For the sake of this modelling activity we assumed that the prosumers are subject to real time pricing electricity tariffs and that therefore those perspectives align. On the other hand the amount of centralised system flexibility is strongly reduced: Electric vehicles users proceed in 'dumb charging' by simply following a static load profile independent of the actual wholesale price. For the hydrogen market, industrial demand response and large-pumps, the available flexibility is also reduced and we enable our model our model to optimise only up to 25% of the derived potentials for heat pumps and only up to 10% for industrial demand.

Additionally, we quantified the models' sensitivities towards increasing gas prices and in order to assess their potential impact on the development of the future electricity system. This is currently of particular importance given the discussions on the requirement to limit the imports of Russian natural gas. Other aspects like the uncertainty concerning future cost/price of carbon-free power system flexibility provision, exemplified by green gas (as representative for green hydrogen or biogas) or details on RES policy design were also analysed by means of sensitivity analyses.

6.3.3 Key input parameters and assumptions

This section provides an overview on key input parameters and assumptions that are common to all scenarios as well as the underlying data.

Before digging into details, we start we a brief recap of these: Key assumptions were to presume the EU Green Deal ambition for 2030, imposing an increase of the overall RES share to (at least) 40% in gross final energy demand by 2030, and a carbon-free electricity system by 2050, implying that RES and nuclear serve to provide the electricity supply in the entire EU by that point in time. Moreover, the assumed full decarbonization of the whole EU economy by 2050 leads to more than a doubling of electricity demand and implies a strong RES uptake in forthcoming years.

In accordance with the qualitative scenario narratives, two key aspects stood originally in focus of the modelling: the level of *power system flexibility* provided in future years, indicating the ability of the power system to react on changes in supply and/or demand, and the degree of *decentralisation*, specifically concerning RES supply thanks to a continuation or phase-out of dedicated incentives for small-scale decentral RES systems.

For the Balmorel model that implied an update of the entire underlying database and expansion for the EU.
While the scenarios differ along the flexibility and decentralization axes – and therefore in many indicators – to enable comparison, we assume the following fundamental outcomes and trends are common to all four:

Decarbonisation ambition

The overall narrative concerning decarbonisation can be summarised as follows:

- The top-line EU targets for energy efficiency, renewable energy and decarbonization are met or exceeded for 2030
- In line with the EU's commitment to achieve 'climate neutrality' by 2050 and the terms of the Paris agreement, Member States' are assumed to collectively reduce greenhouse gas emission by at least 95% compared to 1990 levels by 2050;
- It is assumed that popular support for climate policy, including energy policy, is strong and growing between now and 2050 as the manifestations of climate change become increasingly apparent – as a consequence, 'political will' to enact climate policy is adequate to fulfil the goals above

As a consequence of the above, within all scenarios the assumption is taken that a full decarbonisation of the energy system – zero CO_2 emissions –, and in particular of the power system is achieved until 2050 at EU level. In general terms, this has strong implications on future technology choices (e.g. fossil CCS is no viable generation option in the power sector, as it is not fully zero-carbon) and on energy market developments.

To achieve the full decarbonisation within our stylised energy system representation, a strong increase in carbon prices is assumed in modelling (69, 212 and 529 $€_{2020}/tCO_2$ for the years 2030, 2040 and 2050).

Electricity demand

The assumed full decarbonization of the whole EU economy by 2050 leads to more than a doubling of electricity demand by 2050 compared to today. Due to a lack of cost-effective carbon-free alternatives sector coupling is predominant and strong electrification of heating, industry and transport acts as a driver for increased electricity demand. For our modelling, default future trends concerning electricity demand were taken from the "Electrification" scenario of the recently completed EC study concerning renewable space heating under the revised RED (cf. Kranzl et al., 2021). These consumption trends can be classified as being in accordance with former studies assessing the impacts of a deep decarbonisation of the whole EU economy, cf. EC (2018) or Crespo et al. (2020).

More precisely, a default final electricity demand per country was given as a restriction to Balmorel. This default final electricity demand comprises the total final electricity demand minus the electricity required for sector coupling via heat supply, electromobility and the production of hydrogen. Electricity demand for the heat supply and electromobility are provided as input parameter to the respective Add-On described in 6.3.1. The part of the hydrogen demand that has to be produced in Europe via electrolysis induces an additional block of final electricity consumption that is however dependant on the electrolysis technology in use and therefore also varies from scenario to scenario.

In consequence the electricity demand resulting from the system optimization in Balmorel may be much higher than the default electricity demand even if one includes the two sector coupling roads via heat pumps and electromobility. Exemplarily for the year 2050, we set a default (final) electricity demand of 4300 TWh as exogeneous input parameter. Yet the modelled final electricity demand at EU27 level well exceeds the 5000 TWh due to the electrolysis of ~ 700 TWh of hydrogen. (with variance on the exact value across electricity system trend scenarios). As stated above, compared to today this implies more than a doubling of electricity demand.

(Fossil) Fuel price trends

Default fossil fuel price trends as illustrated in Table 6-1 are taken from the Global Energy and Climate Outlook 2019 (GECO (2019)). These fuel prices were also at the basis of the EC study mentioned above (cf. Kranzl et al., 2021) where our electricity demand assumptions stem from. Using those fuel price trends thus constitutes a coherent assumption.

While said trends reflect in principle a strong climate ambition on the global level, they might appear moderate in relation to current events on the global market. In consequence, and in addition to the default assumptions also a *high fossil fuel price case* was assessed for sensitivity purposes, cf. Table 6-2. Under that trend natural gas prices as well as prices for other fossil fuels are expected to decline compared to current price peaks but, later on, remain at – compared to default assumptions – higher price levels in the near and mid future. This is currently of particular importance given the discussions on the requirement to limit the imports of Russian natural gas.

Table 6-1. Default fossil fuel price trends (Source: GECO , 2020)

Fuel price trends in $€_{2020}/MWh_{th}$	Natural gas	Coal	Lignite	Oil	Nuclear
2030	10.9	2.8	1.1	13.0	1.0
2040	13.0	3.3	1.1	15.8	1.0
2050	13.9	3.6	1.1	19.2	1.0

Table 6-2. High fossil fuel price trends (used for sensitivity assessment of high fossil fuel prices) (Source: own assumptions based on GECO, 2020)

Fuel price trends (high fossil fuel price scenario) in $€_{2020}/MWh_{th}$	Natural gas	Coal	Lignite	Oil
2030	18.0	4.6	1.8	21.5
2040	20.6	5.1	1.7	25.0
2050	20.8	5.3	1.7	28.8

<u>High uncertainty on future cost/prices for green gas:</u> Please note that in accordance with the guiding principle to head towards carbon neutrality, natural gas is expected to be fully replaced by green gases of renewable origin, including green hydrogen, biogas or other synthetic carbon-neutral gases, by 2050. For this decarbonisation option, representing a key option for the provision of power system flexibility in future years, future cost/prices are highly uncertain. In order to reflect that in our modelling, two distinct price trends were assumed:

- In the (default) high price scenario it was assumed that the price for green gases takes orientation on the price of natural gas plus the cost for related CO_2 emission allowances under the EU Emission Trading Scheme. That price trends reflects a high demand for green gas combined with limited supply options and in consequence limited competition on the supply side of the market.
- In the low price scenario former bottom-up price projections for biogas fed into the gas grid served as basis, reflecting first lessons learned from demo projects in the Netherlands and expert judgements concerning expected future progress.

As applicable in Table 6-3, by 2050, the difference between both price trends is significant: In the (default) high price scenario green gas was assumed to be available at around 155 €/MWh by 2050 whereas in the low price scenario less than a third of that was assumed (i.e. ca. 50 €/MWh).

Table 6-3. Distinct price trends for green gases (i.e. high and a low price scenario) (Source: own assumptions)

Fuel price trends for green gas in $€_{2020}/MWh_{th}$	High price scenario	Low price scenario
2030	68.9	55.2
2040	94.7	52.5
2050	155.3	49.8

Grid expansion

As default we presume a strong expansion of the power system infrastructure in future years, specifically of the transmission grid. The net transfer capacities, that are an exogeneous input parameter for our power system modelling with Balmorel stem from the ten year network development plan 2020 (TYNDP2020) from ENTSOE (2021). In order to ensure comparability between our scenarios that focus on the supply side of the power sector, for all four of our scenarios we rely on the NTCs derived from the Distributed Energy (DE) scenario. This scenario is compliant with the 1.5° C target of the Paris Agreement and that presents a decentralized approach to the energy transition. While it presents such a decentralized approach it also entails the largest expansion of NTCs of all the TYNDP scenarios and therefore does not pose restrictions to our scenarios on the less decentralized axis. The current TYNDP2020 includes NTCs for 2020, 2030 and 2040, however not yet for 2050. It is assumed that for 2050, the NTCs remain at their maximum potential. The full NTC data set that was used for our modelling can be found in our data repository (see below on data availability).

Technology cost trends

The general data source for technology cost trends in the energy sector was the ASSET study (cf. De Vita et al., 2018), reflecting assumptions used in the EC's own energy and climate modelling done by use of the PRIMES modelling system.

For RES technologies a different approach was used as described in Box 6-2 below.

Box 6-2. Approach used in Green-X on modelling technological learning of RES technologies

Thus, for most RES-E technologies, the future development of investment cost is based on technological learning. Two key parameters determine the development of investment cost of a certain RES technology: the deployment & the learning rate.

Assumptions on future RES deployment:

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 RES deployment consists of the following components:

- Deployment within the EU27 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 2020 (IEA, 2020). For the analysis performed within AURES II we make use of the IEA Stated Policies scenario and the technology-specific global deployment indicated therein.

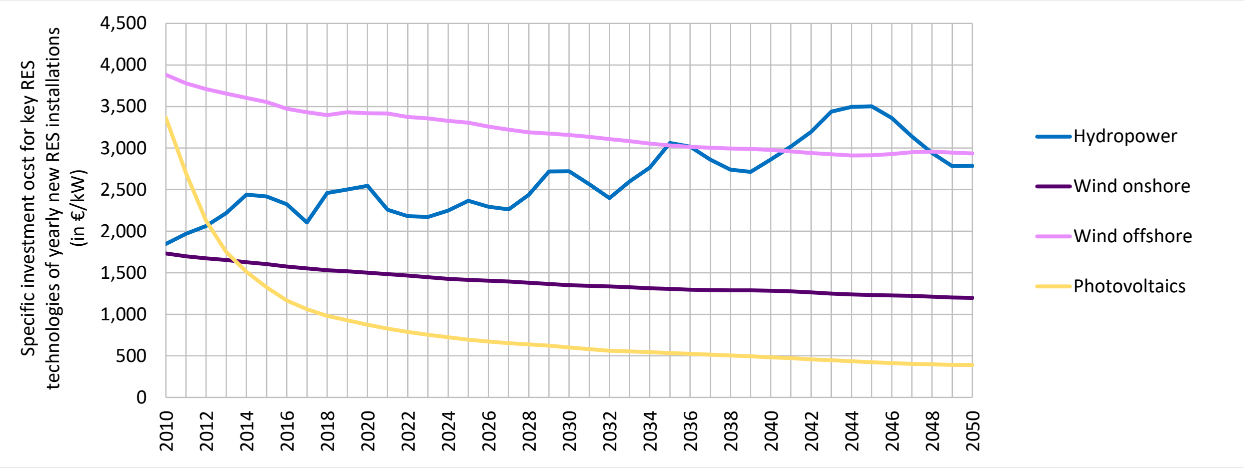
Assumptions on learning rates:

Complementary to future RES deployment, assumptions on future learning rates for key RES technologies (apart from CSP as discussed above) are taken from corresponding recent topical studies and are as follows:

- PV (central and decentral): 20% in the period up to 2025, declining to 17.5% post 2030
- Wind (on- and offshore): 7%
- Hydropower: zero – i.e. no future cost reductions are expected for this mature technology.

Figure 6-3 illustrates the outcomes of the approach taken for RES cost trends where expected cost developments for RES technologies stem from Green-X modelling. The exemplified trends in investment cost refer to a specific scenario (i.e. the "Make-do-and-mend" scenario in the case of (default) high green gas prices) and showcase the specific investment cost for a new RES installation on average at EU27 level in a given year. As applicable from this graph, moderate cost reductions are expected for key RES technologies like solar PV and wind on- and offshore. For hydropower the opposite trend is observable: on average at EU27 level specific investment cost are expected to increase in future years since the available future potential is comparatively limited, specifically for large-scale projects. Consequently, a tendency to invest in small-scale installations is presumed for this technology.

Figure 6-3. Development of specific investment cost of selected key RES technologies at EU27 level, exemplified for the "Make-do-and-mend" scenario in the case of (default) high green gas prices



Final remarks and Data availability

Please note that all cost data presented in this chapter are expressed in real terms, using €$_{2020}$.

For increasing transparency in the approach used and the underlying data and results, key modelling data is publicly available in the Zenodo repository "AURES II, WP8, Dataset Input Data" by Resch, Geipel, Hasengst. (2022)!

6.4 Results

This section is dedicated to inform on the outcomes of our analyses on the future of RES auctions in a changing electricity system. Results are presented for the two complementary elements of the assessment: the power system analysis reflecting predefined long-term trends in a changing electricity system, done by use of the open-source energy system model Balmorel, and the RES policy analysis, done by use of TU Wien's Green-X model.

6.4.1 Results from the power system analysis – assessing distinct long-term trends of a changing electricity system

This section presents the modelling results on the European electricity supply in the various scenarios introduced previously in section 6.3.2. These results were obtained with the open-source energy system model Balmorel, integrated in a modelling system with the RES policy model Green-X through multiple iterations.

Before discussing the results of the power system analysis in detail, it has to be noted that, as outlined under the modelling framework (cf. section 6.3.1), a large part of the renewable energy capacity is already determined by the Green-X model and is given as a restriction to the system optimization within the Balmorel model. This holds for the vast amount of RES electricity capacity at country level from the following technologies: wind (onshore and partly offshore), PV (decentral and utility scale) and CSP, hydro, geothermal, and certain fractions of biomass[11]. Furthermore, nuclear power generation is prescribed in order to depict

[11] In the case of biomass, only the amount of electricity generated from biowaste and solid biomass in the Green-X model was prescribed as biomass in Balmorel. This was because Balmorel had the option to freely optimize the capacity and use of gas power plants using a certain share of biogas (50% in 2030, 75% in 2040 and 100% in 2050).

the policy preferences and the corresponding pathways shown in section 6.3.2.

The electricity demand side is also largely determined by the general assumptions taken as prescribed in section 6.3.2. The total final electricity demand (including sector coupling, i.e., use of electricity for hydrogen production, heat supply, and electromobility) per country is given as a restriction to Balmorel. Nevertheless, the electricity demand resulting from the system optimization in Balmorel may be higher due to e.g. additional hydrogen production for re-electrification or other storage options, a different choice of technology for the heat supply in heat grids, higher curtailment, and transport losses (factors being subject to the system optimization).

This modelling approach means that there remains only a certain fraction of the total electricity supply that can be optimized within Balmorel. In the following, we will call this amount of electricity the “gap”. This gap between the actual total electricity demand and the prescribed generation can be filled with electricity from fossil fuels (taking into regard the assumed CO_2 price), biogas and additional offshore wind. Because of its importance for the interpretation of the model results, we will discuss the gap together with the results.

The installed capacity of the technologies with prescribed generation follows directly from the underlying generation profiles in Balmorel, while for the other technologies it can be optimized by the model.

Before delving into the modelling results right below and in order to facilitate the interpretation of the results, here a quick recap on the modelled scenarios: “Top down” and “Shiny Happy Energy Community” are those scenarios with a high degree of system flexibility, while Leviathan and “Make Do and Mend” are those with only limited flexibility. On the decentralization axis, “Shiny Happy Energy Community” and “Make Do and Mend” represent a decentral approach towards the energy transition while “Leviathan” and “Top Down tech” represent a more centralized approach.

