A REGULATOR'S GUIDE TO THE USE OF PRODUCTION SIMULATION TOOLS FOR MARKET ANALYSIS

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A REGULATOR'S GUIDE TO THE USE OF PRODUCTION SIMULATION TOOLS FOR MARKET ANALYSIS

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Authors: Božidar Radović, Waisum Steinborn-Cheng, Christian Hewicker

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1 Introduction

The National Regulatory Authorities (NRAs) from the regions of Europe and Eurasia (E&E)[1] are actively working to improve the performance of electricity markets. As most of these countries are contracting parties to the Energy Community, their transmission system operators (TSOs) are obliged to regularly assess long-term generation adequacy and prepare long-term network development plans in each individual country in line with the applicable rules set out by the European Union. The NRAs have the responsibility to monitor this process, and, in most cases, review and approve the corresponding plans or assessments.

The NRAs are also involved in promoting the development of functioning electricity markets and the regional integration of national markets. This may involve detailed market studies and simulation, i.e., in order to assess the potential impact of corresponding changes on generation costs, market prices, cross-border exchanges, competition, and market liquidity.

Through its cooperative agreement with the United States Agency for International Development (USAID) Bureau for Europe and Eurasia, the National Association of Regulatory Utility Commissioners (NARUC) implements the Enhancing Stability and Technical Expertise in European and Eurasia Energy Markets (ESTEEM) for USAID-assisted countries and USAID Missions. With funding support from USAID, NARUC seeks to provide technical advisory support to the NRAs in the E&E region to expand their knowledge and improve their capabilities in these fields.

While the benefits of market coupling are clear, the decisions to move forward can be challenging in a technical and political regard. It is, therefore, paramount that regulators, TSOs, and other industry stakeholders have an open dialogue, and that NRAs have a robust understanding of the benefits and challenges that market coupling can bring in order to prepare for the impact of such scenarios. Similarly, E&E regulators must be able to critically review and assess the long-term development plans put forward by the TSOs and other network operators.

Against this background, NARUC has commissioned the authors to prepare primers that address the principles, use, and understanding of two important types of analytical tools commonly used by TSOs and/or other relevant stakeholders in this context. This document (Primer II) focuses on the use of market simulation tools for generation expansion planning and market simulations. In parallel, another primer (Primer I - A Regulator's Guide to the Use of Load Flow Study Tools for Transmission Planning) has been prepared to discuss the use of load flow studies in the same context.

As explained in the following chapter, market simulations can be conducted for different purposes, such as for generation expansion planning or to simulate the (daily) operation of electricity markets, generation dispatch, and cross-border exchanges. In practice, different tools or models may be used to serve these purposes. In this context, it is important to carefully differentiate between the terms 'model' and 'modeling tool. The difference between these terms is often misunderstood. For the discussion in this document, we refer to a 'modeling tool,' or simply a 'tool,' as a software package that allows for simulating and/or optimizing electricity markets and generation.

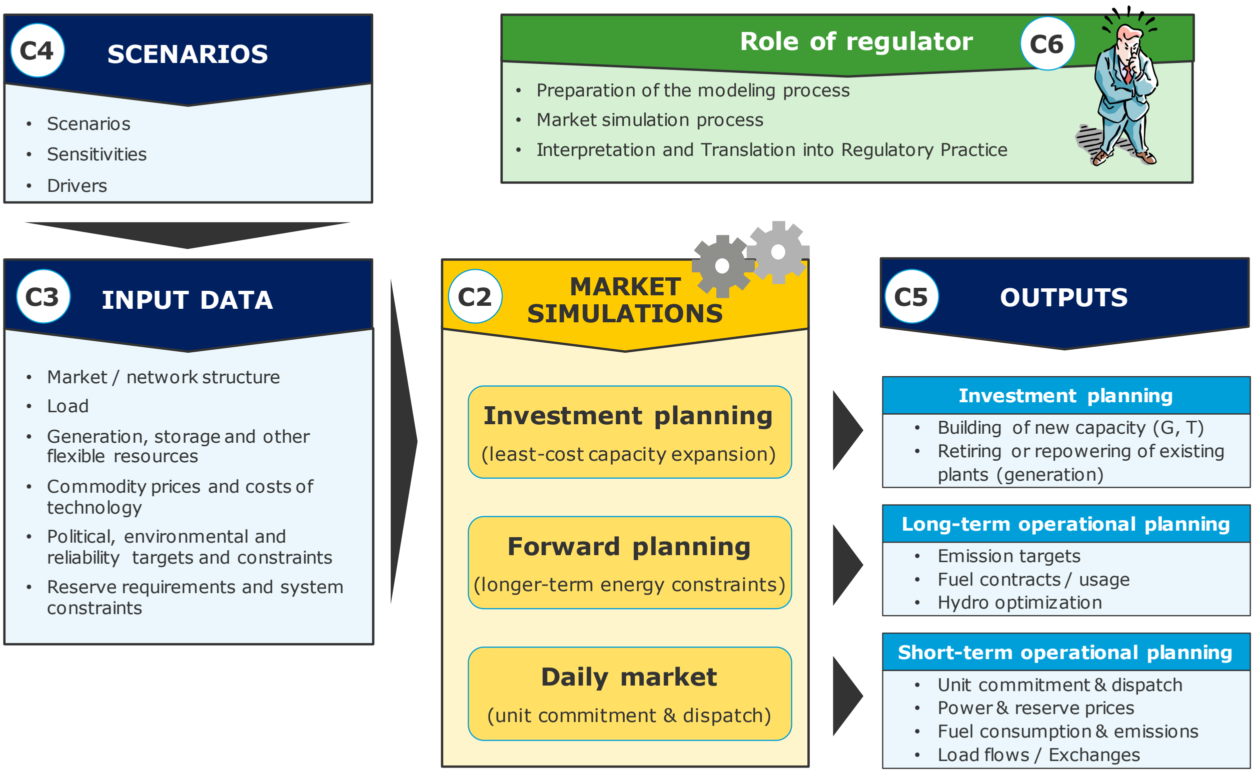
As such, a tool basically consists of an algorithmic framework and relevant user interfaces, which principally allows for dealing with any market or power system. In contrast, we refer to a 'model' as a

[1] For the purposes of this project, this includes the National Regulatory Authorities (NRAs) from Albania, Armenia, Bosnia & Herzegovina, Georgia, Kosovo, Moldova, Montenegro, North Macedonia, and Ukraine.

tool that has been configured or populated with a given data set to represent a given electricity market or generation park. In other words, a tool can be used to set up different models, whereas a model is always based on a combination of a chosen tool and a given set of data.

As shown in Figure 1, the structure of this primer aims at reflecting the different steps and components involved in the overall process of model setup, application, and interpretation. More specifically:

- Chapter 2 (C2) describes the concepts of different market simulation tools.
- Chapter 3 (C3) describes relevant input data for a tool.
- Chapter 4 (C4) discusses methods and benefits of scenario development and sensitivity analysis.
- Chapter 5 (C5) provides insights into how to interpret the results of different market simulations.
- Chapter 6 (C6) explains the role of regulators in interpreting the market simulation results and relaying such information to decision makers.



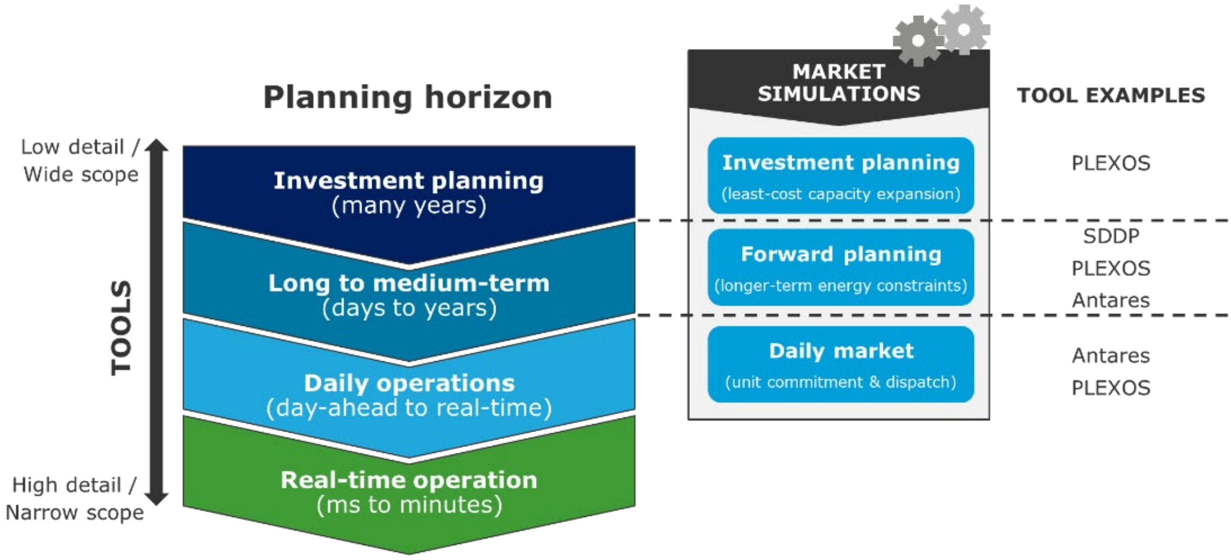
C = Chapter

Source: DNV GL

2 Fundamental Purpose and Available Tools

The relevance of market modeling has drastically changed over time. Vertically integrated electricity utilities began to perform market modeling in the 1950's, mostly for capacity expansion studies. The main objective of vertically integrated utilities was to provide enough available installed capacity in order to cover electricity demand at a minimum cost (generation expansion planning) within a reasonable Loss of Load Probability (LOLP).

Over the past decades, the liberalization of electricity markets and the rapid growth of variable renewable energy (VRE) sources has created new challenges for market stakeholders and regulators alike. This has fostered the need to develop new and more sophisticated market simulation tools. In line with changing requirements and increasing computational power, electricity market tools have been developed, which aim to model power sector operation and quantitatively evaluate market situations on different timeframes.



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As Figure 2 illustrates, market modeling may address different questions and issues, which can be broadly associated with different time horizons. Specific tools have been developed to address these requirements and different planning horizons. Overall, the following three core functionalities are common features of market simulation tools:

- **Capacity expansion planning** tools identify the optimal combination of generation new builds and retirements and, in some cases, transmission upgrades (and retirements). The optimization is based on economic investment decisions, with the objective of minimizing total system costs, subject to defined reliability targets and/or environmental targets. Besides investments into generation capacity, market simulations can also be used to assess the benefits of grid investments for enabling a more efficient use of generation units at different locations.[2] As a general rule, corresponding models focus on the optimization of indicators like the net present value of electricity supply or the levelized costs of electricity (LCOE). Furthermore, they usually rely on annual time intervals and are based on a simplified representation of generation, flexible resources, and/or the overall power system.