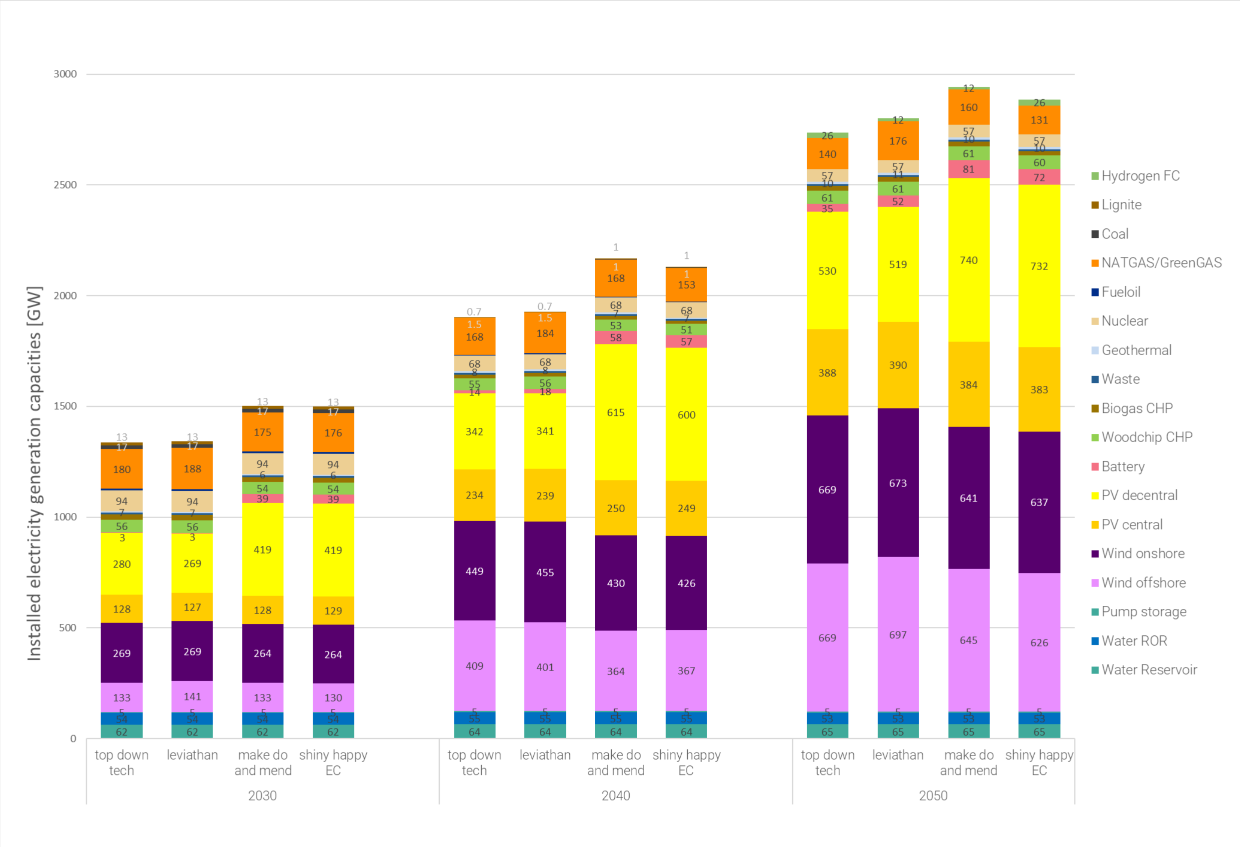
Installed capacities and electricity supply

First, we will look at the technology-specific power plant stock at EU level, that is the cumulated available generation capacity for all available conventional and renewable technologies. Figure depicts those capacities for all modelled years (2030, 2040, 2050) and for all four key scenarios.

Most importantly, we observe that capacities for bituminous coal and lignite are phased out rapidly. Already in 2030 only a fraction of currently available capacities remain in Europe. At this time coal constitutes only around 2% of the overall capacity in Europe, while in 2040 no coal power plant is required to dispatch the necessary electricity supply. The other conventional generation technology, namely gas only slightly decreases its total European fleet size in absolute terms. Exemplarily it falls from 175 GW in 2030 to 160 GW in 2050 in the “Make Do and Mend”. The decrease is similar in the other scenarios. While the total gas capacity thus remains roughly at the same order of magnitude in absolute values, it diminishes significantly in relative terms. Furthermore, the plants themselves are subject to a progressive fuel switch from natural gas towards green synfuels to avoid the high cost for carbon allowances and to fulfill CO2 reduction targets. In total, this leads to a continuous phase out of fossil fuels and a fully decarbonized power sector by 2050!

Next, we observe a strong increase in the total electricity generation capacity following the increase in total electricity demand that is taken as exogeneous input parameter. The general trend for all scenarios contains a doubling of the power plant stock from 1500 GW in 2030 to 3000 GW in 2050. On the one hand this reflects the actual increase in total electricity demand due to electrification of other sectors yet it is also related to the lower amount of full load hours of volatile renewable energy sources compared to their dispatchable counterparts. Regarding the total capacity of dispatchable renewable energy sources, namely geothermal, biomass, biogas and hydro, one can observe that their aggregated value does not vary between the scenarios and that it remains roughly at their 2030 level, with only slight increases until 2050. This is due to the limited potential of those technologies making a stronger expansion unfeasible.

Figure 6-4. Comparison of the technology-specific power plant stock at EU level in all modelled years (2030, 2040, 2050) and for all four key scenarios (Source: Balmorel modelling)



The main increase in total electricity generation capacity is linked to the expansion of photovoltaic and wind power and to their respective sub-technologies decentral small-scale PV and utility size PV as well as onshore and offshore wind turbines. In aggregate terms, the total PV capacity roughly doubles from 2030 to 2050 across all scenarios while the total wind capacity nearly triples. However, while this general trend is common to all four scenarios, it is in relation to the total deployment of solar and wind capacities that we observe the largest differences between the scenarios:

First and foremost, we constate a much larger capacity fleet of photovoltaics in the “Make Do and Mend” and “Shiny happy Energy Community” scenarios compared to the other two. In 2050, the two decentral scenarios contain a total of 1115-1124 GW decentral PV while in the less decentralized the capacity amounts to 909-918 GW. The difference is entirely related to the higher amount of decentral PV, meaning that the amount of utility scale PV is virtually identical across the scenarios. The different value attributed towards the prosumage of decentral PV (e.g. retail price vs wholesale price) as described in the scenario description actually lead to this preference of our models towards the decentralized PV technology. However, it is also noteworthy that the relation between the amount of decentralized PV compared to utility scale PV, changes over time. While in 2030 for each kilowatt peak of centralized PV three kilowatt peak of decentralized PV are installed, in 2050 this factor diminishes to the factor of two! We attribute this shift towards the increased deployment of utility scale PV in the later years to the progressive depletion of the potential for decentral roof top PV. The described higher PV capacity in the decentralized scenarios goes hand in hand with a lower total capacity of wind power in said scenarios. The reduction is thereby equally split between both wind power technologies. Yet due to the higher amount of full load hours of wind compared to PV, the reduction is not as large in absolute terms as the increase in PV capacity.

Another difference between the four scenarios that occurs the axis of centralization is the amount of added battery storage capacity. As described in the scenarios, the expansion of decentral PV was linked to the deployment of home storage options to increase auto-consumption values of prosumers. Consequently, their overall deployment is roughly doubled.

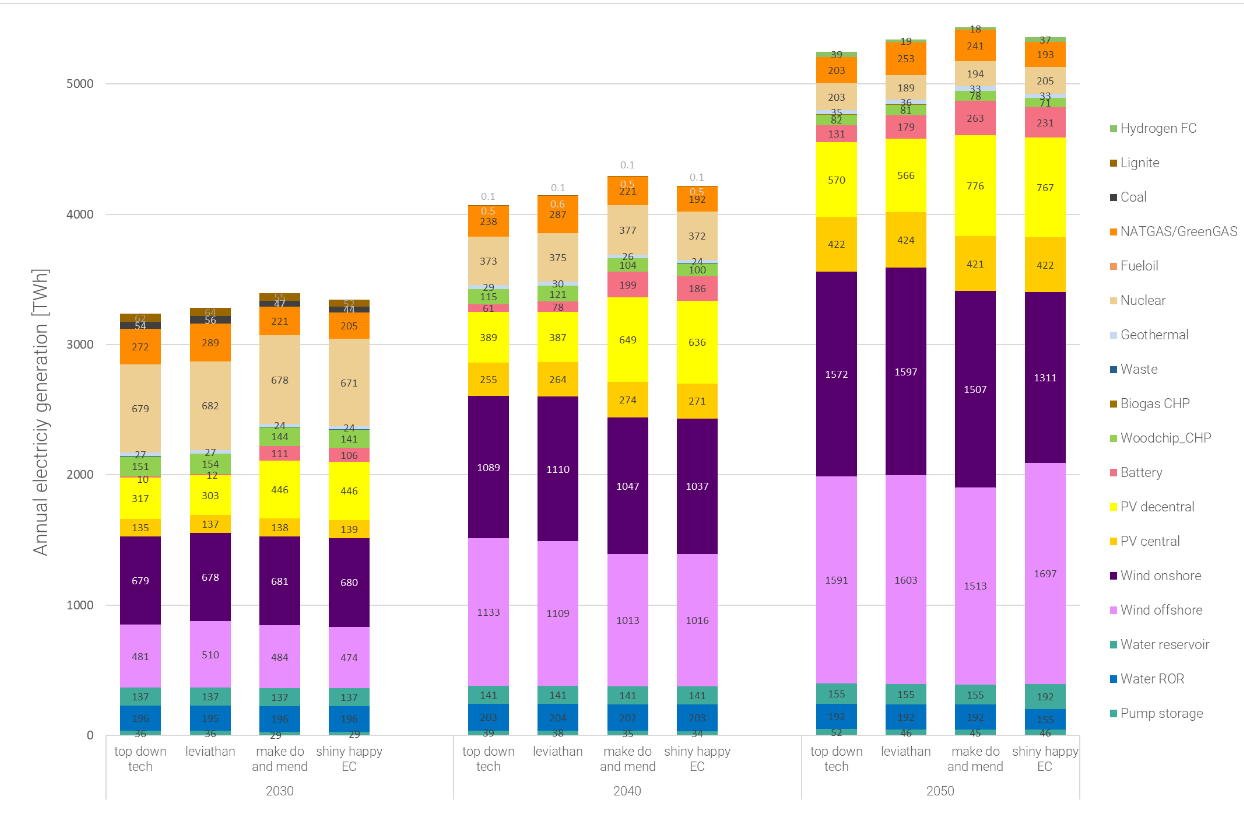
Along the flexibility axis, we observe that the flexible scenarios, e.g., "Shiny happy Energy Citizen" and "Top Down Tech" contain lower amounts of dispatchable gas capacity as well as lower amounts of battery storage compared to their respective counterpart on the same side of the centralization axis. The additional flexibility in these scenarios is characterized by the option to shift demand from time of high prices towards times of low prices, for example via smart charging of electric vehicles, industry demand response or residential heating shifting potentials through the usage of heat pumps. This allows to integrate larger amount of volatile renewable energy, thereby reducing the need for more expensive dispatchable power plants. Also, it can reduce the reliance on lossy electrical storage to level supply intermittencies of renewable energy sources. Lossless shifting of demand compared to the classical battery storage cycle entails a lower total consumption of electricity and thereby a reduced need for total generation capacity.

As for the storage option via the hydrogen road, e.g. electrolysis of hydrogen and reconversion into electricity in times of high demand, we can observe that our model does actually invests into hydrogen fuel cells but only to a very minor degree amounting to less than 1% of total installed capacity.

Next, we will look at Figure depicting the amount of electricity that is actually generated with the power plant park discussed before. Provided that generation is directly linked to the available capacity fleet, the overall picture and trends are alike. However, there are some noteworthy specifics that can be derived from the generation figure.

Most importantly, we observe the prominence of wind power as a share of the total generation. While it cannot surprise given the capacities and the higher full load hours compared to photovoltaic generation, it is nevertheless striking that in 2050 roughly 60% of the total generation stems from on- and offshore wind power.

Figure 6-5. Comparison of yearly technology-specific electricity generation at EU level in all modelled years (2030, 2040, 2050) and all four key scenarios (Source: Balmorel modelling)

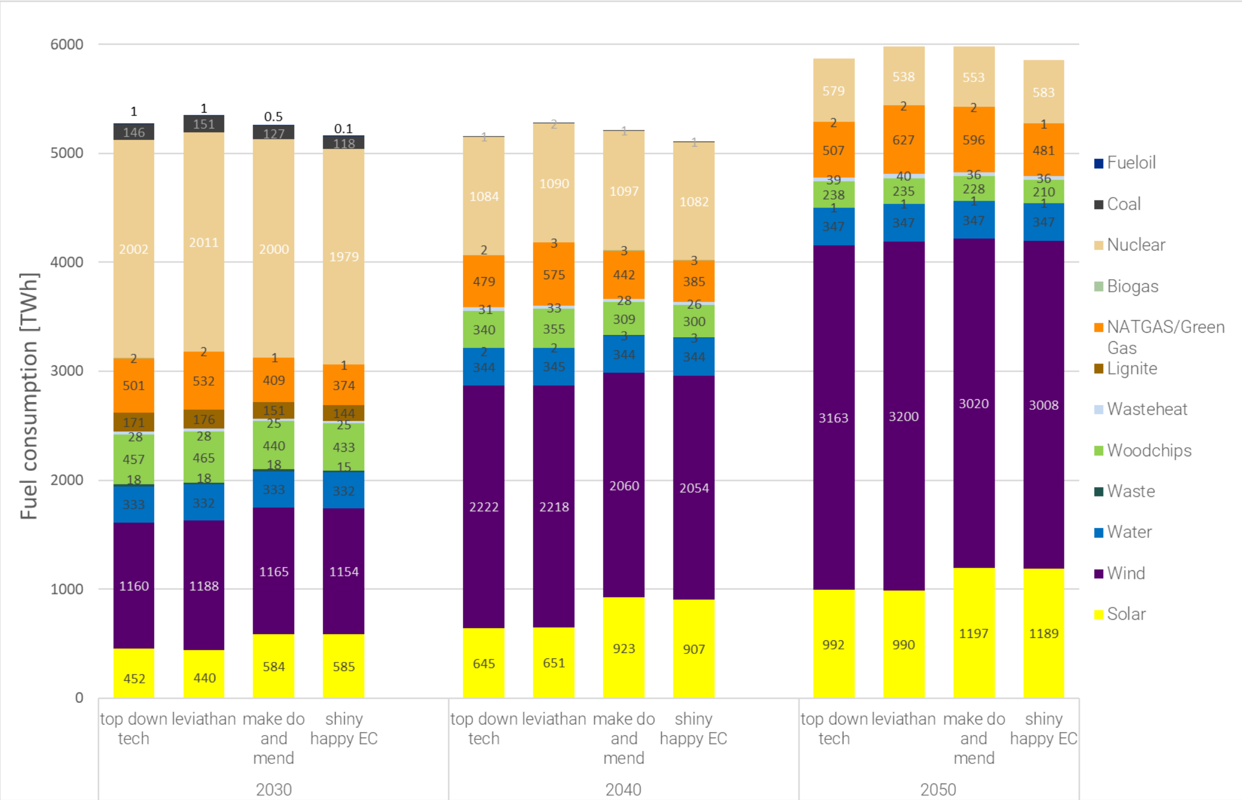


Furthermore, it is noticeable that the dispatchable generation technologies running on either renewable energy carriers such as biomass or (green) hydro carburants are dispatched only in very few hours of the year limiting the full load hours to not more than 2000 hours per year. This means, that our optimization model uses those capacities to fulfill the demand in times of very low renewable infeed and where other flexibility options are either not available or too costly. We constate that dispatchable generation technologies in 2050 will play only a minor role in terms of overall electricity generation yet a critical role as a flexibility provider for matching demand and supply in key hours. The historically used base load providers are no longer used, with the only exception being the remaining nuclear power plants.