- **Medium-term planning** tools are tailored to addressing aspects like hydro and fuel optimization, maintenance planning, or resource adequacy assessment. These tools typically focus on weekly time steps. Similar to capacity expansion tools, the analysis is typically based on a simplified representation of operating constraints, especially with regards to intertemporal constraints such as ramping limits and minimum-up/minimum-down times. Similarly, many tools rely on load duration curves or other simplified measures of load.
- **Unit commitment and economic dispatch (UCED)** aims to optimize the hourly scheduling and operation of generation and other flexible resources. This requires consideration of the detailed (hourly) profile of load and electricity generation from variable resources (e.g., wind and solar power). Similarly, corresponding tools usually allow for a detailed representation of relevant technical and commercial parameters, including in particular intertemporal constraints. Therefore, it is crucial that the optimization problem takes these time constraints into account in order to simulate the real functioning of the generation mix.

Besides changing circumstances, the evolution of market simulation models has also been influenced by constant improvements made to computational power. Early market simulation tools had to rely on many simplifications in order to limit computational complexity and computation times. Consequently, they were often based on **heuristic optimization**, using pre-defined decision rules. While they were able to identify a 'good' outcome, they did not necessarily find an optimum solution.

Today, most market simulation tools are based on **linear programming** techniques, such as mixed-integer linear programming (MILP). Their key advantage is that they are principally able to identify an optimal solution. Moreover, in combination with powerful state-of-the-art solvers, corresponding models can be applied even for large markets or power systems at a national, regional, or continental scale. But despite considerable improvements to computing power, the application of MILP approaches still reaches its limits for larger systems as computation time increases exponentially, notably for 'integer' variables, such as the decision to start or stop a generating unit. For this reason, corresponding tools still allow for certain simplifications, such as the linearization of integer constraints or heuristic elements.

For similar reasons, dedicated tools and techniques have been developed for **stochastic optimization**, i.e., for dealing with stochastic uncertainties of key input variables. Traditionally, stochastic optimization techniques were applied for hydro optimization, i.e., the optimal scheduling of hydropower with large reservoirs in hydro-based systems. In recent years, corresponding models have also become important for dealing with the variability of renewable energy sources, such as wind and solar power.

For further information, Annex 8.1 provides an overview of three state-of-the-art-modeling tools, which reflect different approaches and which have been used in the region extensively.

[2] Compare ENTSO-E. 2nd ENTSO-E Guideline for Cost Benefit Analysis of Grid Development Projects. FINAL – Approved by the European Commission. Brussels, 27 September 2018. Available at https://eepublicdownloads.blob.core.windows.net/public-cdn-container/clean-documents/tyndp-documents/Cost%20Benefit%20Analysis/2018-10-11-tyndp-cba-20.pdf; Last accessed: July 18, 2020

3 Input Data Requirements

High quality input data are decisive for accurate and robust market simulations. Indeed, good input data are often as equally important as the selection of the modeling tool. Data needs are driven by the choice of the modeling tool, on the one hand, and the specific scope and focus of the modeling exercise, on the other.

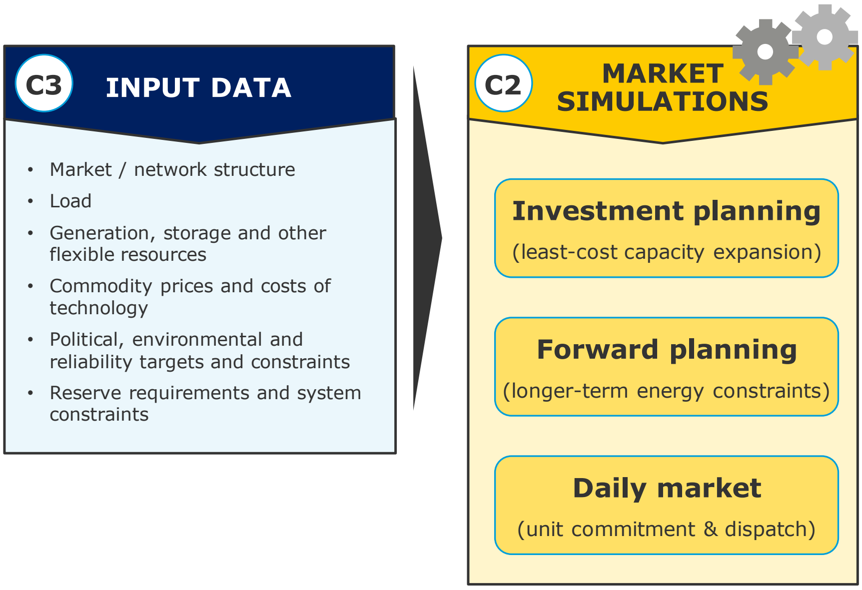

Figure 3: Different categories of input data for market simulations

Source: DNV GL

As shown by Figure 3, one can differentiate between the following categories of input data.[3]

- **Basic market and network structure.** Includes the possible breakdown of a larger geographical area into one or more market areas (or 'bidding zones'), relevant network constraints, and the market approach to account for these constraints. Internationally, different concepts are used for this purpose. These range from bilateral net transfer capacities (NTC) over the so-called "flow-based" approach to a nodal representation of the network.
- **Load.** Includes information on the total consumption, the peak load, the load profile and load duration curves, demand side management, and the geographical distribution of the load.
- **Generation, storage, and other flexible resources.** Includes general information, technical and economic characteristics, and resource availability and other operating constraints of generation, storage, and other relevant assets.
- **Commodity prices and technology cost.** Includes cost information on fuels, as well as costs for technologies, operation, and maintenance.
- **Political, environmental, and reliability targets and constraints.** Allows to specify targets and constraints, such as carbon reduction targets or minimum values for system reliability indices.

[3] Section 8.2 in the annex includes a more detailed discussion of different types of input data and data sources.

- **Reserve requirements and system constraints.** Contains information on additional system constraints and on reserve requirements.

Not all data sources are suitable for obtaining all types of data. Table 1 includes an indicate mapping of different input parameters to typical data sources.[4] A green field indicates that the data source is generally well suited, and a yellow field means a limited suitability. It should be noted that expert estimates are always a possible data source and are thus not listed.

Table 1: Mapping of data sources to required input data

	Governmental targets and strategies	Rules, standards & criteria	Network operator and stakeholder data	Publicly available information	Own analysis and studies
Basic market and network structure		(✓)	✓	✓	
Load	✓		✓	✓	(✓)
Generation, storage, and other flexible resources	✓		✓	✓	(✓)
Commodity prices and technology cost			(✓)	✓	(✓)
Political, environmental and reliability targets and constraints	✓	✓	✓	✓	
Technical constraints (e.g., reserves or local grid constraints)			✓		(✓)

A green field indicates that the data source is generally well suited, and a yellow field indicates limited suitability

Source: DNV GL

[4] Please refer to section 8.3 in the annex for a discussion of methods or approaches for collecting and/or estimating relevant information.

4 Scenario Development and Analysis

4.1 Use of scenario and sensitivity analysis

Scenario analysis for market simulations can either be used to evaluate the impact of different assumptions or changes on the current or future power system, or to investigate possible pathways to a predetermined future. Accordingly, energy scenarios can be grouped into prescriptive or descriptive scenarios:[5]

- ***Prescriptive/normative scenarios*** define a certain (future) state and the pathway to achieve that state. Corresponding scenarios are also known as visions, backcasts, pathways or roadmaps. Visions are scenarios that are desired and to a certain extent plausible futures.
- ***Descriptive scenarios*** are used to assess the impact of different assumptions or market design options, such as market coupling. In descriptive scenarios, there is no predetermined outcome. Rather, the outcome is determined by the market simulation using the underlying assumptions.

By definition, the primary objective of prescriptive scenarios is to compare and assess the impact of the corresponding 'design decisions' under different pathways on other parameters, like total system costs, costs to consumers, or market prices. Similar to capacity expansion planning, prescriptive scenarios focus on longer term structural changes. In this case, however, the future state is an input rather than an output to the model. Consequently, the analysis is of a more indirect nature, i.e., detailed production cost simulations or the simulation of day-to-day market operations are used to obtain insight into the relative performance of the pre-defined expansion or market design options.

In contrast, descriptive scenarios are in a sense 'open ended,' insofar that the desired end state is not known in advance. Consequently, they can be used for traditional long-term expansion planning as well as for assessing the impact of certain exogenous developments, which are beyond the control of the regulator or other entities. Possible examples include a techno-economic evaluation of future fuel price developments, different VRE penetration levels, or different levels of demand on future generation and/or market prices.

The main purpose of scenario analysis is not to predict the future, but to highlight the main drivers which push the future into different directions. More precisely, scenario development helps us to understand possible future developments and to identify the main influencing factors.

Academic literature provides a range of different definitions of and approaches to scenario analysis; see for instance Meinert[6] and Davis.[7] For the purpose of this document, the following discussion concentrates on several specific steps and aspects important for market simulations. More specifically, the following discussion differentiates between the following four key steps:

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[5] T. Mai et al., "RE-ASSUME A Decision Maker's Guide to Evaluating Energy Scenarios, Modeling, and Assumptions," June 14, 2013, https://doi.org/10.2172/1090954; William McDowall and Malcolm Eames, "Forecasts, Scenarios, Visions, Backcasts and Roadmaps to the Hydrogen Economy: A Review of the Hydrogen Futures Literature," *Energy Policy* 34, no. 11 (July 2006): 1236–50, https://doi.org/10.1016/j.enpol.2005.12.006.

[6] Sascha Meinert, *Scenario Building: Field Manual*, *ETUI* (ETUI - Brussels, 2014), https://www.labourline.org/Record.htm?idlist=1&record=19116869124919340419.

[7] Ged Davis, *Scenarios: An Explorer's Guide* (The Hague: Shell International BV, 2008), https://www.shell.com/energy-and-innovation/the-energy-future/scenarios/new-lenses-on-the-future/earlier-scenarios/_jcr_content/par/expandablelist/expandablesection_842430368.stream/1519772592201/f5b043e97972e369db4382a38434d4dc2b1e8bc4/shell-scenarios-explorersguide.pdf.

1. Identification of boundary conditions vs. uncertain drivers;
2. Assessment and selection of relevant drivers;
3. Scenario building; and
4. Uncertainty and sensitivity analysis.

4.1.1 Identification of boundary conditions vs. uncertain drivers

As described in chapter 3, each model requires a large number of input parameters. While many of the corresponding parameters will be subject to a considerable degree of uncertainty, others can be expected to be known with sufficient accuracy, such as the structure of existing generation or grid capacities. Similarly, certain boundary conditions can be regarded as a given, as for instance defined policy targets. As it is practically impossible to consider possible variations of all relevant inputs, and combinations thereof, it therefore makes sense to differentiate between *known givens* and *uncertain drivers* (see Figure 4).

Similarly, not all changes will have an equal impact on the modeling results, either in general or for the particular purpose of the analysis at hand. Furthermore, it seems useful to only focus on drivers that can be expected to have an important impact on model outcomes.

A typical example of given assumptions, which are well known and foreseeable for the time horizon of a given study, are the cost of mature technologies, such as thermal power stations. In contrast, drivers refer to parameters, which are uncertain during the evaluation period. Some typical examples include commodity prices or technology prices of emerging technologies, such as battery storage, carbon capture sequestration (CCS), etc.