One additional aspect that needs to be addressed is the difference in the overall total electricity generation across the scenarios, given that the final electricity demand was exogeneous input parameter identical to all four scenarios. Differences that occur are linked to different flexibility and storage uses that are more or less efficient. The scenario with the highest electricity generation is the "Make Do And Mend" scenario, being the scenario that comprises low system flexibility and as well as a decentralised approach to the transition. This can be explained by the scenario's strong reliance on electric battery storage to match supply and demand. On the one hand, the decentral character and the subsequent high prevalence of electric storage in prosumer households favors a high number of lossy battery storage cycles and on the other hand more efficient flexibility options that can shift demand without losses are not available.

Finally, as a part of this section about the electricity supply results, we look at the European fuel consumption in the four key scenarios and that is depicted in Figure . Here, only the original fuel, e.g. provenance of the electricity is presented and energy carriers and options that solely serve as an intermediate storage like electric batteries or hydrogen are not included.

Figure 6-6. Comparison of fuel consumption (excl. electricity) in the EU's power sector in all modelled years (2030, 2040, 2050) and for all four key scenarios (Source: Balmorel modelling)



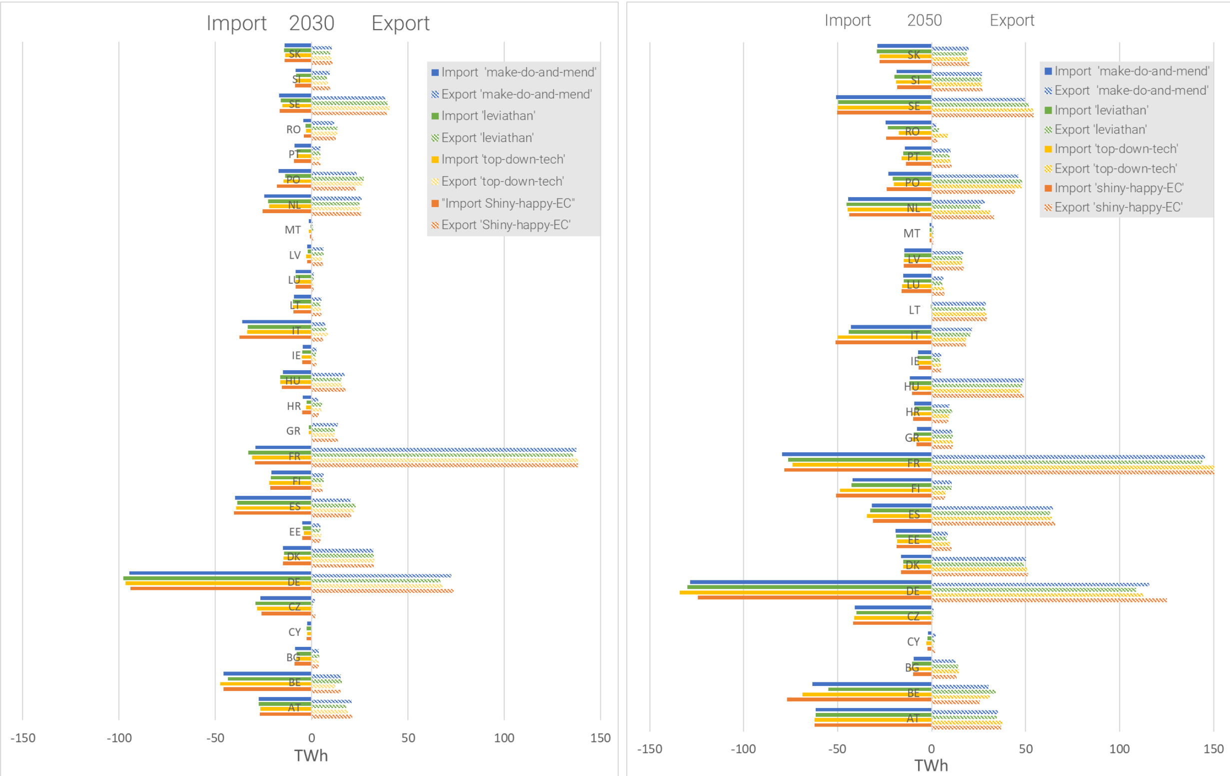
It is most striking that unlike the electricity generation and the capacity size of the European power plant fleet, the fuel consumption does only moderately increases between 2030 and 2050 and even decreases in the decade between 2030 and 2040. Of course, this is due to the progressive phase out of thermal power plants that have an electric efficiency in the range of 0.3 to 0.4 unlike intermittent renewables that are attributed a statistical efficiency of 1. However, it sets into relation the overall need for primary energy that remains surprisingly constant over time and that contradicts the popular narrative that our energy consumption in the power sector is increasing disproportionably quick.

Next, we note the prominent role that nuclear power still constitutes in 2030 and its steep decline in the years thereafter. It drops from a total share of 40% in 2030 to less than 10% in 2050. Then and in contrast to the capacity and generation charts presented above, we observe identical fuel consumption values for the non-dispatchable renewable energy sources and that the differences in fuel consumption between the four scenarios stem solely from differences regarding the dispatchable technologies.

Cross-border electricity exchange

In this section we look at one flexibility option that is critical for the integration of intermittent renewable sources, the levelling of the regionally varying renewable feed-in and load via the cross-border exchange of electricity. As described in the section on input parameters and key assumptions, the net transfer capacities between the European Member States were assumed to be identical across all scenarios. Figure depicts

Figure 6-7. Comparison of cross-border electricity change (in TWh) across EU Member States at a yearly balance in 2030 (left) and 2050 (right) for all four key scenarios (Source: Balmorel modelling)



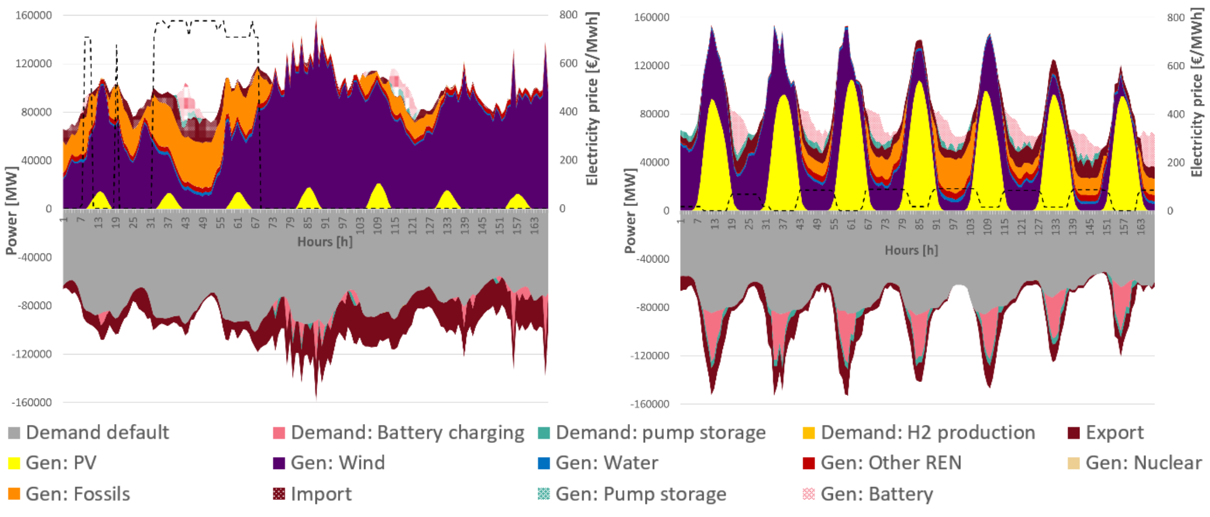
The cross-border electricity exchange across EU Member States at a yearly balance. Given the identical NTC values across the scenarios, it is unsurprising that the energetic flows differ much less across scenarios than across the years. The small differences that are nevertheless occur can be explained by the varying degrees of system flexibility and storage options at the country level. In between 2030 and 2050 however, we can observe that for virtually all member States the total amount of exported and imported electricity significantly increases, thereby taking advantage of the increase in NTC capacities. For example, the electricity imports of Germany increase by more than 30% from 95 TWh in 2030 to 130 TWh in 2050. For most countries, while the absolute value of cross border electricity exchange increases, the relation of imports and exports mostly remains the same. Yet, there are some noteworthy exceptions: Most importantly France, that in 2030 exports significantly more electricity than it imports has a much more balanced relation, even if it still is a net exporter. Lithuania, a country that in 2030 still is a net importer constitutes a purely exporting country and the only one in 2050 that does not import any amounts electricity. This reflects their abundant potentials for dispatchable biomass and hydropower. All the other countries rely on cross border exchange as a tool to match national supply and demand. National unilateralism and potential restrictions on the usage of existing NTC capacities would therefore go to the detriment of an optimal European electricity dispatch and thus to the final electricity consumer.

Hourly dispatch

After having discussed results that were averaged over complete years, we will now look at the electricity dispatch on the hourly level for exemplary time periods. We selected one week in January and one week in June, for which the dispatch in the energy system of Germany and Spain (two of the largest European electricity markets) in the year 2030 and 2050 is shown in Figure 6-8 to Figure 6-11. The figures show the hourly dispatch for the "Make Do and Mend" scenario that can be interpreted as an intermediate scenario given while it does not have access to the full range of flexibility options regarding demand response, heat pumps and electric vehicles, its decentral character provides some level of flexibility via the prosumer electric battery storage installations. Besides the dispatch the chart additionally shows the electricity price in €/MWh on the secondary axis as well as the default and flexibility demand as negative power.

First, we look at the shown winter weeks (w4) for both countries: In Germany already in 2030, the electricity generation is dominated by a substantial amount of wind power feed in. Nearly half of the week, the wind feed in alone is sufficient to satisfy the demand. This supply of renewable electricity at very low marginal generation costs enables also significant amount of electricity exports and leads to wholesale prices of 0€/MWh in more than two thirds of the hours in this week. However, there is a period of time from hour 31 to 70 where we observe very low overall feed in of renewables. Considerable electricity imports as well as the dispatch of conventional fossil plants are required to meet the demand. Spiking prices reaching 600€/MWh are caused by the dispatch of fuel oil plants. Looking at this very week 20 years later with the same renewable generation profile, we observe a general scale up of the wind power production. Solar generation remains however limited even in limited and cannot contribute significantly to meet the demand. Instead, the residual demand in the hours 31 to 70 are covered by mix of electricity stemming from battery storage, hydro power, imports as well as synfuel generation. The usage of fuel oil plants is entirely phased out, leading to a reduced price peak compared to 2030. In 2050, the price is then set by the marginal costs of electricity generation with gas turbines running on green gas.

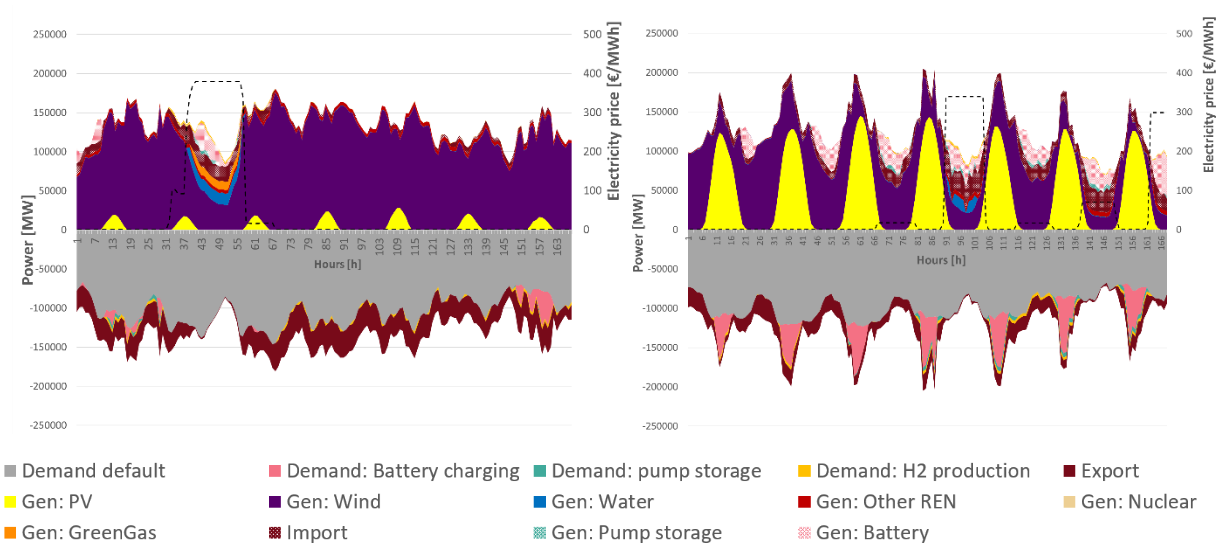
Figure 6-8. Weekly electricity generation in Germany in 2030; on the left week 4 (winter); on the right week 26 (summer) (Source: Balmorel modelling)



In the winter week of Spain in 2030 we observe already considerable amount of renewable feed-in consisting of both solar and wind power. Both technologies provide roughly two thirds of the overall electricity generation. However, wholesale prices never reach the marginal costs of wind and solar meaning that at no hour in this week, this renewable feed in is able to fully met the demand. The respective residual demand always requires the dispatch of some thermal power plants. With prices not exceeding and hovering around

90€/MWh we constate that coal power is the main fuel source for this thermal generation. Twenty years later, the solar generation during the day solar feed even in winter is that high that it enables to charge the electric battery storage systems. This is depicted by demand by the battery demand peaks exceeding the default mand. During the night, the generation is dominated by wind power complemented with dispatchable generation from pump storage and batteries.

Figure 6-9. Weekly electricity generation in Germany in winter (week 4) and summer (week 26) week in 2050 (Source: Balmorel modelling)



Now we look at the shown summer weeks (w26) for both countries: For Germany in 2030 we constate that compared to the respective winter week in 2030, in summer the overall electricity generation is much more volatile, meaning that the difference in generation between day and night is more pronounced. Of course, this is caused by the characteristic solar generation profile. As solar is unavailable during the night, at those hours the residual demand is met by a mix of wind power, fossil fuels, dispatchable renewables as well as battery storage feed in. What is more striking is that on the demand side already in 2030, the solar peak generation exceeds the default demand and is stored mostly into electric battery systems. Accordingly, the wholesale price alternates between 0€/MWh during the day and 100€/MWh during the night. Looking at this same week, 20 years later with the same renewable generation profile we constate that the combined generation of solar and wind energy is sufficient to cover demand is most hours. The use of flexibility options in this week is therefore limited to a few hours of battery generation and some imports during the night. Dispatchable thermal power plants is entirely phased out.

In the summer week of Spain in 2030 we observe similarly to Germany a very volatile generation profile yet with an even stronger focus on solar generation. Once again, we observe demand peaks from the charging of electric batteries to integrate the generation from photovoltaic power plants. During the night, the renewable generation remains insufficient to cover the demand due to the comparatively low feed-in of wind power. Spain therefore relies on the dispatch of a wide range of dispatchable technologies as well as imports. Looking at the same week 20 years later, it is most noteworthy that unlike in 2030, the wind generation is entirely limited to hours during the night. This implies that the potential wind power generation during the day is entirely curtailed and cannot be shifted for use in other hours via flexibility measures.

Figure 6-10. Weekly generation in Spain in winter (week 4) (left) and summer (week 26) (right) in 2030 (Source: Balmorel modelling) (Source: Balmorel modelling)

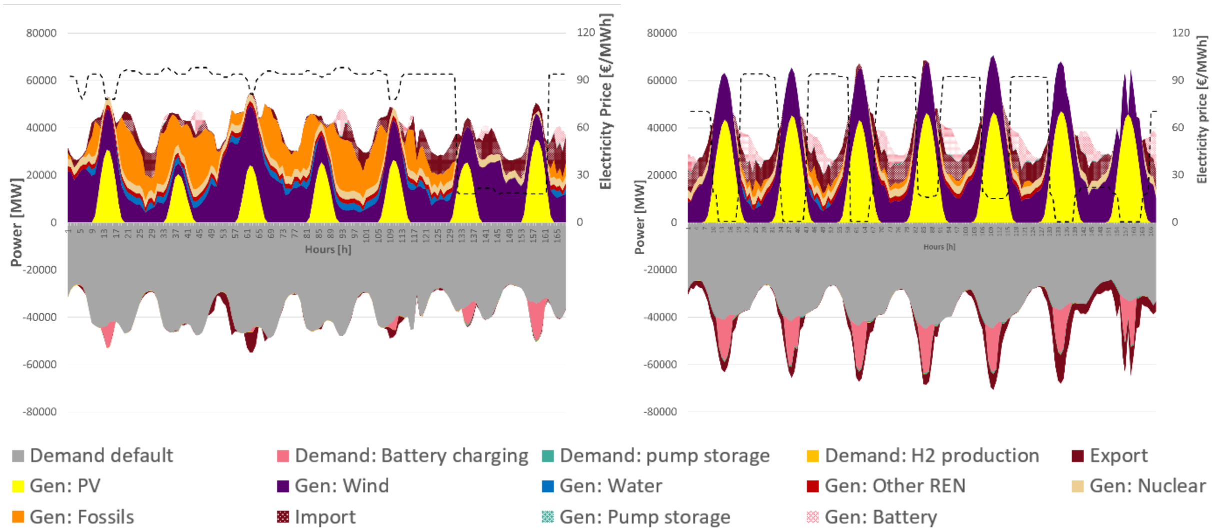
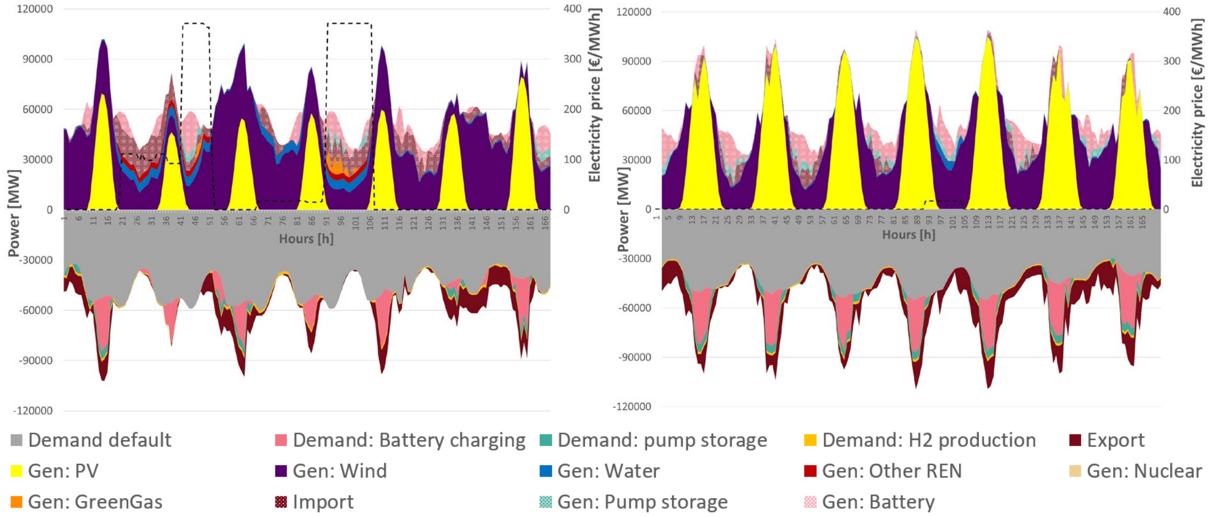


Figure 6-11. Weekly generation in Spain in winter (week 4) (left) and summer (week 26) (right) in 2050 (Source: Balmorel modelling)



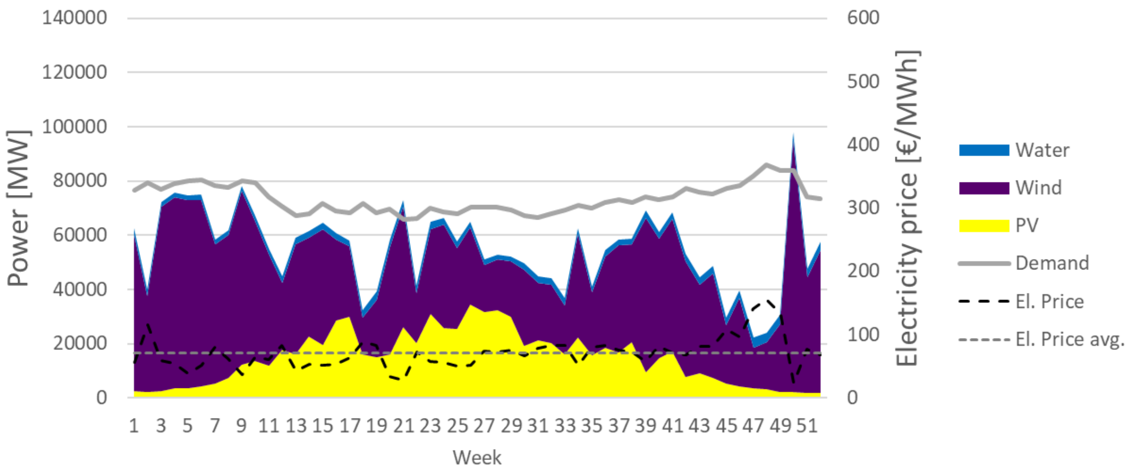
Power system flexibility needs – a closer look at residual load and the impact on wholesale prices

As a part of the results section, we next take a closer look at the overall power system flexibility need. We define this need for power system flexibility as the residual or gap between the non-dispatchable feed in of renewable energy sources compared to the default electricity demand. The default electricity demand is the gross electricity demand before flexibility options are employed. This gap has to be filled by (a combination) of dispatchable electricity generation, demand shifting via storages, demand response or sector coupling or actual demand shedding.

Figure 6-12 to Figure 6-15 illustrate this gap for Germany and Spain and the years 2030 and 2050 respectively. Each figure shows the feed in of non-dispatchable renewable energy meaning solar, wind and run of river as well as the default electricity demand and the (averaged) electricity price. As a disclaimer it must be emphasized however that those charts present values that are averaged over a week, and therefore solely present a reflection on the general trend and the season flexibility requirements. The total flexibility need of the power sector is thus underestimated, yet the general trend depicted in the charts below provides nevertheless some noteworthy insights.

The figures show that for both Germany and Spain in 2030 in nearly all weeks of there is a requirement for dispatchable energy supply or additional flexibility. The largest difference between the default demand and the non-dispatchable renewable supply occurs in week 47 for both countries. This gap goes hand in hand with the highest electricity prices of the year. As a general trend we can observe that the electricity price strongly correlates with the size of the gap, e.g. the absolute amount of required power system flexibility. The main difference between Germany and Spain in 2030 is that in Spain wind and solar energy are more complementary to each other entailing a lower weekly volatility of the RE generation. In consequence the price level in Germany is also slightly higher than in Spain (85€/MWh vs 65€/MWh)

Figure 6-12: Yearly RES generation, electricity demand and wholesale prices for Germany, 2030 (Source: Balmorel modelling)



As for 2050, the figures show that for Germany the non-dispatchable RE generation covers the electricity demand in half of the total weeks of the year, while in Spain it actually exceeds the national demand in three quarters of the year. This makes Spain a net exporter of renewable electricity and leads to very low average electricity prices (50€/MWh). Analogously to 2030, the observed electricity price in both countries correlates with the need for intraseasonal power system flexibility leading to higher prices if the gap between RE generation and default demand increases. In aggregate we observe that the intraseasonal flexibility requirement is much larger for Germany than for Spain explaining the formers higher average electricity prices.

Figure 6-13: Yearly RES generation, electricity demand and wholesale prices for Spain, 2030 (Source: Balmorel modelling)

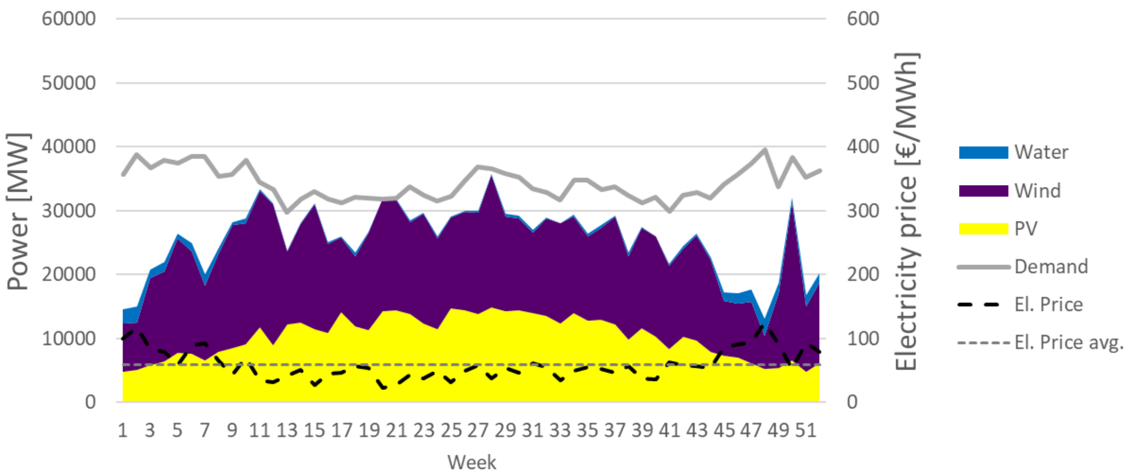


Figure 6-14: Yearly RES generation, electricity demand and wholesale prices for Germany, 2050 (Source: Balmorel modelling)

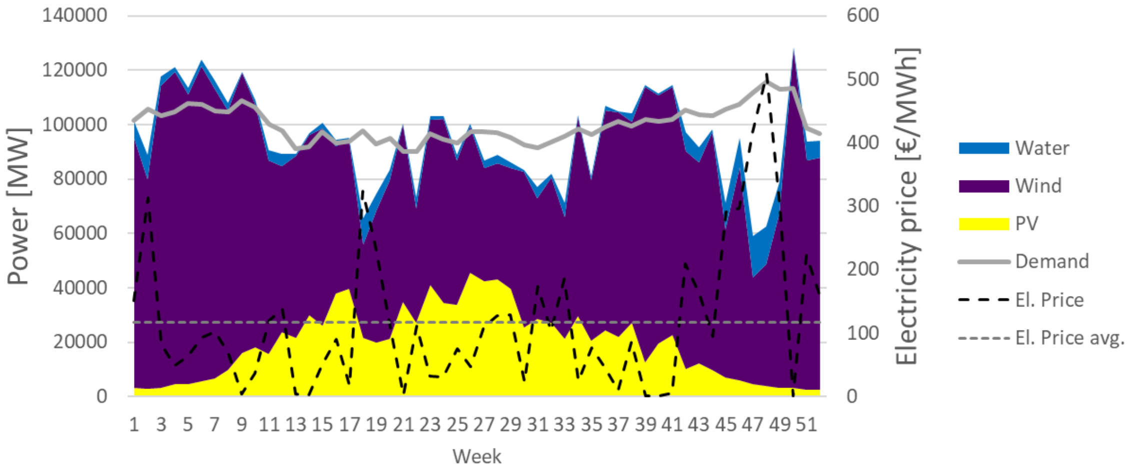
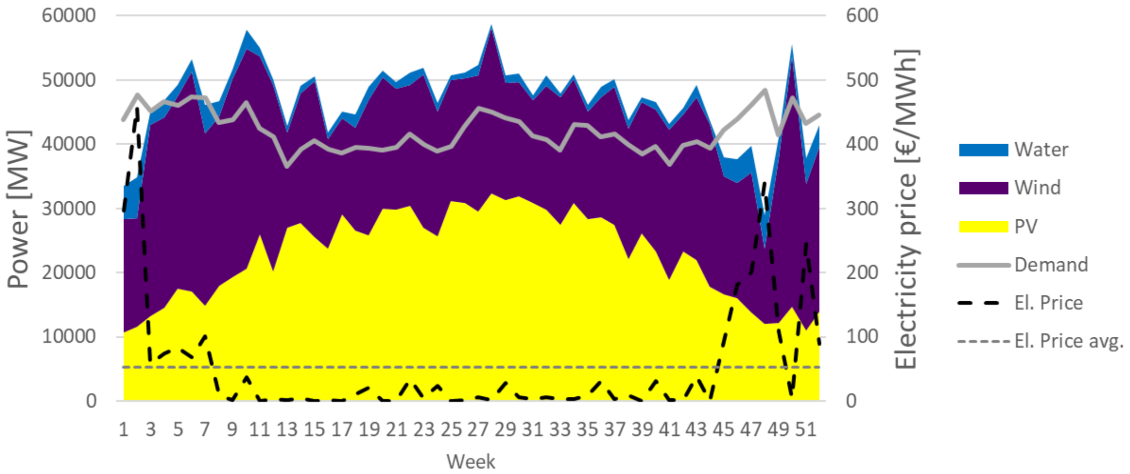


Figure 6-15: Yearly RES generation, electricity demand and wholesale prices for Spain, 2050 (Source: Balmorel modelling)



However, and most interestingly the mentioned correlation between prices and the requirement for system flexibility is less stringent in the case of Germany. There, while the general correlation still holds, we nevertheless observe a few weeks (e.g. W29 & W30) where the wholesale price is below average and close to zero, even though there is a significant gap. In Spain such circumstances do not occur in 2050. We therefore conclude that Germany disposes of a proportionally larger potential that enables it to fill the gap between non dispatchable RE generation and default demand with low marginal cost flexibility options.

6.4.2 Results from the RES policy analysis – assessing the future need for dedicated RES support in a changing electricity system

This section is dedicated to inform on results from the prospective energy policy analysis dedicated to RES, specifically on the impact of a changing electricity system on the need for dedicated RES support. The main tool used for that purpose is TU Wien's Green-X model, a specialised energy system model offering a sound coverage of support instruments for renewables as well as on the available resources and corresponding cost of individual RES technologies within Europe.

As outlined in section 6.3.1, within the integrated model-based analysis Green-X has been complemented by the Balmorel model, serving to analyse the interplay between demand, supply and storage in the power system of tomorrow. Balmorel has been used to identify the gap in system flexibility that needs to be covered by available flexibility options (incl. various storage technologies, flexible supply options including green gas or flexibility options on the demand side) for safeguarding supply security in future years when variable renewables like wind and solar PV times are the dominant generation assets and when fossil fuel based dispatchable generation assets are no longer viable options for doing so. For results on that part of the analysis we refer to the previous chapter.

Below we start with a brief recap on the role of renewables in Europe's electricity system of tomorrow. Complementary to the insights gained from the power system analysis, we take a closer look at the uptake of renewables over time, and on how that is spread across technologies. Subsequently we analyse how that may differ by scenario and which parameters are key influencer in this respect. A large part of the analysis is then dedicated to assess the energy policy needs and the corresponding impacts, informing on expected cost trends and on how large the financing gap may be that needs to be covered by dedicated support instrument for RES technologies. Here RES auctions may serve as predominant tool for providing public support. Subsequently we generally focus on the four trend scenarios concerning electricity system developments that have been identified in the corresponding qualitative analysis undertaken within the AURES II study, cf. Woodman and Fitch-Roy (2020). Later on, we complement these with sensitivity cases concerning key input parameter and assumptions in accordance with the topical focus.