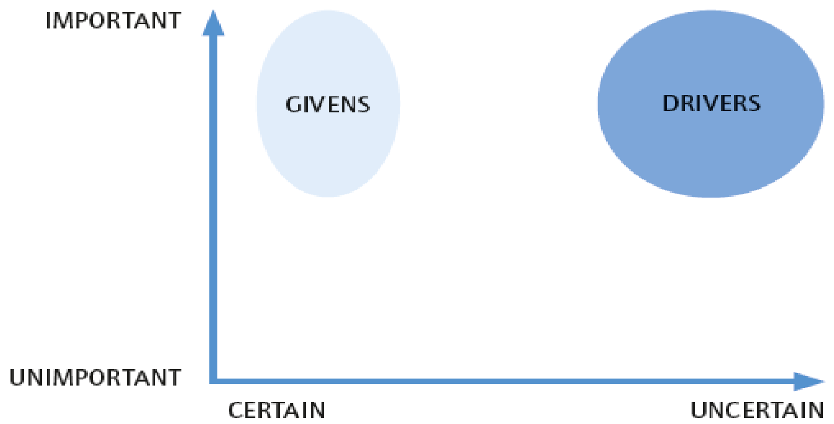


Figure 4: Givens and drivers for scenario analysis [8]

Scenario analysis should focus on the evaluation of drivers that have the highest influence on the future development. Table 2 shows an example of main drivers of different scenarios. For example, the "current and announced policies" driver describes a descriptive scenario, and the main driver "100% renewable goal" describes a prescriptive scenario.

[8] Meinert, *Scenario Building*.

Table 2: Example of main drivers in selected future energy transition studies [9]

Scenario Name	Organization	Outlook Period	Main driver	Share of VRE at end of outlook period
WEO New Policies (2012)	IEA	2035	Current and announced policies	18%
WEO 450 (2012)	IEA	2035	2 degrees stabilization	27%
BP Energy Outlook (2013)	BP	2030	"Most likely future"	12%
Rethinking 2050	European RE Council	2050	100% renewable goal	96%

A selection of relevant drivers for scenario analysis is listed in Table 3. In this context, it is important to note that market simulations tools are generally based on the principle of cost minimization. Consequently, any cost related drivers can be expected to have the largest impact on modeling results. In contrast, non-technical drivers can be considered in an indirect way only, for instance by taking exogenous assumptions on their impact on other parameters.

Table 3: Relevant drivers for energy scenario development [10]

Financial / Economic	Technical	Market design, regulation, and policy	Non-Technical

• **fuel prices**
• **CAPEX/OPEX (generation, transmission expansion)**
• **discount rates / WACC**
• **technology learning (cost reduction)**
• **life-cycle costs of technologies (retirement decisions)**
	• load growth, incl.
	  ○ economic development
	  ○ population growth
	  ○ energy efficiency
	  ○ power-to-gas (electrolysis)
	  ○ electrification (heat, transportation)
	• load profile (daily, weekly, per season)
	• reserve requirements
	• fuel and energy constraints or availability
	• weather years (e.g., changing hydrology)
		• regional market integration (e.g., market coupling, balancing, load-frequency control (LFC) block structures)
		• CO_2 emission targets
		• VRE penetration level targets
		• environmental costs (e.g., externalities) / CO_2 cost
		• technology / fuel subsidies
			• public opposition ('NIMBY')
			• permitting issues (e.g., transmission lines, dams, etc.)
			• market supply chain issues

[9] Mai et al., "RE-ASSUME."
[10] Mai et al.

4.1.2 Assessment and selection of relevant drivers

The importance of the individual driver depends on the main driver of the energy scenario and the market simulation tool being used. A rough estimation of the impact of the different drivers on investment planning and dispatch optimization is shown in Figure 5.

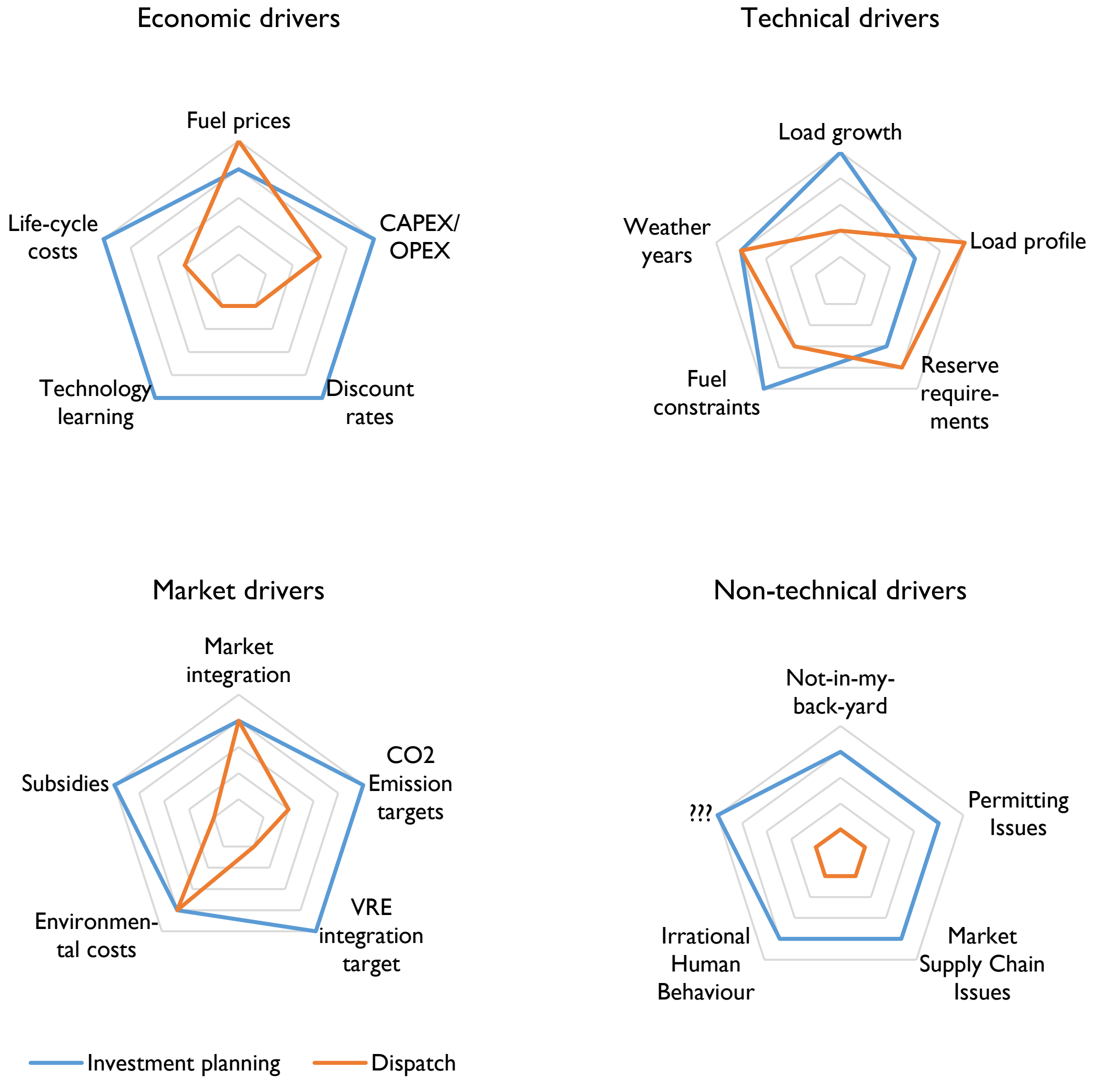


Figure 5: Impact of different drivers on investment planning and dispatch optimization

Source: DNV GL

4.1.3 Scenario building

To develop a robust scenario analysis, it is rarely helpful to rely on a single scenario. Rather, a combination of different scenarios which can be compared to each other can enable an insight into the impact of, for example, different oil prices, demand growth assumptions, and other drivers. Figure 6 shows different approaches for developing energy scenarios.

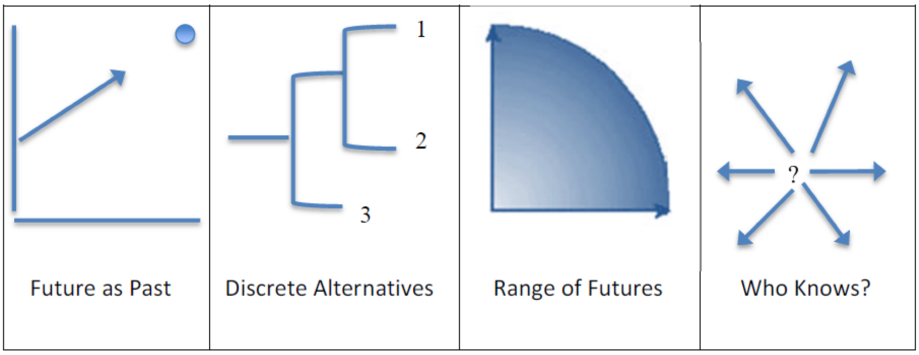


Figure 6: Selected approaches to energy scenarios[11]

4.1.4 Uncertainty and sensitivity analysis

As highlighted in chapter 3 and Table 3, energy systems are influenced by many different factors. Therefore, it is unlikely that the scenario and/or model developers are aware of all the particularities of each individual assumption. For this reason, robust scenario development is often complemented by uncertainty and sensitivity analysis:

- Uncertainty analysis is used to quantify the uncertainty of an input parameter. This type of analysis is also used to exclude input parameters with either a low level or no impact on the scenario outputs and to classify input parameters into givens and drivers.

- Sensitivity analysis focuses on the impact caused by variations of one or a few input variables have on the model outcomes. In contrast, scenarios usually provide for simultaneous changes of many different input assumptions. Sensitivity analysis is thus useful to assess the specific impact of key and/or highly uncertain variables.

A limiting factor for sensitivity analysis is the computation time. For example, a sensitivity analysis with five (uncertain) input parameters and three states per parameter (high, base, low) would lead to 3^5 = 243 possible combinations. Depending on the computation time it might be infeasible to evaluate all these combinations. Likewise, it may become difficult or even impossible to compare and interpret the results in a meaningful way, unless very simple and straightforward metrics are used.

The most common approach is to limit the number of sensitivity cases and to change only one input parameter at a time. This essentially means that a base case scenario is defined and evaluated. The base case usually contains the most likely assumptions for each parameter. Then for each parameter, a less likely assumption (e.g., high/low state) will be conducted. This simple approach allows the relative impact of individual parameters. In the previous example, for instance, this approach drastically reduces the number of simulations for this example from 243 to 11 simulations (1x base case simulation + 2x5 simulations per state and parameter).

[11] Mai et al.

4.2 Selected case studies

4.2.1 IPCC scenarios on global warming

The International Panel on Climate Change (IPCC) created four scenarios to assess if and through which measures the emission of greenhouse gases can be reduced to limit global warming to 1.5°C.[12] Figure 7 illustrates the emission reduction pathways which are assumed in the four scenarios.

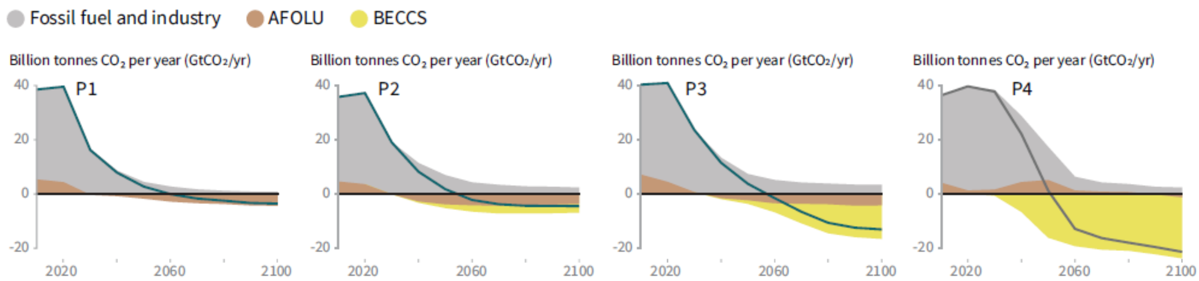


Figure 7: Illustration of the carbon reduction pathway in the IPCC scenarios [13]

All four scenarios assume the uptake of carbon dioxide removal (CDR) technologies, such as bioenergy with carbon capture and storage (BECCS) and removals in the agriculture, forestry, and other land use (AFOLU) sector. Despite these similarities, each of the scenarios is characterized by a different set of drivers, which are summarized in Table 4 below.

[12] Intergovernmental Panel on Climate Change, *Global Warming of 1.5°C*, 2019, http://www.ipcc.ch/report/sr15/.
[13] Ibid.

Table 4: Summary of main drivers in the IPCC carbon reduction scenarios[14]

	P1	P2	P3	P4
Narrative	Social, business, and technological innovations result in lower energy demand while living standards rise, especially in the global South.	Broad focus on sustainability including energy intensity, human development, economic convergence, and international cooperation	Societal as well as technological development follows historical patterns	Economic growth and globalization lead to widespread adoption of greenhouse-gas-intensive lifestyles, including high demand for transportation fuels and livestock products
Decarbonization driver	Downsizing of energy system and decarbonization of energy supply	Sustainable and healthy consumption patterns, low-carbon technology innovation	Decarbonization of energy supply and production, limited demand reduction	CDR technologies
Prevalent CDR technology	Afforestation	Limited use of BECCS	BECCS	Strong use of BECCS

Source: DNV GL, based

4.2.2 Future energy scenarios by the National Grid

To support its future oriented analysis, for instance in the context of transmission planning, the British TSO National Grid has developed a set of 'Future Energy Scenarios' (FES). These scenarios are supposed to reflect '*credible pathways for the future of energy for the next 30 years and beyond.*'[15] In practice, the four scenarios are used by National Grid as a starting point for various studies and market simulations. The FES are an example of descriptive scenarios, where a range of drivers is defined, which then result in assumptions regarding technology penetrations and other assumptions. The FES include four scenarios (Figure 8), which are characterized by two main sets of drivers:[16]

- *Speed of decarbonization*: Take up of low-carbon solutions driven by policy, economic and technological factors, and consumer sentiment.
- *Level of decentralization*: Proximity of energy supply to end consumer. Describes the level of centralization of generation and technologies such as electric vehicle charging.

[14] Ibid.
[15] National Grid, "National Grid ESO - Future Energy Scenarios; http://fes.nationalgrid.com/
[16] Ibid.

It should be noted that the scenarios are not meant to represent forecasts of expected pathways. Instead, National Grid explicitly acknowledges that the actual development will likely be a combination of each of the four scenarios.

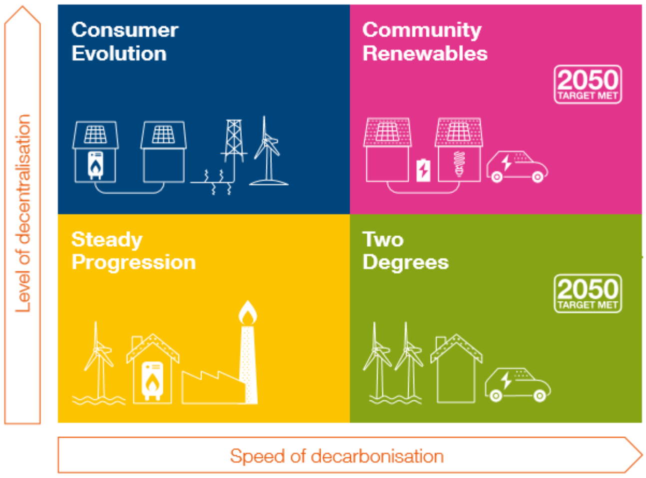


Figure 8: High-level overview of National Grid's Future Energy Scenarios[17]

Each scenario is characterized by a combination of five external drivers, which describe the development in the respective scenario in the following areas:

- *Policy support*: the level of support mechanisms to encourage low-carbon solutions;
- *Consumer engagement*: modification of consumer behavior in response to price and readiness to choose alternative heat and transport options;
- *Economic growth*: the overall economic climate (GDP growth);
- *Technology development*: the pace of innovation for developing new or existing technologies; and
- *Energy efficiency*: the energy efficiency of appliances and thermal efficiency solutions for new and existing buildings.

Figure 9 provides an overview of specific assumptions for each of these drivers in the four scenarios.

[17] National Grid, "Future Energy Scenarios" (London: National Grid, 2019), http://fes.nationalgrid.com/media/1409/fes-2019.pdf.

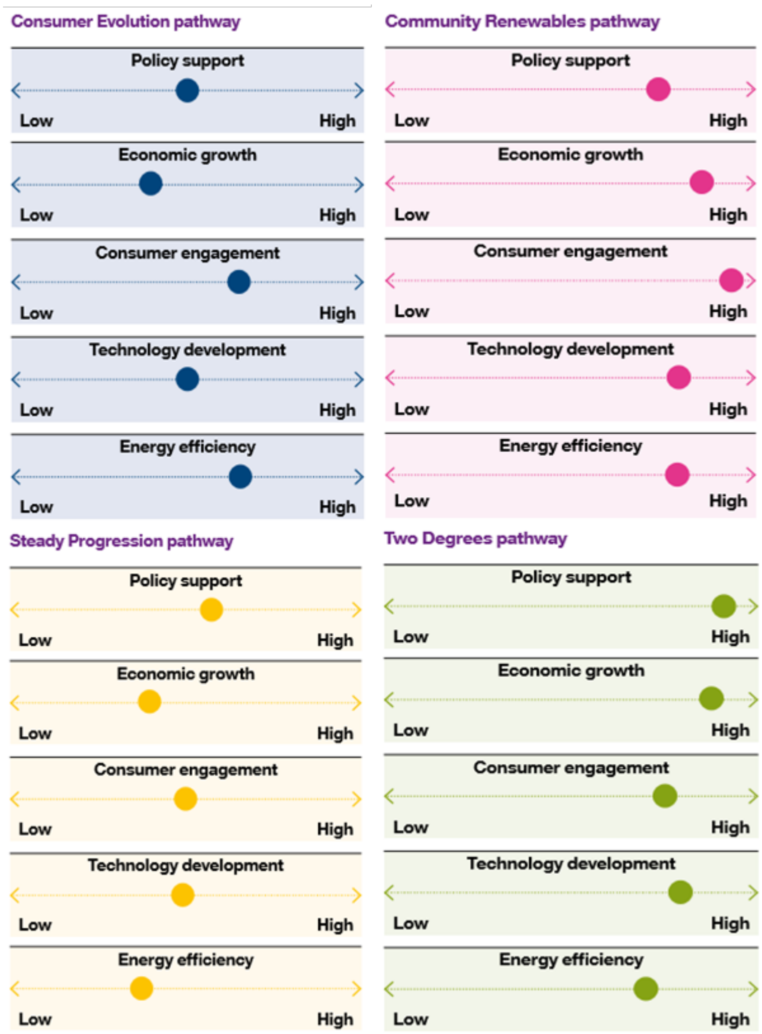


Figure 9: Overview of the drivers in National Grid's Future Energy Scenarios [18]

[18] National Grid.

5 Interpretation and Assessment of Results

Market simulations produce data in many different aspects. Typically, not all data are needed for the objective of the analysis, so the relevant outputs need to be identified and extracted. Market simulation results can be visualized on different timescales using the tool's interface. Specific outputs can be grouped and summarized by executing queries through the interface. This is illustrated in Figure 10 which shows the data interface of PLEXOS, through which the modeling results can be accessed and aggregated. The displayed results can then be extracted or copied into excel files.

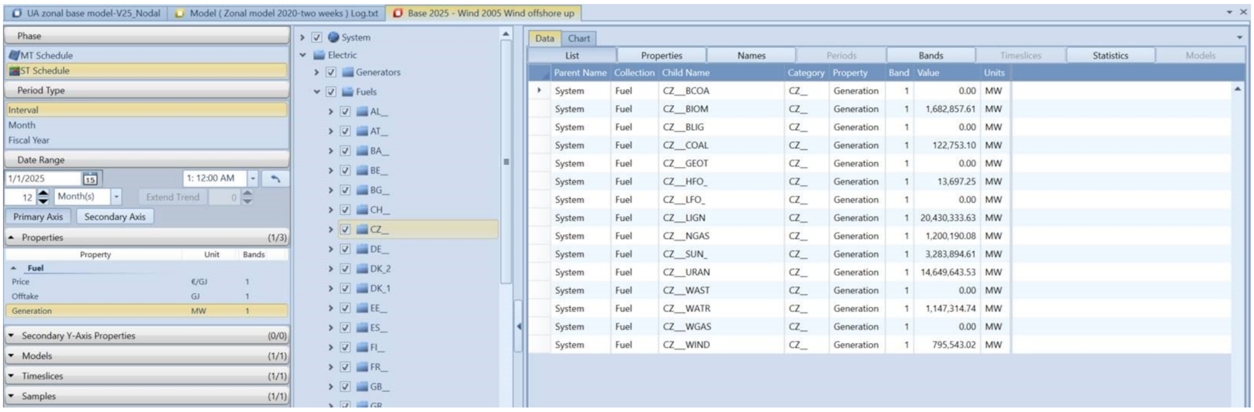


Figure 10: Example of model outputs in PLEXOS

Source: DNV GL analysis

Moreover, most market simulation tools provide the possibility to visualize the results through the interface. Figure 11 illustrates how the Antares modeling software can produce a graph visualizing the unserved energy and thus provides an example for a graphic representation of the results which can be extracted from the model.

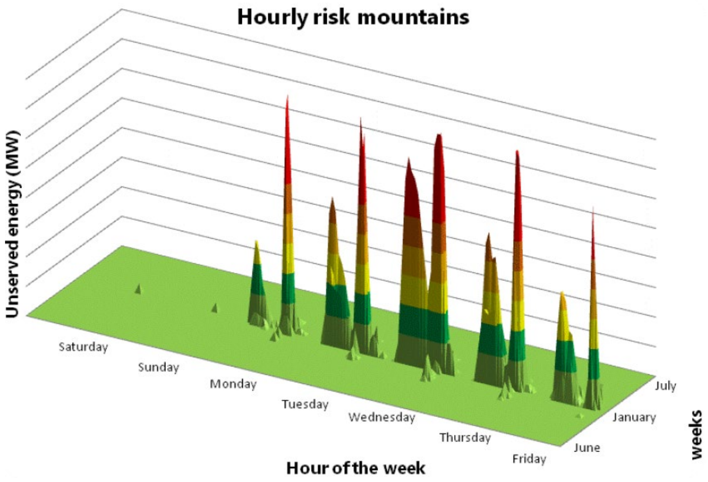


Figure 11: Example for visualization of unserved energy in Antares [19]

As discussed in previous chapters, the outputs of the market simulations strongly depend on the type of study conducted, as well as on the modeling tool used. Some of the most common output types are highlighted in Table 5.