Please note that in general, and if not stated otherwise, all figures and data refer to the aggregated EU27 level (excl. the UK) and all cost data are reported in real terms, using €$_{2020}$ as price basis.

RES uptake within the European Union until 2050

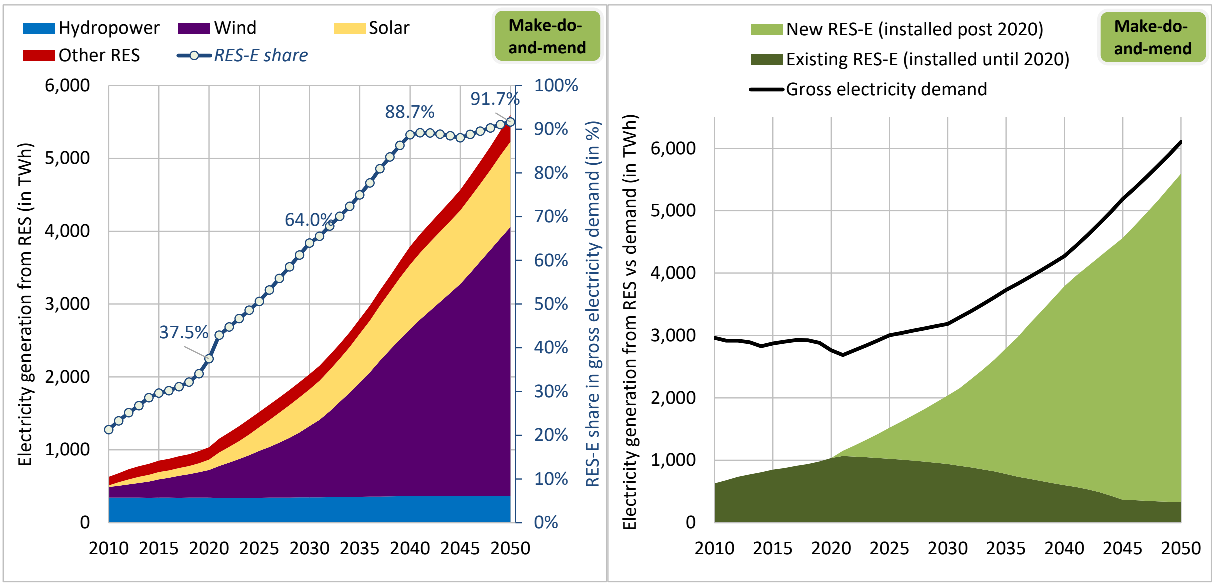
Below we take a closer look at the according to our modelling expected uptake of renewables in Europe's electricity sector. We thereby complement the explanations and insights provided for the power system analysis undertaken by the Balmorel model as provided in the previous section of this report.

As starting point, Figure 6-16 offers a thorough comparison of the historic and expected future development of electricity generation from RES at EU level up to 2050, exemplified for the long-term trend scenario "Make-do-and-Mend". More precisely, the graph on the left provides a breakdown of RES-E generation by technology whereas the graph on the right indicates the age distribution of the power plant stock, distinguishing between existing (installed up to 2020) and new (post 2020) RES installations. Both graphs also show how RES contribute to meet the given demand for electricity by indicating the overall RES share in gross electricity demand (left) or by depicting the demand trend in absolute terms (right).

If we look back in time, we see that a strong renewables growth has been achieved within the EU's electricity sector throughout the past ten years: electricity generation from RES has increased from 630 TWh in 2010 to 1,036 TWh by 2020 – in relative terms this corresponds to an increase of the RES share from 21.3% (2010) to 37.5% (2020). This impressive trend needs to be maintained if we take a look at the expected RES share developments in future years: taking deep decarbonization as our overall guiding principle implies an increase of the overall RES share in the electricity sector to about 64% by 2030, and to more than 91% by 2050. In absolute terms the accompanying strong growth in electricity consumption imposes even a strengthening of RES developments in future years compared to the historic record. Electricity generation from RES needs to at least double within the next ten to eleven years and to more than quadruplicate until 2050 compared to the status quo (2020).

The bulk of electricity generation that stems from already established RES plants (installed until 2020) is marked in dark green at the bottom of Figure 6-16 (right). This share is declining over time and by 2050 only hydropower facilities that typically have the longest technical lifetimes among all RES (and conventional) technologies are expected to remain in the power system by that point in time.

Figure 6-16. Development of electricity generation from RES at EU level, broken down by technology (left) and by age structure (i.e. existing vs. new (post 2020) RES installations) (right) according to the long-term trend scenario "Make-do-and-Mend" (Source: Green-X modelling and Eurostat (2022))



A comparison of the technology trends shown in Figure 6-16 (left) indicates the following aspects:

- Apparently, wind energy dominates the picture – already today (2020) and in future years (2030, 2040, 2050) the largest share of RES-based electricity generation will come from this particular technology. The growth from 376 TWh today (2020) to 3,691 TWh in 2050 appears however impressive. A closer look at the distribution between on- and offshore wind shows the dominance of onshore wind today and in the near future. According to modelling, that picture will change until 2050. According to the exemplified trend scenario "Make-do-and-Mend" offshore is expected to contribute a comparatively similar amount of electricity as onshore wind for meeting our electricity needs at EU level by 2050.
- Apart from wind energy, photovoltaics is the other key technology in future years. Modelling indicates a significant increase in PV deployment – i.e. from 144 TWh today (2020) to 1172 TWh by 2050 according to the exemplified trend scenario "Make-do-and-Mend". Post 2020 newly established residential PV systems are expected to generate 738 TWh by 2050 in the "Cooperation – High Demand" scenario, and slightly less (727 TWh) in the "National Preferences – High Demand" scenario. Central PV systems rank next, achieving slightly lower but among the two scenarios comparatively similar levels of deployment.
- Electricity generation from hydropower is the third largest contributor to RES generation today and in future, compared to wind and photovoltaics the deployment is however less impressive: Electricity generation from hydropower is expected to grow moderately from 345 TWh today (2020) to 364 TWh by 2050 according to the exemplified trend scenario "Make-do-and-Mend". Here already in prior (up to 2020) established plants make up the lion's share, implying that only a small uptake of newly built hydropower plants appears feasible according to modelling. One needs to consider here that according to literature and in accordance with current practice future potentials that acknowledge environmental and societal constraints are limited across Europe.
- Other RES technologies like biomass, geothermal electricity, tidal stream or wave power show only comparatively minor contributions by 2030 and by 2050 under the underlying framework conditions where least-cost options are prioritized in modelling. A growth in electricity from these technology options is however applicable in our modelling: Electricity generation from other RES is expected to

grow from 170 TWh today (2020) to about 367 TWh by 2050, implying more than a doubling compared to today.

Complementary to the above, Table 6-4 provides a comparison of 2050 electricity generation from RES at EU level among assessed long-term scenarios. In general, only small differences between assessed scenarios are applicable therein:

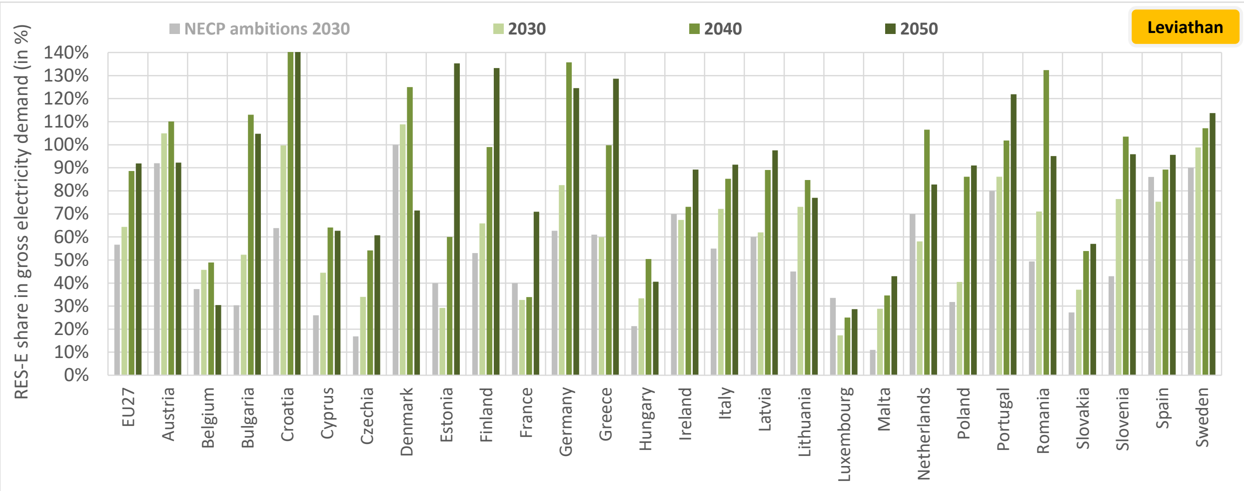
- The overall 2050 RES share in electricity demand varies only at a negligible extent between 91.6% ("Shiny happy energy citizens") and 91.9% ("Leviathan")
- The technology-specific deployment shows also only small variations, with the exception of solar (i.e. Photovoltaics and CSP) where the trend scenarios that have conceptionally put emphasis on decentralisation (i.e. "Make-do-and-mend" and "Shiny happy energy citizens") show a stronger contribution of solar. Reason for that is the prioritisation of decentral PV systems in those scenarios, and, in consequence, the stronger uptake of solar overall.

Table 6-4. Comparison of 2050 electricity generation from RES at EU level for assessed long-term trend scenarios (Source: Green-X modelling)

Comparison of 2050 RES supply at EU level	Scenario:	Make-do-and-mend	Top Down Tech	Leviathan	Shiny happy energy citizens
RES-E generation (total)	TWh	5594.7	5606.3	5607.8	5593.8
RES-E share	%	91.7%	91.8%	91.9%	91.6%
Hydropower	TWh	364.3	364.8	365.1	364.0
Wind	TWh	3691.0	3800.3	3780.9	3692.4
Solar	TWh	1172.2	1060.4	1054.0	1175.3
Other RES	TWh	367.2	380.8	407.8	362.1

Next, Figure 6-17 provides an overview on the expected country-specific RES deployment in the electricity sector. More precisely, this graph allows for a comparison of the planned and the, according to modelling, expected future (2030, 2040, 2050) country-specific RES shares in corresponding gross electricity demand, here exemplified for the long-term trend scenario "Leviathan". Planning indicates here the national perspective for 2030 as proclaimed by Member States in their 2019-edition of National Energy and Climate Plans (NECPs).

Figure 6-17. RES shares in gross electricity demand by MS in selected years (2030, 2040, 2050) according to the long-term trend scenario "Leviathan" (Source: Green-X modelling and Eurostat (2022))



Key results derived from the comparison of country-specific RES shares in future years are:

- With the exception of countries like Estonia, France, Greece, Ireland, Luxembourg and Spain, national planning as postulated in the 2019-edition of NECPs needs to be revised to bring Member States back on track with EU Green Deal needs as presumed in modelling for 2030.
- As in the past strong differences in demand-related RES shares are generally observable across countries. Despite the assumed transformation of the electricity sector towards carbon neutrality by 2050, differences in country-specific RES deployment are also applicable in the years to come. This also holds for 2050 when renewables reach a demand share of more than 91% at EU level.
- By 2050 the list of countries with a significantly higher domestic RES generation than the domestic demand under all illustrated scenarios includes Croatia, Estonia and Finland. In these countries RES shares larger than 130% are expected for 2050.
- Germany, Greece, Portugal and Sweden are among those countries that achieve a moderate oversupply of RES generation compared to domestic demand at a yearly balance by 2050 – but in these countries RES shares are smaller in magnitude compared to the above.
- Austria, Bulgaria, France, Ireland, Italy, Latvia, Lithuania, Netherlands, Poland, Romania, Slovenia and Spain are countries that expectably achieve a comparatively even balance between RES generation and overall domestic electricity demand in 2050 according to modelling.
- Countries that have to heavily rely on (RES-based) electricity imports by 2050 are Belgium, Cyprus, Czechia, Hungary, Luxembourg, Malta and Slovakia – i.e. in these countries the 2050 RES share is (well) below 70%.

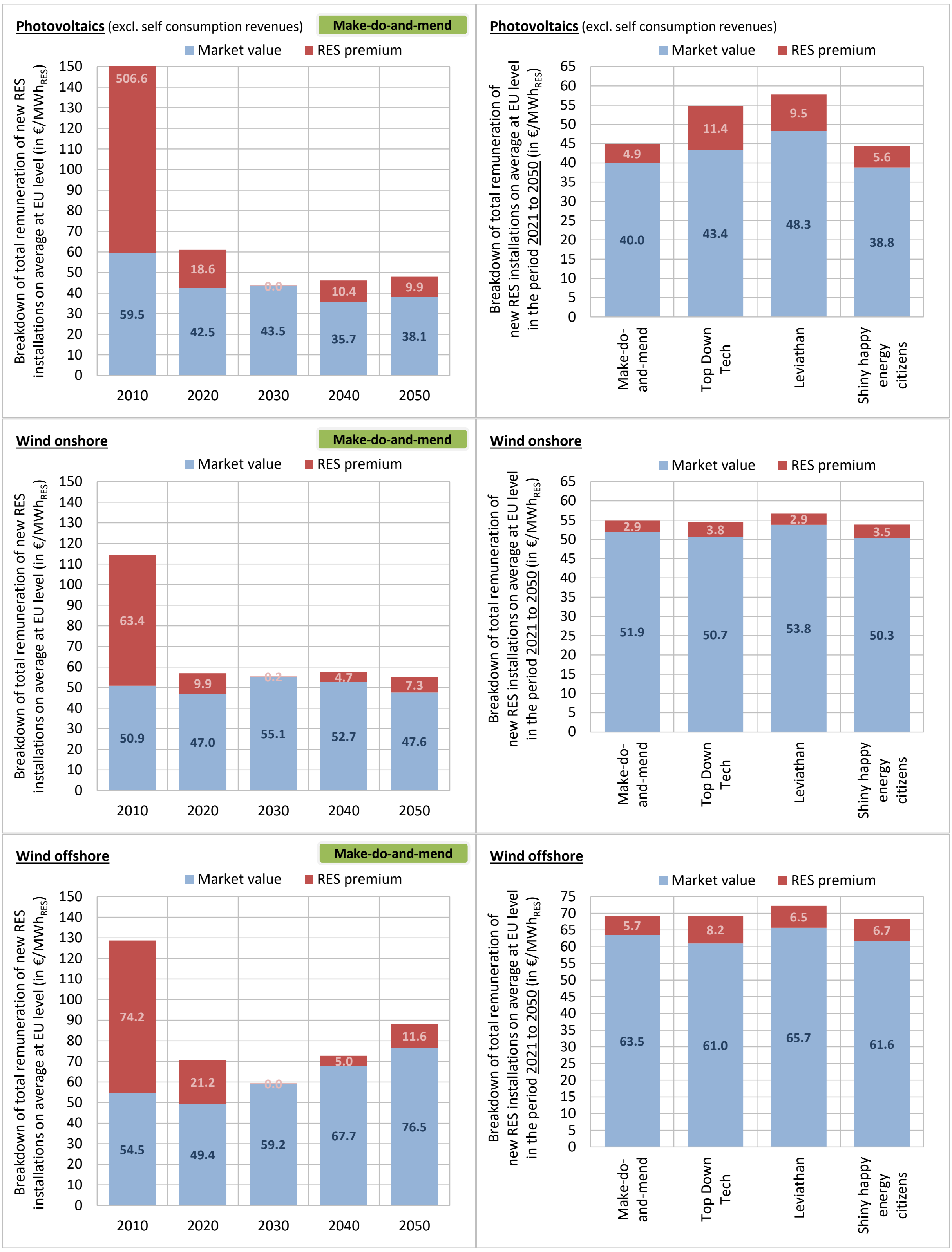
The impact of long-term electricity market trends on total remuneration of RES technologies

This section is dedicated to assess the impact of long-term electricity market trends on total remuneration of RES technologies, shedding light apart from overall remuneration needs on their distribution. Here a distinction between market and support revenues is applied in subsequent graphs. Doing so allows for identifying the need for dedicated RES support, provided via RES auctions, in the mid to long future. Our analysis comprises all four distinct long-term trends scenarios of a changing European electricity system and builds within this section on default assumptions as discussed in section 6.3, incl. default (low) prices for fossil fuels in combination with default (high) prices for green gas as key contributor for meeting future power system flexibility needs.