Table 5: Typical outputs of market simulation models

Investment planning	Long-term operational planning	Short-term operational planning
• new capacity (when, where, which type/capacity) • retirement date for existing power stations • repowering of existing generation • generation / system adequacy • capital cost • loss of load expectations	• long term schedule for hydro power stations (hydro constraints) • long term schedule fuel constraint conventional generation • maintenance schedule	• unit commitment & economic dispatch • fuel consumption • VRE curtailment • reserve allocation • cross-border exchanges • energy cost • reserve cost • capacity factors of individual generators/power stations • load shedding

Source: DNV GL

Not all of these outputs are necessarily relevant for regulators. Conversely, regulators may have an interest in additional indicators that are not calculated by all market simulation tools. In such cases, outputs need to undergo additional data processing. For regulatory purposes, the following outputs appear to be most important:

- **Generation dispatch patterns and characteristics.** Includes information on the dispatch patterns of individual plants as well as on an aggregated level. Allows an insight into the electricity mix, the production cost pattern, and the fuel consumption of the modelled market.

[19] Rte, "Antares - Probabilistic Tool for Electric Systems. A New Tool for Adequacy Reports and Economic Simulations" (Rte, 2020).

- **Commercial electricity exchanges between different market areas.** Allows an insight into the impact of interconnecting infrastructure on the commercial electricity exchange between countries.
- **Price level and costs.** Enables the prediction of the development of wholesale and ancillary price levels. More detailed analyses yield information on the price setting role of individual (generating) capacities.
- **System reliability.** Assessment of the system reliability using both deterministic metrics and probabilistic methods.
- **Social welfare and congestion rent.** The results of market modelling exercises can be analyzed with regard to social welfare, which comprises the producer surplus, consumer surplus and congestion rents (see Text box 1).
- **Margins and profitability.** Market simulations enable margins and profitability of individual generating units to be assessed.
- **Market concentration.** Market simulations allow estimations for the potential evolution of market concentration under different scenarios of market integration to be made.
- **Environmental externalities.** Includes the indirect costs to society, for example through the emission of greenhouse gases.
- **Impact on fuel imports.** The impact of the interconnection of markets and other factors on the import of fuels can be estimated using market simulation techniques.
- **Flexibility and VRE integration.** Market simulations allow for the estimation of the future need for backup capacity and additional flexibilities in the electricity system.
- **Cost of re-dispatch.** By combining several sequential market simulation runs, it may be possible to estimate incremental costs of re-dispatch as required to resolve congestion in zonal markets.

Text box 1: Social welfare output from market simulation for Southeast Europe

The objective of the "Assessment of the Impacts of Regional Electricity Market Integration in Southeast Europe" project[20] was to analyze and quantify the impacts of electricity market integration in the SEE region. For this purpose, a regional electricity market model (using the Antares software tool) was used to analyze and quantify the impact of different levels of market integration for the year 2025.

As part of the study, the impact on social welfare was analyzed for different levels of market coupling ("partial market coupling," "full market coupling") compared to the status quo. As Table 6 shows, full market coupling increases social welfare by EUR 37m as opposed to EUR 26m under partial market coupling. Nevertheless, although the region as a whole benefits from market coupling, these benefits are not distributed equally. Some countries even experience a decrease in social welfare, highlighting the need for addressing distributional effects under market integration projects.

[20] USAID. 2019, Assessment of the Impacts of Regional Electricity Market Integration in Southeast Europe, 25.11.2019

***Table 6: Impact of market integration in SEE on social welfare*[21]**

Market area	Partial market coupling - Separated markets				Full market coupling - Separated markets			
million €	Δ Producer surplus	Δ Consumer surplus	Δ Congestion rent	Δ Total surplus	Δ Producer surplus	Δ Consumer surplus	Δ Congestion rent	Δ Total surplus
AL	8.02	-4.52	-1.41	**2.08**	6.01	2.04	-4.37	**3.68**
BA	30.06	-19.58	-3.24	**7.24**	17.08	-11.82	-0.08	**5.18**
BG	48.50	-32.13	-22.40	**-6.03**	102.05	-67.24	-44.08	**-9.28**
GR	-182.28	244.03	-44.69	**17.05**	-238.53	324.82	-56.46	**29.83**
HR	-10.56	10.41	-5.27	**-5.42**	-10.44	4.36	4.59	**-1.49**
ME	7.88	-5.18	-3.06	**-0.37**	3.50	-2.69	-3.52	**-2.71**
MK	12.01	-13.09	-0.19	**-1.27**	0.55	2.14	-7.87	**-5.18**
RO	56.84	-50.40	-4.42	**2.03**	137.20	-120.37	-12.36	**4.48**
RS	60.13	-56.21	-1.38	**2.54**	46.89	-41.57	-5.10	**0.22**
SI	-8.48	8.71	5.63	**5.86**	-12.48	12.83	14.09	**14.44**
XK	4.86	-2.84	0.50	**2.53**	-0.10	1.71	-3.76	**-2.14**
TOTAL SEE	**26.97**	**79.19**	**-79.94**	**26.23**	**51.72**	**104.22**	**-118.92**	**37.02**

[21] Ibid.

6 Role of the Regulator

The role of the regulator in the modeling process varies from country to country. This chapter gives an indication of possible roles that the regulator can take during the preparation and execution of the modeling process.

6.1 Preparation of the modeling process

The main role of regulators in preparation of the modeling process is setting the regulatory framework, which facilitates and standardizes the collection and exchange of data between relevant stakeholders, as well as the process of market modeling. The standardization ensures that all entities (e.g., the TSO) have access to the relevant data they need for their operation. There are several aspects which need to be covered by the regulator during this standardization process:

- *Facilitate communications and stakeholder engagement*. It must be ensured that the regulations for collecting, preparing, and exchanging the data applies to all relevant stakeholders. These include generators, consumers, network operators, system operators, as well as operators of other relevant assets such as interconnectors and storage facilities.
- *Relevant data*. It should be clear which stakeholder needs to collect and exchange which information. An example would be that the operator of a generating unit would have to provide information on technical characteristics and capabilities to the system operator. The objective should be that the authorized modeling entity has access to all relevant data.
- *Standardization of tools and templates*. To facilitate the standardized data exchange between the market stakeholders and the TSO, the regulator should make regulations concerning the tools and templates to be used for the monitoring, collection, and exchange of data.
- *Process definition*. The entire modeling process should be defined. This includes timing schedules with clear deadlines for all involved stakeholders. Moreover, the approval process as well as the consultation and review of key assumptions should be standardized. Where applicable, an approval process for the key assumptions, modeling inputs and results should be established.
- *Coordination between TSO and DSOs*: Especially with the growing penetration of variable renewable energies, it is increasingly important to ensure proper coordination between the planning processes at the transmission and distribution level, incl. data collection, development of scenarios and assumptions and analysis of modeling results. This should be requested and monitored by the NRA.

It should be noted that the standardization of data exchange processes is not always developed by the regulator and that in some countries, such as the UK, the TSO takes the lead in these activities. However, it is always the regulator's role to ensure the compliance of all market stakeholders with the existing regulation and grid codes.

6.2 Market simulation process

The role of the regulator during the market simulation process varies greatly. In some countries, the regulator has the right to monitor, review, instruct and approve many steps in the process, while in others the involvement might be minimal. The activities through which a regulator can be involved in the modeling process include:

- Definition of assumptions and scenarios

- Review or approval of assumptions or scenarios before the simulation (with or without a consultation of other stakeholders). Possibly including the right to suggest or demand changes to the assumptions or additional scenarios. Could include the right to be provided additional information. Changes to the scenarios could include an extension for the deadline of the stakeholders involved in the review process.
- Review or approval of preliminary results (with or without a consultation of other stakeholders). Possibly including the right to suggest or demand changes to the assumptions or additional scenarios. Could include the right to be provided additional information. Changes to the scenarios could include an extension for the deadline of the stakeholders involved in the review process.
- Review or approval of final results (see Text box 2)

Moreover, the information which the regulator is provided varies from country to country. In some countries, the regulator is only provided the report. In others, they are provided the report and some extra information in appendices, and in some countries, the regulator has the right to be provided all information and results.

Text box 2: Involvement of ACER in the development of the ENTSO-E TYNDP[22]

Figure 12 illustrates the schedule for the development of the ten-year network development plan (TYNDP) by the European Network of Transmission System Operators for Electricity (ENTSO-E). Almost all activities are under the exclusive authority of the TSOs. At least formally, the Agency for the Cooperation of Energy Regulators (ACER) is involved at a very late stage only, i.e., when the final draft of the TYNDP is submitted by ENTSO-E for ACER's opinion (see highlight in green).

2019	October - November	Submission window for electricity transmission and storage projects to the TYNDP 2020
	November - January	Release of draft scenarios for consultation
2020	May	Publication of final 2020 scenarios report
	July	Publication of the draft Identification of System Needs 2040
	July	Publication of the draft Regional Investment Plans
	July – August	Submission window for future projects addressing system needs
	October	Release of the draft TYNDP 2020 package for public consultation
2021	January	Submission draft TYNDP 2020 to ACER for opinion
	March	Publication of the final TYNDP 2020 package

Figure 12: Schedule for development of TYNDP 2020

6.3 Using market simulation results in regulatory practice

Regulators may use the market simulation studies for several purposes, both on a national and regional level. In line with the introduction in chapters 1 and 2, possible applications and further analysis may either be related to investment measures or other technically-oriented studies, for instance with regards to the system integration of renewable energy sources. Likewise, regulators may use market simulations to investigate possible changes to market design, including for instance national wholesale or balancing market arrangements, market integration of renewables or regional integration with other countries, such as market coupling.

One of the prime examples is the use of market simulation results for the cost-benefit analysis (CBA) of proposed investments. As explained by the example in Text box 3, the necessary information is usually obtained by means of market simulation studies, i.e., by calculating and comparing the

[22] ENTSO-E, "TYNDP - Planning the Future Grid," TYNDP, 2020, https://tyndp.entsoe.eu/.

corresponding indicators with and without the proposed interconnector project. As illustrated by the example in Text box 1 on page 23 above, similar simulations may also be used to assess market integration measures, such as market coupling. Although the latter type of analysis may require a slightly different model setup, the principal approach and key indicators are broadly comparable.

In practice, very few regulators engage in market simulations themselves, although they use certain outputs for internal analysis. Nevertheless, to enable a substantiated review and assessment of any market simulation results, regulatory staff must be able to understand the basic principles, drivers and functioning of market simulation models, their limitations, and approaches. These requirements correspond to the underlying objectives of this document, such that we refer to the corresponding chapters for further information.