Concerning levelized cost of electricity (LCOE) from RES, a moderate to strong decline in RES technology cost is generally presumed, in accordance with technological learning trends (cf. Figure 6-3). The imposed strong RES uptake implies however to use also less preferable sites which, in turn, may countervail the cost decline caused by technological learning.

A detailed illustration of the future development of total remuneration of key RES technologies (i.e. PV, on- and offshore wind) at EU level in the period up to 2050 is provided by Figure 6-18. More precisely, the graphs on the left-hand side of Figure 6-18 show the development of total remuneration of new RES installations from key RES technologies (i.e. PV (top), onshore wind (middle) and offshore wind (bottom)) at EU level over time, exemplified for the long-term trend scenario "Make-do-and-mend". The graphs on the right-hand side complement the above via a comparison of average (2021 to 2050) total remuneration between all assessed long-term trend scenarios. In overall terms, in accordance with LCOE trends, total remuneration of key RES technologies like onshore wind and PV is generally expected to decline in future years compared to 2020 levels. One can observe a decline in total remuneration in the near future, i.e. by 2030. In subsequent years up to 2050, according to modelling total remuneration is projected to increase again – but total remuneration for both technologies will remain below 2020 levels.

Figure 6-18. Comparison of total remuneration of new RES installations from key RES technologies (i.e. PV (top), onshore wind (middle) and offshore wind (bottom)) at EU level over time for the long-term trend scenario "Make-do-and-mend" (left) and on average in the period 2021 to 2050 for all assessed long-term trend scenarios (right). (Source: Green-X modelling)

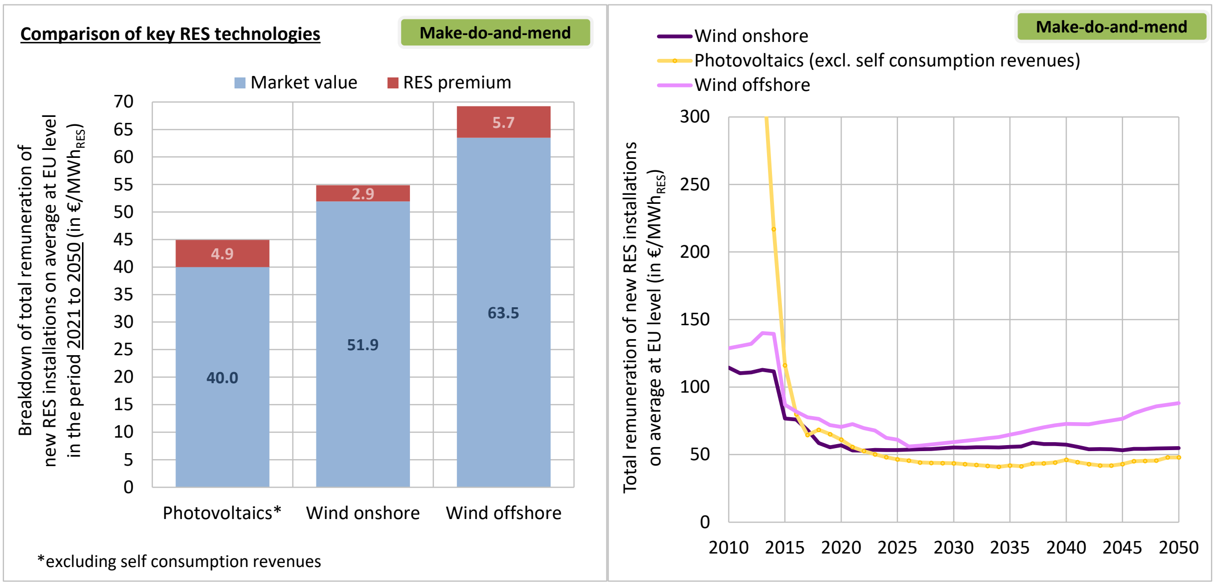


Since Figure 6-18 informs also on the decomposition of total remuneration, i.e. on the market-driven income (cf. the pale blue bars named as "market value") and on the support-driven income (cf. the red bars named as "RES premium"), we can elaborate on the need for dedicated RES support in forthcoming years below. As applicable from the graphs on the left-hand side, by 2030, under default (high) prices for green gases and, in consequence, moderately high wholesale price levels, zero-subsidy auctions can be expected for all key RES technologies. By 2040 and beyond, moderate RES support is however again required to fill the remuneration gap according to the illustrated long-term trend scenario "Make-do-and-mend". Reason for that is generally the decline of market values driven by self-cannibalism, specifically for PV – as a consequence of the required strong PV uptake in accordance with decarbonization needs. According to modelling, similar trends are applicable for wind onshore, although market values are higher compared to PV. For offshore wind Figure 6-18 indicates, in contrast to PV and onshore wind, an increase in total remuneration over time – a consequence of the impressive offshore deployment in the years closer to 2050, implying that also moderate sites need to be used. Since the market value of offshore wind is higher compared to PV and onshore wind, on-top RES support for offshore wind remains moderate. As a general observation, the graphs indicate for all key RES technologies a comparatively similar and moderate height of dedicated RES support.

A comparison of average total remuneration between the distinct long-term trend scenarios – cf. the graphs on the right-hand side of Figure 6-18 – shows that total remuneration is comparatively similar in the case of on- and offshore wind. In the case of PV stronger differences are applicable: the two scenarios emphasizing decentralisation (i.e. "Make-do-and-mend" and "Shiny happy energy citizens") require significantly lower total remuneration and dedicated support compared to the scenarios where centralisation is presumed. Reason for that is the assumed self-consumption privilege for small scale PV installations across the whole EU in the trend scenarios with emphasis on towards decentralisation. This implies additional revenues and, in turn, reduces the need for dedicated RES support provided e.g. via RES auctions.

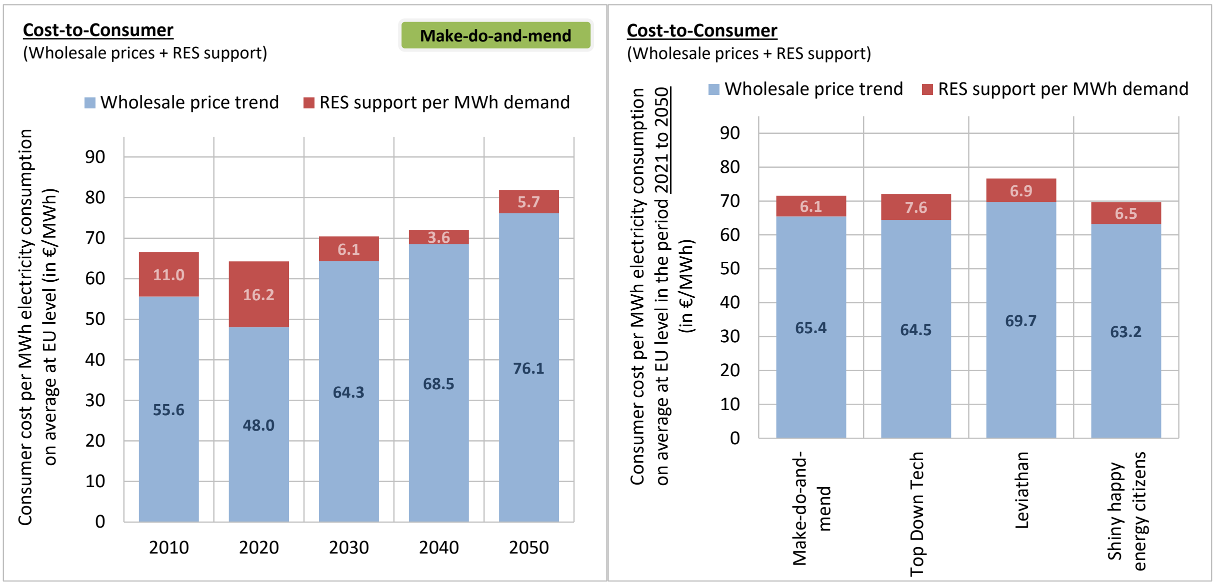
Complementary to the above, Figure 6-19 compares average (2021 to 2050) total remuneration of new RES installations at EU level across all key RES technologies (i.e. PV, onshore and offshore wind) according to the long-term trend scenario "Make-do-and-mend". As applicable from this graph, total remuneration is lowest for PV, followed by onshore wind and offshore wind. For dedicated RES support, a different ranking occurs as a consequence of differences in market values: here onshore wind appears as least-cost option, followed by PV and offshore wind.

Figure 6-19. Comparison of average (2021 to 2050) total remuneration (left) and over time (right) of new RES installations from key RES technologies (i.e. PV, onshore and offshore wind) at EU level according to the long-term trend scenario "Make-do-and-mend". (Source: Green-X modelling)



Finally, Figure 6-20 indicates the impacts electricity consumers may face, showing the average yearly consumer cost in specific terms (per MWh electricity consumption). More precisely, the graph on the left-hand side shows the development over time, exemplified for the long-term trend scenario "Make-do-and-mend", and the graph on the right-hand side compares average (2021 to 2050) cost-to-consumer among all assessed long-term trend scenarios. The cost elements taken up in that comparison comprise the wholesale electricity price and the RES-related support.[12] Under default (high) prices for green gas consumer cost per MWh of electricity consumed are expected to increase steadily over the whole period up to 2050, with a peak value of 81.9 €/MWh at that point in time. The comparison of the different trend scenarios shows a similar cost range across all assessed scenarios. Differences between the trend scenarios are however applicable: In accordance with the naming "Shiny happy energy citizens" ranks best, followed by "Make-do-and-mend" and "Top Down Tech". Highest consumer cost can be expected under the trend scenario "Leviathan" as a consequence of highest wholesale prices among all four scenarios.

Figure 6-20. Comparison of cost-to-consumer of the RES uptake at EU level over time for the long-term trend scenario "Make-do-and-mend" (left) and on average in the period 2021 to 2050 for all assessed long-term trend scenarios (right). (Source: Green-X modelling)



Sensitivity analysis on the impact of RES policy design

This section is dedicated to a sensitivity analysis on the impact of RES policy design on the need for and height of dedicated RES support in future years. Within our modelling different policy instruments for providing the required financial support to RES-E technologies have been assessed, ranging from umbrella policies approaches, e.g. technology-neutral quotas with certificate trading, on to targeted technology-specific policy approaches, e.g. auctions for feed-in premiums, that offer incentives tailored to individual needs.

We exemplify this for the long-term trend scenario "Make-do-and-mend". Two graphs provide a sound summary of the key results derived: Firstly, Figure 6-21 shows the impact of RES policy design on the development over time of RES-related support expenditures (left) and of RES-related impacts on cost-to-consumer (right) at EU level. This is then complemented by Figure 6-22, indicating the policy design-driven changes in RES-related support expenditures and in cost-to-consumer at EU level on average throughout the whole assessment period 2021 to 2050.

[12] Our comparison of cost impacts on electricity consumer does however not provide the "full picture" since network charges as well as energy-related or general taxes are not taken into consideration. This would however not add value to the scope of our analysis where we aim to assess impacts from electricity market developments and RES-related support requirements, and the overall consequences of these from a consumer perspective.

Figure 6-21. Impact of RES policy design on RES-related support expenditures (left) and on cost-to-consumer (right) at EU level in the period up to 2050 according to the long-term trend scenario "Make-do-and-mend". (Source: Green-X modelling)

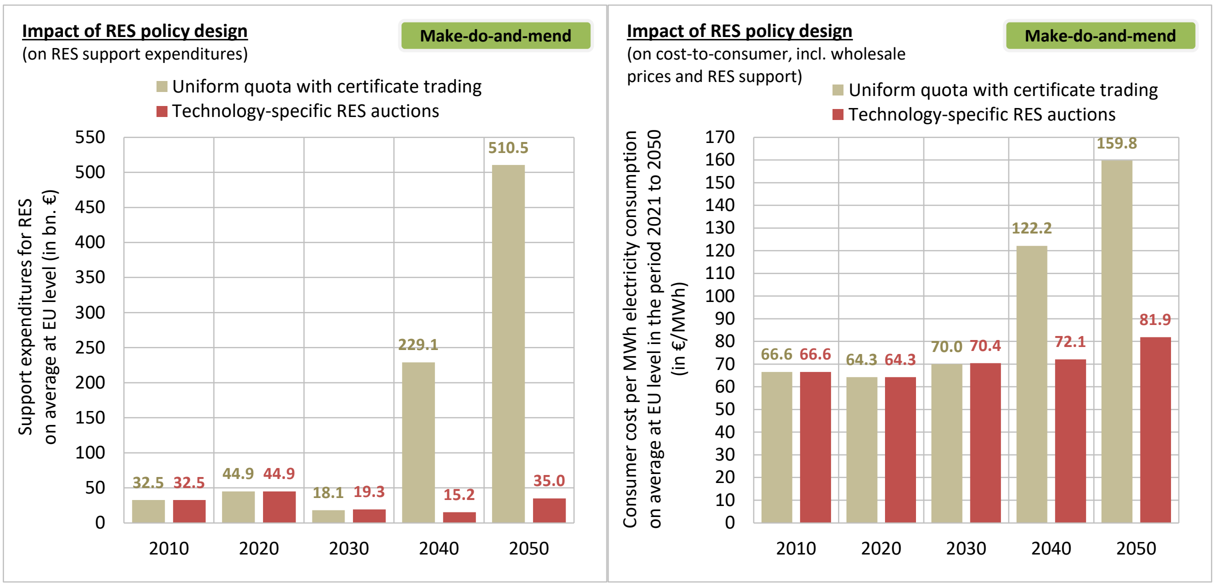
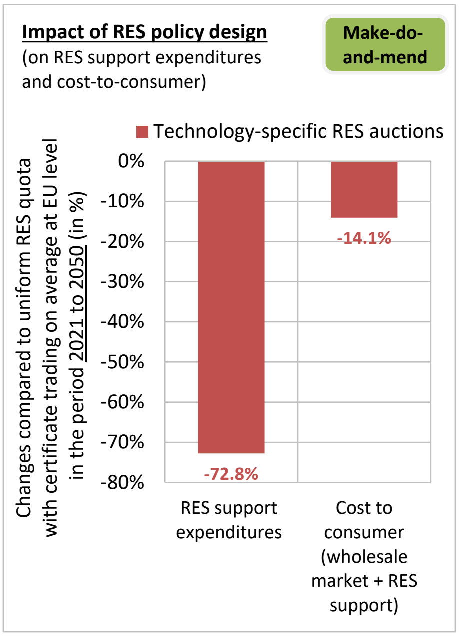


Figure 6-22. Changes in RES-related support expenditures and in cost-to-consumer at EU level on average (2021-2050) driven by RES policy design according to the long-term trend scenario "Make-do-and-mend". (Source: Green-X modelling)



As applicable from these graphs, the selection of an appropriate RES policy framework appears of key relevance for reaching a cost-effective uptake of renewables, specifically if ambitious RES targets are to be met. More precisely, our modelling reveals that targeted policies offering technology-specific incentives tailored to individual needs, done e.g. by use of auctions for feed-in premiums, appear highly beneficial for triggering a cost-effective uptake of RES in the electricity sector. Modelling results show cost savings of ca. 73% when comparing average RES-related support expenditures under targeted RES policy approaches (e.g. technology-specific RES auctions) with umbrella policy approaches (e.g. technology-neutral quotas with certificate trading). Impacts on cost-to-consumer as assessed in a simplified manner within our model-based assessment are expected to decline by ca. 14%.

The outcomes underpin the importance of an appropriate RES policy design for achieving a cost-effective strong RES uptake in forthcoming years. RES support tailored to the technology-specific needs allows for keeping the cost burden for consumer at moderate levels which may, in turn, increase or maintain public acceptance towards decarbonisation that builds to a large extent on renewables.

Sensitivity analysis on the impact of high fossil fuel prices

This section is dedicated to a sensitivity analysis on the impact of high fossil fuel prices on the need for and height of dedicated RES support in future years.

As stated in the intro part, a look at this year's (2022) and last year's economic and political developments, specifically the Russian invasion of the Ukraine, shows that price increases or price turbulence can currently (as of Spring 2022) be observed worldwide in raw material and energy markets, affecting the energy sector and the whole economy significantly, specifically within Europe. Under current high energy prices, even in the absence of dedicated RES support, investments in RES technologies appear cost-competitive and highly attractive for investors despite of the increase of investment cost triggered by the above. The question remains however how long the period of high energy prices may last and how the trend will continue in forthcoming years.

In our modelling default fossil fuel price trends (as illustrated in Table 6-1) are taken from IEA modelling, specifically the IEA's Sustainable Development scenario (IEA WEO 2020). These trends reflect a strong climate ambition globally and, in consequence, compared to today's developments, low fossil fuel prices. This sensitivity analysis builds on an alternative set of price trend assumptions (cf. Table 6-2). Under that trend natural gas prices as well as prices for other fossil fuels are expected to decline compared to current price peaks but, later on, remain at – compared to default assumptions – higher price levels in the near and mid future. This is currently of particular importance given the discussions on the requirement to limit the imports of Russian natural gas.

Below we exemplify the impact of high fossil fuel prices on the need for and height of dedicated RES support for the long-term trend scenario "Make-do-and-mend". Two graphs offer a sound summary of related impacts: Firstly, Figure 6-23 shows at EU level the impact of fossil fuel price trends on the future development of RES-related support expenditures (left) and of RES-related impacts on cost-to-consumer (right). This is then complemented by Figure 6-24, indicating the price-driven changes in RES-related support expenditures and in cost-to-consumer at EU level on average throughout the whole assessment period 2021 to 2050.

Figure 6-23. Impact of high energy prices on RES-related support expenditures (left) and on cost-to-consumer (right) at EU level in the period up to 2050 according to the long-term trend scenario "Make-do-and-mend". (Source: Green-X modelling)

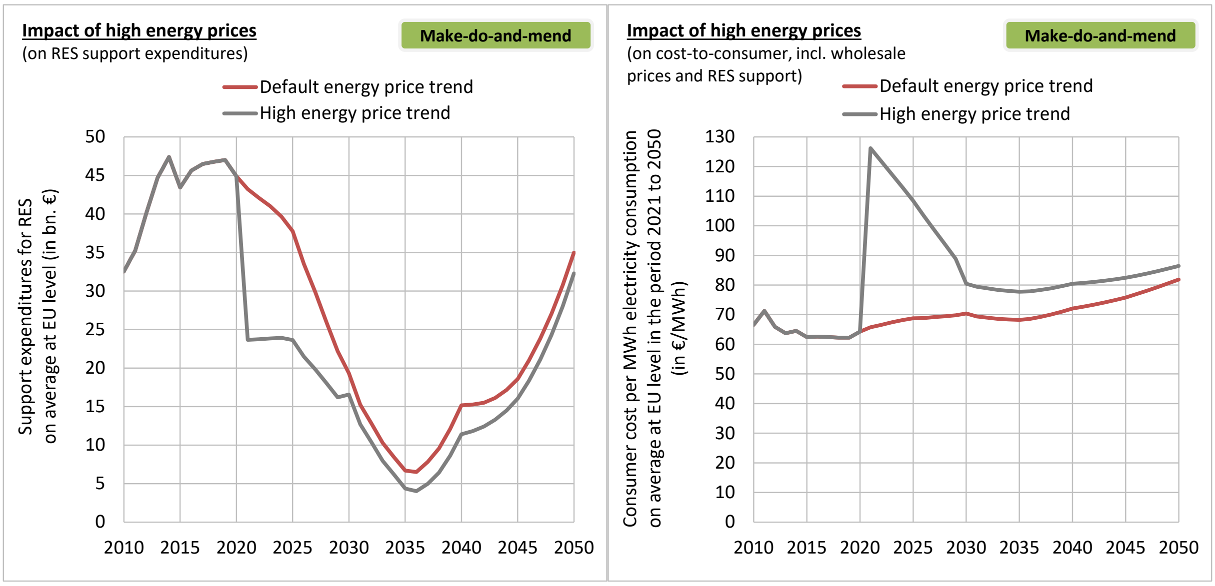
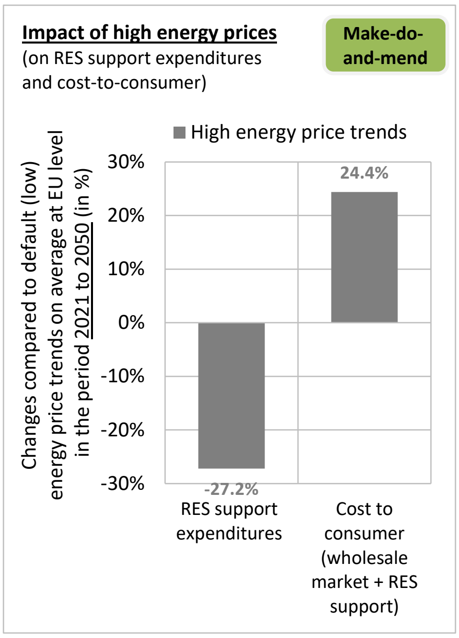


Figure 6-24. Changes in RES-related support expenditures and in cost-to-consumer at EU level on average (2021-2050) driven by high energy prices according to the long-term trend scenario "Make-do-and-mend". (Source: Green-X modelling)



As applicable from these depictions, a continuation of current high energy prices has severe impacts on both the need for and height of dedicated RES support as well as on cost-to-consumer.

On the one hand, high energy prices increase the viability of RES and, in consequence, reduce the need for dedicated RES support significantly. As shown in Figure 6-23, RES-related support expenditures are cut to the half at present. If the phase of high energy prices continues over the near to mid future, modelling shows that this reduction will have a strong impact on support expenditures in the whole period up to 2030. Later on, a convergence process can be expected so that the reduction in support expenditures compared to default levels will get smaller. Throughout the whole assessment period up to 2050 we expect a reduction by ca. 27% (compared to the case of default (low) energy prices), cf. Figure 6-24.

On the other hand, we see a change in the opposite direction for cost-to-consumer in the electricity sector. Here the significant increase in wholesale prices, driven by the high gas prices, is responsible for that change. Over the whole assessment period, cost-to-consumer are expected to increase by ca. 24% compared to default (where low energy prices are presumed).

We can conclude that severe impacts at both ends (i.e. on the height of dedicated RES support and on consumer cost) can be expected from a continuation of currently high energy prices. Renewables can help to lower the cost burden by decreasing our dependency on fossil fuel imports, and they are more than ever economically viable. Thus, an increase in the RES ambition as reaction to the current crisis appears highly recommendable.

Future price trends for green gas – a key determinant on the need for dedicated RES support

For achieving a full decarbonisation of the energy sector, it is expected that natural gas will be fully replaced by green gases of renewable origin, including green hydrogen, biogas or other synthetic carbon-neutral gases, by 2050. As stated in section 6.3, for this decarbonisation option, representing a key option for the provision of power system flexibility in future years, future cost/prices are highly uncertain. In order to reflect that in our modelling, two distinct price trends were assumed:

- As default, In the (default) high price scenario it was assumed that the price for green gases takes orientation on the price of natural gas plus the cost for related CO_2 emission allowances under the EU Emission Trading Scheme. That price trends reflects a high demand for green gas combined with limited supply options and in consequence limited competition on the supply side of the market.
- As sensitivity, a low price scenario was derived and related impacts assessed as discussed within this section of the report. Here former bottom-up price projections for biogas fed into the gas grid served as basis, reflecting first lessons learned from demo projects in the Netherlands and expert judgements concerning expected future progress.

As applicable from Table 6-3, section 6.3.3, by 2050, the difference between both price trends is significant: In the (default) high price scenario green gas was assumed to be available at around 155 €/MWh by 2050 whereas in the low price scenario less than a third of that was assumed (i.e. ca. 50 €/MWh).

This sensitivity assessment analyses the impact of low prices for prices on the need for and height of dedicated RES support for the long-term trend scenario "Make-do-and-mend". As done for other sensitivity cases, the two graphs below offer a sound summary of related impacts: Firstly, Figure 6-25 illustrates at EU level the impact of green gas price trends on the future development of RES-related support expenditures (left) and of RES-related impacts on cost-to-consumer (right). This is then complemented by Figure 6-26, indicating the price-driven changes in RES-related support expenditures and in cost-to-consumer at EU level on average throughout the whole assessment period 2021 to 2050.

The graphs show that low instead of high prices for green gas in future has severe impacts on both the need for and height of dedicated RES support as well as on cost-to-consumer, specifically in later years close to 2050.

On the one hand, low prices for green gas increase the need for and height of dedicated RES support significantly, in particular in the period post 2030. As applicable from Figure 6-25, RES-related support expenditures are only to a minor extent affected in the near future (2030) but post 2035 a strong increase in RES-related support expenditures can be expected. Throughout the whole assessment period up to 2050 modelling indicates more than a doubling of RES support expenditures, i.e. an increase by 111% (compared to the case of default (high) green gas price trend), cf. Figure 6-26.

On the other hand, we see a change in the opposite direction for cost-to-consumer in the electricity sector. Here lower prices for green gas lead to a decline of wholesale prices, specifically in the years close to 2050. Over the whole assessment period, cost-to-consumer are expected to decrease by ca. 20% compared to default (where high prices for green gas are presumed).

Figure 6-25. Impact of low prices for green gas on RES-related support expenditures (left) and on cost-to-consumer (right) at EU level in the period up to 2050 according to the long-term trend scenario "Make-do-and-mend". (Source: Green-X modelling)

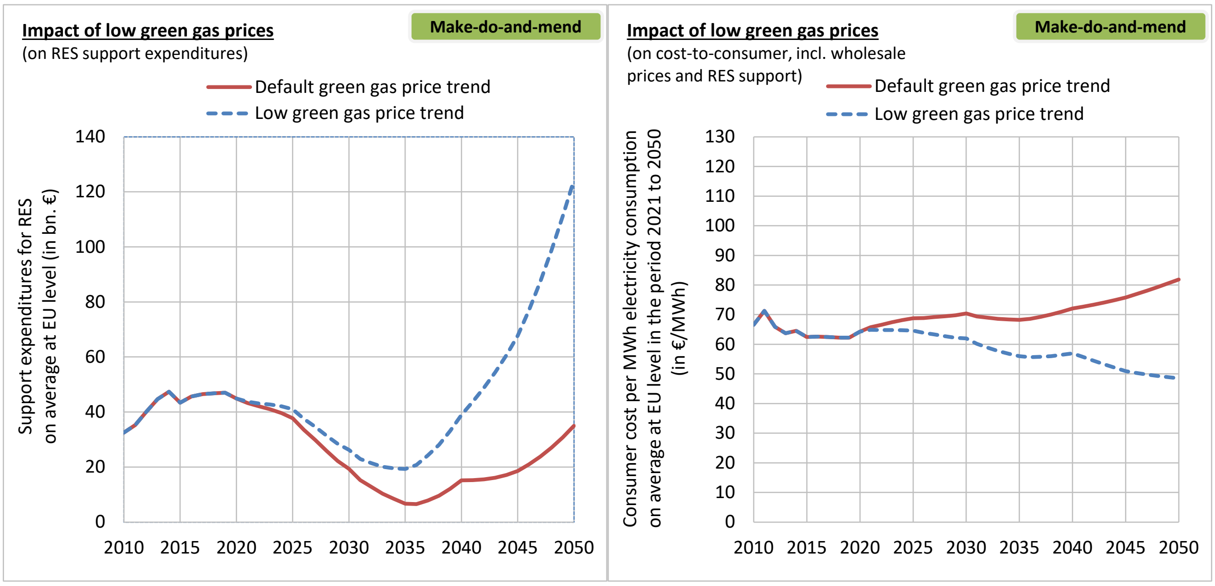
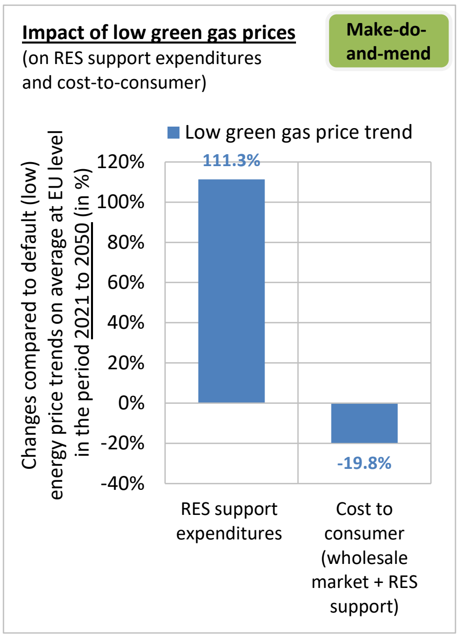


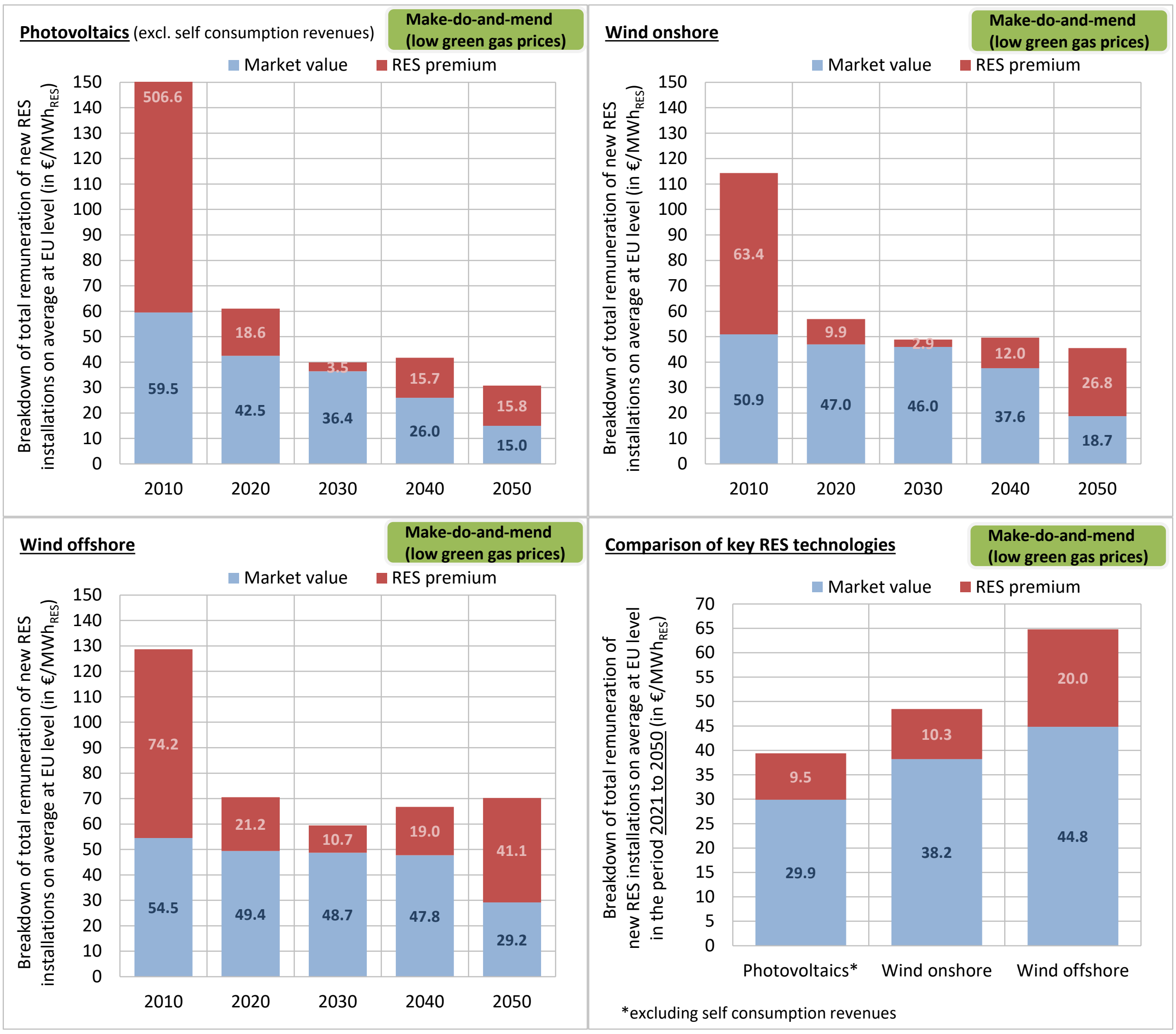
Figure 6-26. Changes in RES-related support expenditures and in cost-to-consumer at EU level on average (2021-2050) driven by low prices for green gas according to the long-term trend scenario "Make-do-and-mend". (Source: Green-X modelling)