Text box 3: Use of market simulations for CBA for interconnector projects

In many cases, market simulation results are used for cost benefit analysis (CBA) of new investment projects. A formal CBA is foreseen for the assessment of projects under the European TYNDP, for new interconnectors and, in many countries, also for larger investments on a national scale.

The standard methodology developed by ENTSO-E relies on consideration of different indicators; see Figure 13. Amongst others, the cost benefit analysis has to consider changes in social welfare, which are associated with the proposed project. This indicator is defined as the "ability of a power system to reduce congestion and thus provide an adequate Grid Transfer Capability (GTC) so that electricity markets can trade power in an economically efficient manner."[23] For interconnector projects, social welfare is often measured in terms of changes in producer surplus (generator income minus generation costs), consumer surplus (total savings for consumption at wholesale market prices), and congestion rents. The corresponding values can all be derived by market simulations, either directly or, in some cases, based on ex-post data processing.

Similarly, market simulations may also provide insights on other indicators, including security of supply (loss of load), RES integration (curtailment of RE), or variations in carbon emissions.

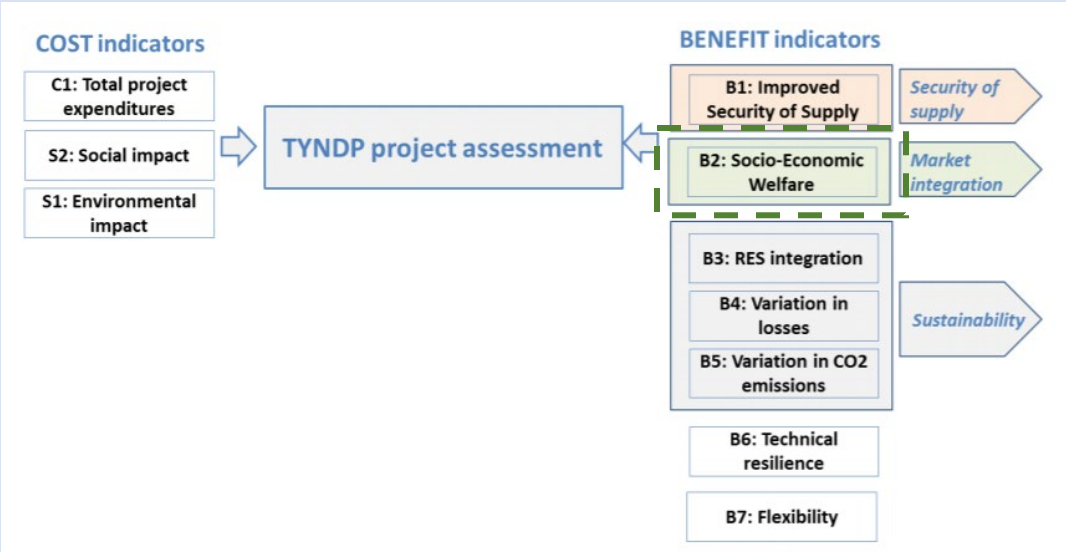


Figure 13: Cost and benefit indicators under ENTSO-E CBA Methodology[24]

[23] ACER, "CBA Methodologies for Electricity Transmission Infrastructure and Scenarios for Energy and Power System Planning," 2016, https://www.acer.europa.eu/Events/ACER-workshop-on-scenarios-and-cost-benefit-analysis-methodology-for-assessing-cross-border-infrastructure-projects/Documents/Final%20Report%20-%20CBA%20and%20scenarios.pdf

[24] Ibid.

7 Concluding Remarks

This primer has provided an overview of the application of market simulations in the context of energy regulation. Market simulations may be used for a range of different purposes, ranging from capacity expansion planning, forecasting of current or future market prices, cross-border exchanges, RE generation or curtailment, or production costs to assessing the impact of changes to market design.

In most countries, regulators do not engage into market simulations themselves but rely on the corresponding activities of system or network operators or procure specific studies from specialized service provides. In either case, however, energy regulators must be able to understand the underlying principles, the role of different inputs, and appropriate tools and approaches for interpretation and further results of modeling results. Likewise, it seems useful if regulators have a basic understanding of the key features, capabilities and limitations of different modeling techniques and tools, which are commonly based on linear programming, heuristics and/or stochastic optimization.

Besides the modelling tool and configuration being used, the outcome of market simulation studies first and foremost depends on the input assumptions being used and the detailed scope of the analysis. For this reason, energy regulators need to pay attention to the definition of scenarios and inputs assumptions, data sources and the process for collecting relevant inputs from stakeholders where applicable. Amongst others, this applies to the structure of generation capacity, consumption and load, hourly profiles of load and variable generation, commodity prices and many other factors. Consequently, it is important for regulator to gain at least a basic understanding of important categories of input data and their (typical) impact on different types of market simulation outcomes.

Equally, energy regulators should be capable of understanding and interpreting typical outputs. As explained above, market simulations can provide a wide range of outputs, with different factors being relevant for capacity expansion studies as opposed to detailed short-term studies. In addition, some indicators may require further analysis, in order to derive specific contributions for certain types of regulatory analysis and assessments.

Depending on the scope and responsibilities for market simulations, the role of energy regulators may vary on a case to case basis. Especially in case of market simulations being carried out by regulated entities, such as network operators or TSOs, regulators should focus on the following three areas:

- **Preparation of the modeling process**, with the aim of setting a framework that facilitates and standardizes the collection and exchange of data between relevant stakeholders, as well as the process of market modeling
- For the **market simulation process**, the role of the regulator should generally focus on monitoring the process, reviewing and/or approving key inputs, scenarios and (preliminary) results and ensuring sufficient stakeholder involvement. Regulators should take a proactive and cooperative approach and are involved at an early stage, incl. the development of scenarios.
- **Use of market simulation results in regulatory practice**, related either to investment measures, technically-oriented studies, or to investigate possible changes to market design. In many cases, market simulations will be used to provide key inputs for subsequent cost-benefit analysis (CBA).

8 Annex

8.1 Illustrative Example of Market Simulation Tools

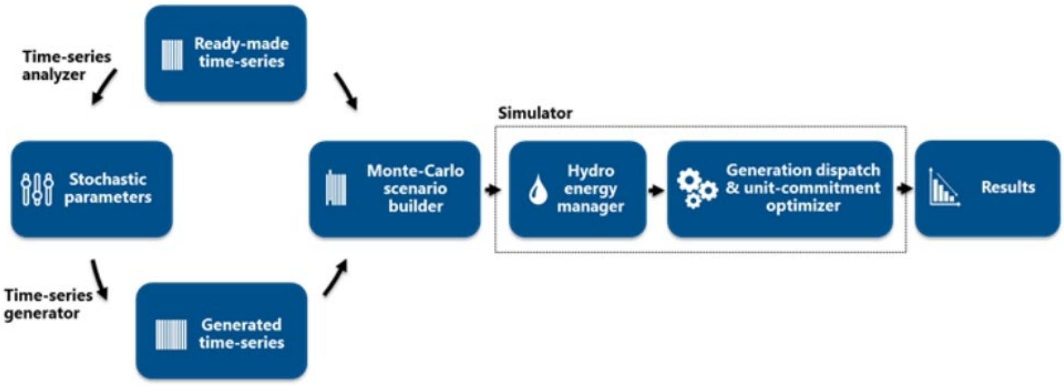
8.1.1 Antares (A New Tool for Adequacy Reporting of Electrical Systems)

Antares (A New Tool for Adequacy Reporting of Electrical Systems) was developed by the French TSO, RTE, for its own use[25] and was later made available to other TSOs and other parties free of charge.[26] Since then, Antares has been used by several other transmission system operators, regulators, academics, or consultants, largely for technical or policy-related studies.

As suggested by its name, Antares was originally developed for the purpose of assessing resource adequacy. Over time, it has also been developed for simulating the short-term operation of electricity markets, mainly as a tool for supporting transmission expansion analysis. Nevertheless, Antares does not currently include any dedicated functionalities for least-cost generation expansion planning and, arguably, it is also less suited for short- to medium-term forecasting of market prices.

Antares conducts economic dispatch based on the concept of mixed integer linear programming (MILP) aiming to minimize the overall system cost while achieving supply-demand equilibrium subject to defined constraints. For this purpose, it calculates a range of plausible operating combinations that reproduce various events that can happen during a one-year system operation (such as availability of conventional power generation, climatic and weather events that impact load, wind and solar generation; variable rainfalls affecting hydro generation, etc.).

As illustrated by Figure 14, Antares builds on sequential Monte-Carlo (MC) simulations with the objective to emulate the economic behavior of the power system. In this sense, each MC-year is built on a succession of weekly sub-problem optimizations. The model calculates the operating set-points for the whole system (optimal weekly unit-commitment and hydro-thermal scheduling) making use of the entered assumptions (costs per power plant, load, availability, etc.).[27]



[25] RTE anticipates the evolution of the French and European electrical system using Antares. RTE published the latest mid-term adequacy forecast on the evolution of the electrical system over a five-year period considering the development of renewable energies, the evolution of the thermal fleet and the commissioning of new interconnections.

[26] Antares-Simulator can be downloaded free of charge, installed on any local computer or server, and used without any limitation.

[27] Antares allows different formulations of the optimization problem with several trade-offs between computational time and complexity. Simplified versions of the systems can be solved in very short times.

Figure 14: Antares model workflow[28]

8.1.2 PLEXOS Market Simulation Software

PLEXOS Integrated Energy is a modeling software developed by Energy Exemplar (formerly Drayton Analytics) and originally conceived for market simulations and generation optimization in thermal systems. Today, PLEXOS has developed into one of the most widely used market simulation packages. In Europe, it is used by ENTSO-E, an increasing number of TSOs, and many generators, utilities, and energy traders as well as investors, regulators, consultants, and academic institutions.

PLEXOS is based on the concept of linear programming and supports mixed integer optimization (MILP). It allows power market modeling and transmission network modeling including load flow security and re-dispatch analysis, herewith using a nodal representation of a power system. It is commonly used for market analysis and capacity expansion planning and portfolio optimization.[29] In addition, PLEXOS has gradually been expanded to include elements of stochastic hydro optimization and links with heat supply and gas networks.

8.1.3 SDDP (Stochastic Dual Dynamic Programming)

Stochastic Dual Dynamic Programming (SDDP), in contrast to the previous tools, is a probabilistic multi-area hydro-thermal production cost optimization tool (dispatch) developed in the late 1980s by the Brazilian company Power System Research (PSR). It was specifically developed for optimizing operation of hydropower storage over the medium-term under stochastic uncertainty and focuses on the determination of so-called water values, although it also offers (less complex) modules for optimizing the short-term operation of mixed hydro-thermal systems.

This tool has been applied in over 40 countries to optimize the use of hydro resources (e.g., South and Central America, U.S. and Canada, Austria, Spain, Norway, the Balkan region, New Zealand, and China). Typical users are consultants, generation companies, grid operators, regulators, and government planners for short, medium- and long-term operation studies.

The simulation of a hydro predominant system is highly complex due to the uncertainty involved in the water inflow. The main characteristic of a hydro plant is that the operator can choose between using the stored hydro energy today (reducing immediate generating costs) or storing the hydro energy for use in the future. In the situation where the operator decides to use the hydro energy today and future inflows are high (allowing reservoir storage levels to increase), the overall system operation is optimized. However, in case of a future drought, more expensive thermal generation will be required to cover the insufficient hydro energy (non-optimal system operation). Thus, the decision of storing or using the available hydro resources relies on an analysis of the consequences of each decision based on future price scenarios.[30]

The importance of detailed hydropower scheduling modeling adds complexity that is not easily incorporated in a Linear Programming (LP) problem. The hydrothermal scheduling is based on a water release policy along the planning period that minimizes the operating cost (including the unserved

[28] Antares Simulator, "Shedding Light on the Future of the Energy System," 2020, https://antares-simulator.org/.
[29] Energy Exemplar, "Energy Exemplar - The Market Leader in Energy Simulation Software."
[30] PSR, "Software | PSR – Energy Consulting and Analytics," Software | PSR – Energy Consulting and Analytics (PSR, 2020), https://www.psr-inc.com/softwares-en/.

energy cost) of meeting demand over this period.[31] The water release policy solves a stage optimization problem by minimizing the current cost of thermal generation plus the expected future cost of meeting demand. SDDP calculates the least-cost stochastic operating policy of a hydrothermal system,[32] as well as several economical indexes such as the spot price (per submarket and per bus), wheeling rates and transmission congestion costs, water values for each hydro plant, marginal costs of fuel supply constraints, and others.[33]

8.2 Input data types

8.2.1 Basic market and network structure

Different concepts are used internationally with regards to consideration of network constraints. As illustrated by Table 7, this primarily relates to the difference between zonal and nodal pricing and, in the latter case, between the use of bilateral net transfer capacities (NTC) as opposed to the so-called 'flow-based' approach in the so-called CORE region in Central and Eastern Europe. In the latter case, the situation gets even more complex as different approaches for forward trading (NTC) and day-ahead market coupling (flow-based) are involved. As European practice shows, the electricity market may furthermore be split into additional 'bidding zones,' whereby each bidding zone corresponds to a separate market with its own zonal price.

In many zonal electricity markets, transmission constraints between countries are accounted for by NTCs, which in practice corresponds to two simple limits to commercial cross-border exchanges at each border (i.e., one in each direction).

In contrast, flow-based approaches require many additional inputs.[34] This may result in several dozen or even hundreds of additional constraints to be considered. Moreover, most of these parameters may change as a result of the prevailing market and/or dispatch situation such that usually require an iterative approach, including comprehensive network analysis.

Finally, Nodal markets require a detailed representation of the grid, including nodes, branches (e.g., lines and transformers), and the switching states and technical parameters (e.g., impedance, rating) of the latter. The corresponding data needs are similar to those for detailed grid analysis.

[31] For instance, the water release policies for a single reservoir can be specified by an expected marginal water value measured in EUR/m^3. This is defined for each possible reservoir level and is the opportunity cost of releasing one unit of water. The optimal release policy generates from all thermal plants that are no more expensive (in EUR/MWh) than the expected marginal water value multiplied by a conversion factor (m^3 per MWh).

[32] The solution methodology traditionally used to solve this dispatch problem is known as stochastic dynamic programming (SDP). However, SDP runs into a computational problem in systems with a large number of hydro plants. The SDDP model applies a new solution methodology representing the future cost function of traditional SDP as a piecewise linear function. Dual dynamic programming computes a water release policy for several different reservoirs with different locations, inflow processes and river systems (multi-reservoir).

[33] Lohmann, Hering, and Rebennack, "Spatio-Temporal Hydro Forecasting of Multireservoir Inflows for Hydro-Thermal Scheduling."

[34] Amprion et al., "Documentation of the CWE FB MC Solution as Basis for the Formal Approval-Request" (Brussels, September 5, 2014), https://www.acm.nl/sites/default/files/old_publication/bijlagen/13001_140530-cwe-fb-mc-formal-approval-request.pdf.

Table 7: Typical market models with regards to consideration of transmission constraints

Basic approach	Consideration of transmission constraints	Bidding zone	Example
Zonal pricing	Net Transfer Capacity (NTC)	country level	Spain, Portugal, Finland
		sub-national	Denmark, Italy, Norway, Sweden
	flow-based capacity allocation	country level[35]	CORE region (Central and Eastern Europe)
Nodal pricing	Detailed grid model (DC or AC): Locational marginal pricing (LMP)	N/A	U.S., New Zealand, Russia, Singapore

Source: DNV GL

These considerations highlight a few factors, which need to be considered for market simulations.

- Ideally, the model setup should be representative of existing arrangements, such that for instance a flow-based or nodal model would be preferable if this concept is used in practice.
- The complexity and data requirements of both nodal and flow-based approaches are much larger than those of simple transport models based on NTCs. Moreover, especially in terms of flow-based capacity allocation, the underlying calculations require many user assumptions, many of which remain ultimately arbitrary. Such assumptions may thus introduce a major degree of uncertainty, especially when being applied to future years with a changing grid, generation and market structure and conditions, thereby undermining the higher 'accuracy' of a more detailed approach.
- Both in Europe and, to a lesser extent, also in the U.S., it is thus common practice to rely on more simplified approaches for future studies, e.g., by relying on NTC-based simulations and/or by using a simplified grid model consisting of multiple smaller zones. It should be noted that a simplification of the modeling approach impacts the model outcomes significantly, which should be considered when making decisions based on these modeling results.

8.2.2 Load

The current and future development and structure of load is one of the key inputs as it is the immediate driver of the need for electricity generation. For the purpose of the different types of analysis introduced in chapter 2, it is useful to differentiate between several dimensions as follows:

- Consumption;
- Peak load;
- Load profile and load duration curves;
- Demand response / Demand side management; and
- Zonal / Nodal distribution.

Consumption defines the total volume of electricity to be produced and is usually measured in TWh/year or GWh/year. For market simulations, it is usually necessary to consider gross annual consumption, i.e., inclusive of network losses at the transmission and distribution level, which may be

[35] Conceptually, flow-based approaches can be equally applied to sub-national bidding zones.

treated either as part of total consumption or as a separate component. Similarly, the generator self-consumption can be either included under consumption or be considered on the generation side.

Peak load, in contrast, defines the maximum load to be supplied at any time throughout a given year (or a similar period) and is usually measured in MW. The definition and measurement of peak load should be consistent with that of consumption, i.e., in terms of consideration of network losses and generator self-consumption. This measure is of key importance especially for market and generation simulations as it is the key driver for the need for 'firm capacity,' i.e., the volume of (generation) capacity, which must be securely available under peak load conditions to supply demand[36]. As such, peak load is a primary input for (medium-term) generation or system adequacy assessments as well as for long-term generation planning.

For most types of analysis, however, additional information on the time pattern or use is required. Typical indicators are, for instance, detailed load profiles or load duration curves:

- **Load profiles** determine the (hourly) change of load over time, i.e., chronologically, and are usually measured either in MW or as a proportion of peak load (e.g., % or p.u.). The temporal variability of load is the key driver for unit commitment and (hourly) dispatch of generation, other flexible resources, and cross-border exchanges. In turn, it thus impacts the operating patterns and average use of different resources and, in liberalized markets, the profile of wholesale electricity prices. For these reasons, knowledge of load profiles is essential for simulating daily market operations as well as for production cost simulations.
- **Load duration curves** principally correspond to a different representation of load profiles, i.e., with load being sorted in descending order (see Figure 15). Whilst load duration curves do not allow for the determination of detailed dispatch profiles, they do provide information on the number of hours, or share of time, for which a certain volume must be supplied to the system, i.e., by generation, storage, or imports. This in turn allows estimating the average utilization of the resources being used for this purpose, thereby creating a link between the volume of capacity required and its average utilization, fuel consumption and variable costs. Traditionally, load duration curves have been a key input for generation expansion studies and medium-term planning. The use of duration curves becomes increasingly difficult in interconnected systems or markets and in systems with a high penetration of variable renewable energies.

[36] Under consideration of possible contributions from electricity import or demand response.

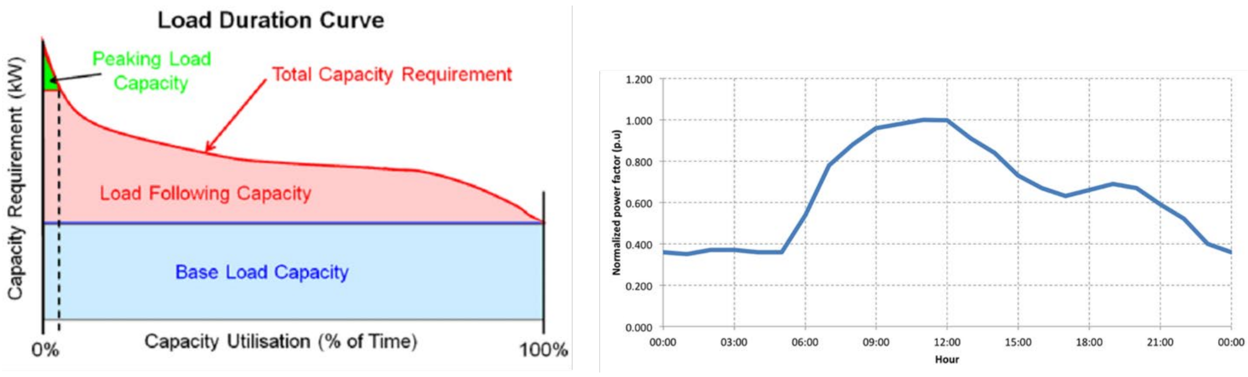


Figure 15: Load duration curve (left[37]) vs. chronological load profile (right[38])

Besides these key drivers, it may also be important to consider the potential for **demand response** and/or short-term **demand side management**, i.e., as a measure to temporarily reduce, increase and/or time-shift demand at times of peak load or minimum residual load (e.g., caused by VRE). As the corresponding capabilities are usually limited to a certain time, they are primarily important for simulating daily market and/or system operations, although they may also be relevant for investment planning and adequacy studies.

All load data generally has to be broken down to a zonal or nodal level, i.e., in line with the overall assumptions on the basic market structure as discussed under 8.2.1 above. In practice, however, this is often limited to consumption, whilst the same (national) load profile may be used for multiple nodes or zones within a given country.

8.2.3 Generation, storage, and other flexible resources

A large proportion of the required inputs are related to specification of power plants and other flexible resources, including for instance energy storage systems on the 'supply side.' From a modeling perspective, this may furthermore include various categories of demand-side resources, like demand response, power-to-gas units, electrolyzers, and other consumers, which may respond to market signals and/or be subject to centralized dispatch. Besides existing facilities, future-oriented studies furthermore require information on the decommissioning of existing plants, the commissioning of units under construction or planning and, for generation expansion studies, in 'candidate plants,' which may be considered for this purpose.