Similar to the default case of high green gas prices, we subsequently show the impact on total remuneration for key RES technologies. Thus, a detailed illustration of the future development of total remuneration of key RES technologies (i.e. PV, on- and offshore wind) at EU level in the period up to 2050 is given in Figure 6-27. More precisely, the graphs show the development of total remuneration of new RES installations from key RES technologies (i.e. PV (top, left), onshore wind (top, right) and offshore wind (bottom, left)) at EU level over time, exemplified for the long-term trend scenario "Make-do-and-mend". At the right bottom we then complement the above via a cross-technology comparison of total remuneration looking at the whole assessment period (2021 to 2050)

Since Figure 6-27 informs also on the decomposition of total remuneration, i.e. on the market-driven income (cf. the pale blue bars named as "market value") and on the support-driven income (cf. the red bars named as "RES premium"), we can elaborate on the need for dedicated RES support in forthcoming years below. As applicable from the graphs, by 2030, even under low prices for green gases and, in consequence, moderately low wholesale price levels, (almost) zero-subsidy auctions can be expected for PV and wind onshore. In the case of offshore wind this might then be limited to best sites only. By 2040 and beyond, RES support is however again required to fill the remuneration gap according to the illustrated long-term trend scenario "Make-do-and-mend". One can also identify here an increasing tendency, meaning that RES support is higher by 2050 compared to 2040. Reason for that is generally the decline of market values driven by self-cannibalism, specifically for PV – as a consequence of the required strong PV uptake in accordance with decarbonization needs. Remarkably, total remuneration is expected to decline towards 2050, driven by the anticipated cost reductions over the whole assessment period. According to modelling, similar trends are applicable for onshore wind, despite higher market values compared to PV. For offshore wind, in contrast to PV and onshore wind, an increase in total remuneration over time – a consequence of the impressive offshore deployment in the years closer to 2050, implying that also sites characterised by higher cost need to be exploited. Thus, the required on-top RES support for offshore wind is expected to reach high levels by 2050.

Figure 6-27. Development of total remuneration of key RES technologies (i.e. PV, on- and offshore wind) at EU level in the period up to 2050 under low prices for green gas according to the long-term trend scenario "Make-do-and-mend". Source: Green-X and Balmorel modelling (cf. Resch et al., 2022)



This sensitivity analysis has shown that the key parameter to determine whether or not only low (or almost zero) subsidies will be required to accommodate the future RES uptake is the future price level on the wholesale electricity market. These prices are, in turn, determined by the future prices at which key zero-carbon flexibility options on the supply side like biogas or green hydrogen will be available. Low prices for green gas would increase RES support but cause at the same time a decline of consumer cost, and vice versa.

6.5 Executive summary

This model-based analysis complemented the narrative scenarios describing plausible visions of EU electricity markets and networks in the period up to 2050. Scenarios were derived using TU Wien's Green-X model, a specialised energy system model with a sound incorporation of various RES policy approaches, closely linked to the open-source energy system model Balmorel, allowing to shed further light on the interplay between supply, demand and storage thanks to a high temporal resolution.

Key assumptions were to presume the Green Deal ambition for 2030, imposing an increase of the overall RES share to (at least) 40% in gross final energy demand by 2030, and a carbon-free electricity system by 2050, implying that RES and nuclear serve to provide the electricity supply in the entire EU by that point in time. Moreover, the assumed full decarbonization of the whole EU economy by 2050 leads to more than a doubling of electricity demand and implies a strong RES uptake in forthcoming years. In accordance with the qualitative scenario narratives, two key aspects stood originally in focus of the modelling: the level of *power system flexibility* provided in future years, indicating the ability of the power system to react on changes in supply and/or demand, and the degree of *decentralisation*, specifically concerning RES supply thanks to a continuation or phase-out of dedicated incentives for small-scale decentral RES systems. Other aspects like future energy price trends or details on RES policy design were analysed by means of sensitivity analyses.

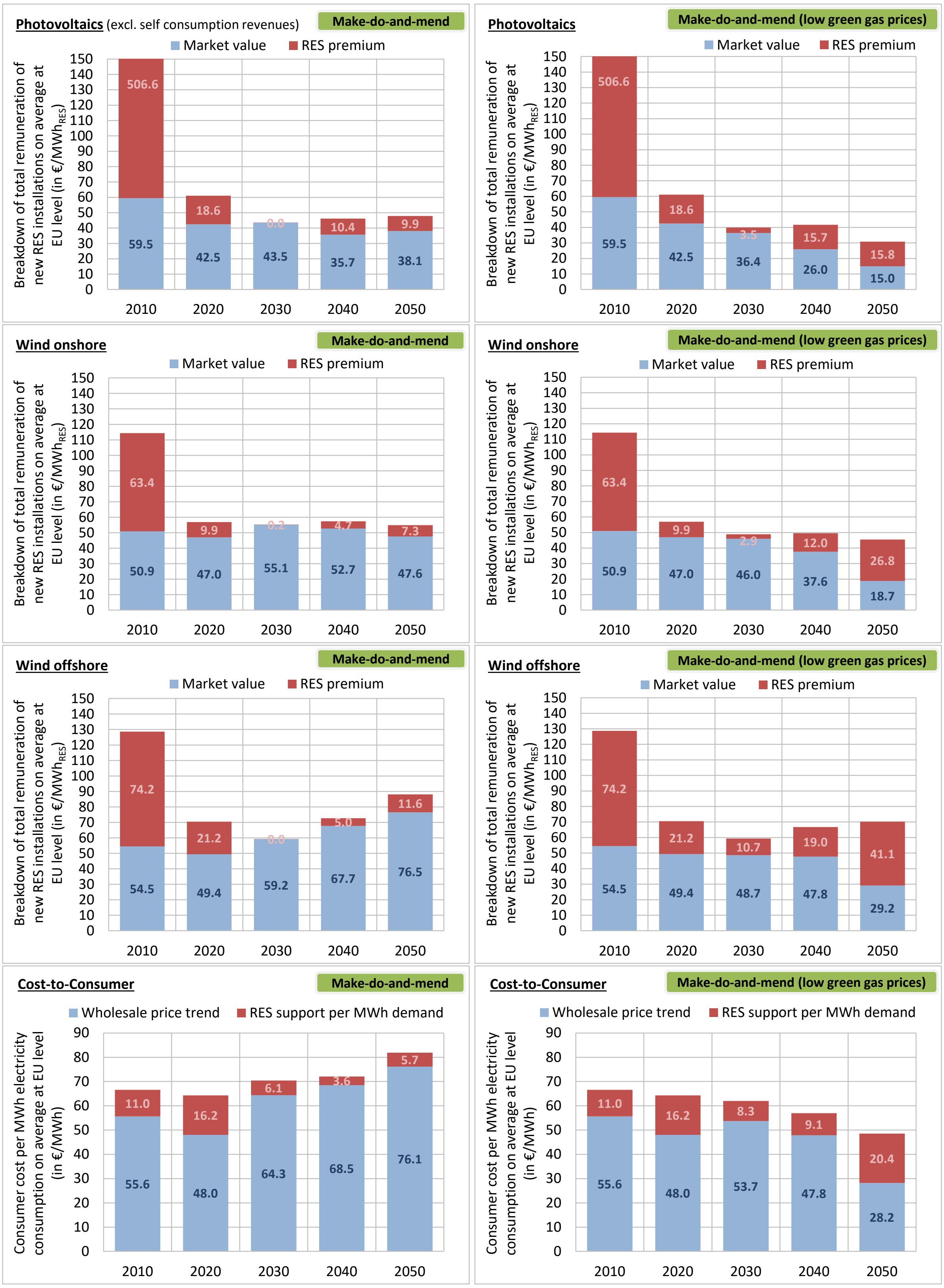
The outcomes of the modelling have shown that a high degree of system flexibility and decentralisation can act as enabler, and even be a prerequisite for a successful RES market integration. The key parameter to determine whether or not only low (or almost zero) subsidies will be required to accommodate the future RES uptake is however the future price level on the wholesale electricity market. These prices are, in turn, determined by the future prices at which key flexibility options on the supply side like biogas or green hydrogen (subsequently named as "green gas" as synonym for both) will be available. For green gas two distinct price trends were assessed: a high and a low price scenario.[13] With high prices for green gas, modelling indicates also high prices on the European wholesale electricity market and vice versa. The impacts of these distinct price trends on total remuneration of key RES technologies (i.e. PV, on- and offshore wind) and on RES-related cost-to-consumer at EU level in the period up to 2050 are shown in Figure 6-28.

In overall terms, total remuneration of key RES technologies like onshore wind and PV is generally expected to decline in future years compared to 2020 levels. There are however strong differences between both price trends for green gas. In the case of high prices for green gas one can observe a decline in total remuneration in the near future, i.e. by 2030. In subsequent years up to 2050, according to modelling total remuneration is projected to increase again – but total remuneration for both technologies will remain below 2020 levels. In contrast to the above, under the scenario of low green gas prices one can observe a (more or less) continuous decline of total remuneration over the whole period up to 2050. For offshore wind, the third key pillar for future electricity supply, total remuneration is expected to decline until 2030 but, later on, an increase in total remuneration can be expected under both price trends. The increase is however stronger in the case of high prices for green gas.

Since Figure 6-28 informs also on the decomposition of total remuneration, i.e. on the market-driven income (cf. the pale blue bars named as "market value") and on the support-driven income (cf. the red bars named as "RES premium"), we can elaborate on the need for dedicated RES support in forthcoming years below. By 2030, even under low prices for green gases and, in consequence, low wholesale price levels, low or even zero-subsidy auctions can be expected for all key RES technologies. By 2040 and beyond, RES support is required to fill the remuneration gap, despite declining remuneration levels for onshore wind and PV in the case of low green gas prices. Reason is generally the decline of market values driven by self-cannibalism – as a consequence of the required strong RES uptake in accordance with decarbonization needs. According to modelling, similar trends are applicable for wind on- and offshore, although market values are higher compared to PV. Similar to total remuneration, there is also a strong difference in RES support between both price trends for green gas. The need for and height of dedicated RES support is significantly higher in the case of low green gas prices due to lower market-driven revenues feasible under these wholesale price developments.

[13] In the high price scenario it was assumed that the price for green gases takes orientation on the price of natural gas plus the cost for related CO_2 emission allowances under the EU Emission Trading Scheme. In the low price scenario former bottom-up price projections for biogas fed into the gas grid served as basis. By 2050, the difference between both price trends is significant: In the (default) high price scenario green gas was assumed to be available at around 155 €/MWh by 2050 whereas in the low price scenario less than a third of that was assumed (i.e. ca. 50 €/MWh).

Figure 6-28. Development of total remuneration of key RES technologies (i.e. PV, on- and offshore wind) as well as cost-to-consumer of the RES uptake at EU level in the period up to 2050 according to selected electricity system trend scenarios – with default (high) (left) or low prices for green gas (right). (Source: Green-X modelling)



The graphs at the bottom of Figure 6-28 indicate the impacts electricity consumers may face, showing the average yearly consumer cost in specific terms (per MWh electricity consumption). The cost elements taken up in that latter comparison comprise the wholesale electricity price and the RES-related support.[14] Here again a strong difference between both "gas price worlds" is observable. In the case of (default) high prices for green gas (cf. Figure , left) consumer cost per MWh of electricity consumed are expected to increase steadily over the whole period up to 2050, with a peak value of 81.9 €/MWh at that point in time. In the case of low green gas prices the opposite trend can be expected: Consumer cost per unit of electricity consumption are expected to decline until 2050, reaching a minimum value of 48.5 €/MWh by 2050 – almost half the price compared to the case of high prices for green gas.

Summing up, the assessment allowed for identifying key parameter that determine the need for and the height of dedicated RES support in forthcoming years. The key parameter to determine whether or not only low (or almost zero) subsidies will be required to accommodate the future RES uptake is the future price level on the wholesale electricity market. These prices are, in turn, determined by the future prices at which key zero-carbon flexibility options on the supply side like biogas or green hydrogen will be available. In general, with massive amounts of high vRES infeed there are many times during a day and year when prices are well below current wholesale price levels. During times of low solar radiation or low wind, hydrogen, green gas, batteries and other flexibility options have to contribute to meet the given demand. If these flexibility options are available at low cost/prices, the need for dedicated support increases but consumer cost are expected to decline and vice versa.

6.6 Conclusions

As RES technologies become more and more competitive, auction prices may fall below wholesale prices in some countries in Europe, especially in those with more favourable resource potentials (mostly PV and wind). The case studies prepared under the AURES II project already provide some examples for this trend. Yet, it is still uncertain whether the current trend of a market-based RES expansion will continue and whether zero-subsidy auctions and/or PPAs will make a significant contribution to the RES increase needed to meet future European RES targets. One critical factor opposing this trend is the limited ability of the electricity system to integrate vRES leading to a reduction in market values and thus a reduction in incentives for market-based expansion. In this context, qualitative scenario developments and accompanying modelling activities carried out within AURES II aimed for shedding light on the above, informing on the need for dedicated RES support in forthcoming years. The outcomes of the modelling have shown that a high degree of system flexibility and decentralisation can act as enabler, and even be a prerequisite for a successful RES market integration. The key parameter to determine whether or not only low (or almost zero) subsidies will be required to accommodate the future RES uptake is however the future price level on the wholesale electricity market. These prices are, in turn, determined by the future prices at which key flexibility options on the supply side like biogas or green hydrogen will be available. If these flexibility options are available at low cost/prices, the need for dedicated RES support increases but, due to the lower wholesale prices, consumer cost that include both the wholesale prices and the RES support are expected to decline. The opposite trends can be expected in the case of high prices for green gas.

[14] Our comparison of cost impacts on electricity consumer does however not provide the "full picture" since network charges as well as energy-related or general taxes are not taken into consideration. This would however not add value to the scope of our analysis where we aim to assess impacts from electricity market developments and RES-related support requirements, and the overall consequences of these from a consumer perspective.

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Technical Report on the Modelling of RES auctions
(Horizon 2020 project AURES II, D8.5)

AURES II is a European research project on auction designs for renewable energy support (RES) in the EU Member States.

The general objective of the project is to promote an effective use and efficient implementation of auctions for RES to improve the performance of electricity from renewable energy sources in Europe.

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