Without going into detail, the following list contains an illustrative summary of input parameters, which need to be considered for different types of market simulation models and studies:

- **General information**: Includes name and location of resources, de-/commissioning dates where applicable as well as information on whether the resources are subject to the market or centralized dispatch.
- **Technical and economic characteristics**:

[37] J Carlsson et al., *Best Practices and Informal Guidance on How to Implement the Comprehensive Assessment at Member State Level* (Luxembourg: Publications Office, 2015).
[38] Paolo Lazzeroni et al., "Impact of PV Penetration in a Distribution Grid: A Middle-East Study Case," in *2015 IEEE 1st International Forum on Research and Technologies for Society and Industry Leveraging a Better Tomorrow (RTSI)*, 2015, 353–58, https://doi.org/10.1109/RTSI.2015.7325123.

- Technology and fuel type(s) used, including information on different types of hydropower plants (e.g., run-of-river, pondage, (pump) storage with or without natural flows), technical and/or economic lifetimes;
- Number of units, installed / maximum capacity, minimum stable level, heat rates / efficiency, round-trip-efficiency (pump/storage), ramping and start up capabilities, minimum up/down times, storage capacity etc. (compare Figure 16);
- Frequency and duration of planned maintenance events, forced outage rates and durations;
- Fixed and variable operation and maintenance costs; and
- Capital / Investment costs, annuity / interest rates (candidate plants).

* **Resource availability and other operating constraints**:
  - Conventional plants: fuel supply constraints, take-or-pay (ToP) contracts etc.
  - Hydropower: Volume, time profile and variability of natural inflows, hydrological constraints (e.g., for irrigation, regulation of water levels etc.);
  - Variable RE: Time profile and variability of resource availability, forecast errors; and
  - Must-run or other operating constraints, for instance due to network constraints, for heat supply (CHPs) etc.

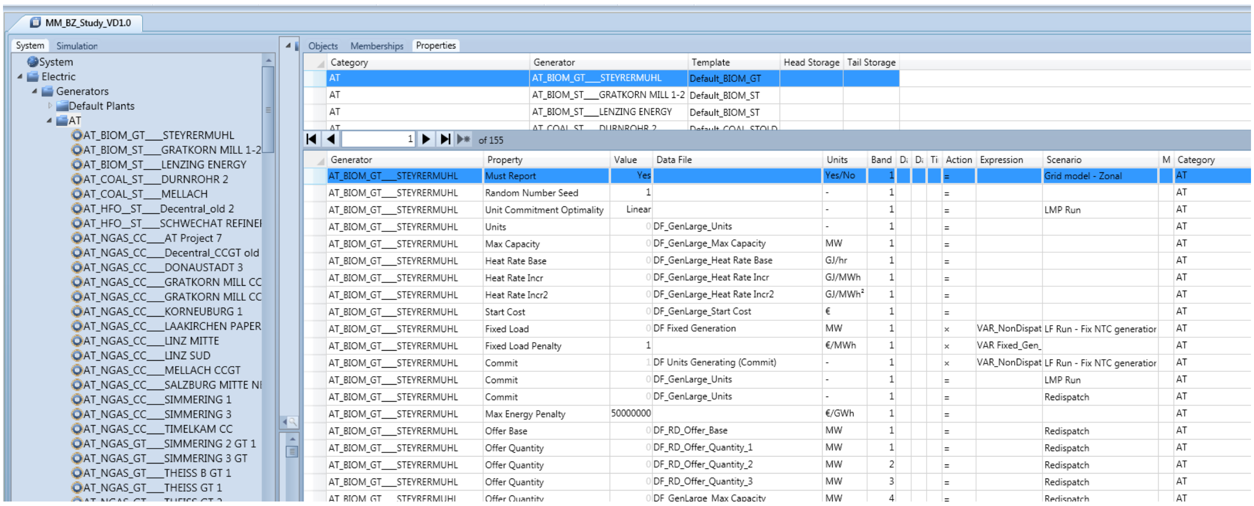


Figure 16: Example of technical inputs for a power plant in PLEXOS

Source: DNV GL

Depending on the software being used, users may have the choice between several hundred parameters. For instance, PLEXOS contains more than 250 so-called 'input properties' for generators alone, even without counting a large number of other parameters that may be used to specify the relation with the network, fuel supply, hydropower reservoirs, heat supply, desalination, etc.

In practice, however, only a fraction of these 250 properties will really be required in most cases and the relative importance of different categories of inputs again depends on the scope and purpose of the modeling exercise. Additional inputs can significantly increase the computation time, which highlights the need for carefully balancing the desired degree of 'accuracy' against input requirements and model complexity.

8.2.4 Commodity prices and costs of technology

Some of the parameters mentioned above, i.e., capital and O&M costs are obviously influenced by overall economic and other developments, which do not necessarily depend on the local country or market, or at least not entirely. For instance, effective capital costs also depend on the evolution of interest and exchange rates, whilst O&M costs may also be influenced by the development of local labor and other costs. Similarly, both capital and O&M costs – as well as some of the technical parameters discussed above – may be influenced by technical progress. Generally, these developments are primarily important for long-term studies, mainly in the context of generation expansion or renewables integration studies.

Similar considerations apply to fuel and other commodity prices, such as carbon prices in the European ETS or similar mechanisms or taxes elsewhere. Changing fuel prices etc. have an immediate impact on the variable costs of generation. In addition, they often are subject to considerable volatility and may even change the economic merit order of different technologies, as for instance experienced in the European electricity markets in the aftermath of the 2008/2009 financial crisis and, more recently, the reform of the ETS mechanism. Consequently, fuel and commodity prices are a primary input for both long-term planning and short-term market or production cost studies, whilst they are of less relevance for adequacy analysis.

8.2.5 Political, environmental and reliability targets and constraints

Long-term planning studies, for instance for generation or system expansion or renewables integration, generally need to comply with defined external targets or constraints, most of which are ultimately set by policymakers, the regulator, or other authorities. Typical examples include:

- Targets or constraints with regards to fuel, technology, or location of future plants, for instance as defined in a country's energy strategy or similar binding or non-binding plans, agreements or other documents at a national, sub-national or international scale;
- Environmental targets and constraints, for example on the reduction of carbon or other emissions, or the share of electricity generated from renewable energies or low-carbon technologies; and
- Security and reliability standards, e.g., on the permitted number, frequency, or duration of supply interruptions (at the system level), required reserve margins, restrictions on the share of imported fuels, (or electricity) etc.

Especially for the last category, it is often also necessary to specify relevant indicators and input parameters. Examples include the value of lost load (VoLL), i.e., the estimated value that consumers would be willing to pay to avoid a disruption of their electricity service,[39] the loss of load probability (LOLP), energy not served (ENS), or others.

[39] IRENA, "Planning for the Renewable Future: Long-Term Modelling and Tools to Expand Variable Renewable Power in Emerging Economies," 2017, /publications/2017/Jan/Planning-for-the-renewable-future-Long-term-modelling-and-tools-to-expand-variable-renewable-power.

Please note that typical reliability measures for electricity supply at the retail or distribution level, such as SAIDI, SAIFI etc. are not usually considered by market simulation models as they primarily depend on the structure and reliability of distribution networks.

8.2.6 Reserve requirements and system constraints

In some countries, such as Italy, Spain, Ireland, Greece, Russia or most of the U.S., the centralized electricity markets cover the supply of wholesale electricity as well as reserves and, potentially, other ancillary services. In contrast, in many other European countries, wholesale electricity markets are largely decoupled from the provision of reserves and other ancillary services. At first sight, this seems to suggest that it would be possible to focus on the generation of wholesale electricity only.

Nevertheless, the final dispatch of generators (and other resources) may still be influenced by the underlying technical needs and requirements. Indeed, the corresponding plants must either retain part of their capacity or keep more expensive units in operation as a precondition for providing such services. As a result, the capacity, which can be effectively made available to the market will be reduced, and/or some more expensive units may be subject to 'must run' constraints.

As a result, it is often necessary to include those services into the market simulation, in order to obtain realistic results. This may require the implementation of additional model features and constraints to represent the procurement of relevant products, for instance for frequency containment reserve (FCR), frequency restoration reserves (FRR) and replacement reserves (RR). To do so, the model obviously requires inputs on the necessary volumes of reserves to be held available.

In some countries, the operation of individual power plants or generators within certain parts of the network may furthermore be subject to additional operating constraints, for instance due to congestion in 'weaker' parts of the transmission grid or a limited degree of flexibility. In addition to plant-specific constraints discussed under section 8.2.3 above, it may thus also be necessary to implement similar constraints on groups of plants or resources.

8.3 Collection and Estimation of Input Data

For setting up a market simulation model, it is necessary to either collect and/or estimate the input data, principally the entire range of parameters introduced in chapter 3. Data can be obtained from various sources. This section provides additional information on potential sources of data for the input parameters. Where applicable, this section also discusses potential approaches, which may be considered for deriving input parameters that cannot simply be taken from an existing source.

Figure 17 provides an overview of typical sources, which are used for collecting and/or defining the necessary inputs for market simulation models. In the following, these data sources are presented and illustrated using appropriate examples. Moreover, we also comment on their relevance or suitability for different categories of input parameters.

Figure 17: Typical sources of input data for market simulations

Source: DNV GL

8.3.1 Governmental targets and strategies

As discussed in section 8.2.5 political, environmental, and reliability targets and constraints are often based on political, legislative, and/or regulatory decisions. As a consequence, these inputs can often be directly taken from according legal, governmental; or regulatory documents. Many countries publish strategies concerning their electricity sector, especially with targets and forecasts regarding carbon emission reduction and renewable penetration. Some reports also contain technology-specific forecasts such as for EV penetration or electric heating in the residential and industrial sector. Typical examples include traditional 'energy strategies' or development programs, such as those in use in many countries that are part of the Energy Community. However, similar studies, plans or programs also exist in many EU member states.

One relevant example of national planning and strategies are the National Energy and Climate Plans,[40] which must be prepared by all EU member states and parties to the Energy Community. The NECPs contain a detailed and descriptive mapping for the development of the energy system of the corresponding country for the period between 2021 and 2030. Amongst others, the NCEPs also contain information on developments in energy efficiency, renewables, greenhouse gas emission reductions, interconnections, and research and innovation efforts. As a result, these plans can also be used to derive inputs for various other areas, such as the development load, installed capacity of generation, or cross-border capacities.

For illustration, Text box 4 outlines some information which can be extracted from the NCEP, using the example of Croatia. In this particular example, the text box provides information on the development installed VRE capacity and energy consumption. However, as mentioned before, the full plan also includes a wide range of other assumptions and other potential inputs for modeling of the country's electricity market. It should be noted that these plans tend to be unrealistically optimistic and ambitious regarding the penetration of new low-carbon technologies in order to achieve the carbon emission reduction targets.

[40] European Commission, "National Energy and Climate Plans (NECPs)," Text, Energy - European Commission, January 23, 2019, https://ec.europa.eu/energy/topics/energy-strategy/national-energy-climate-plans_en.

Text box 4: National Energy and Climate Plan for the Republic of Croatia [41]

The Croatian government provided the National Energy and Climate Plan as required by the EU, which provides detailed information on the expected developments of the energy system until 2030, e.g., the installed capacity of different generation types, the generated electricity, and the anticipated electricity consumption. Moreover, the report includes an outlook for the energy system until 2050. Figure 18 shows the forecasted installed renewable capacity and the expected primary and final energy demand in Croatia, respectively.

Installed renewable energy capacity	**Primary and final energy consumption**

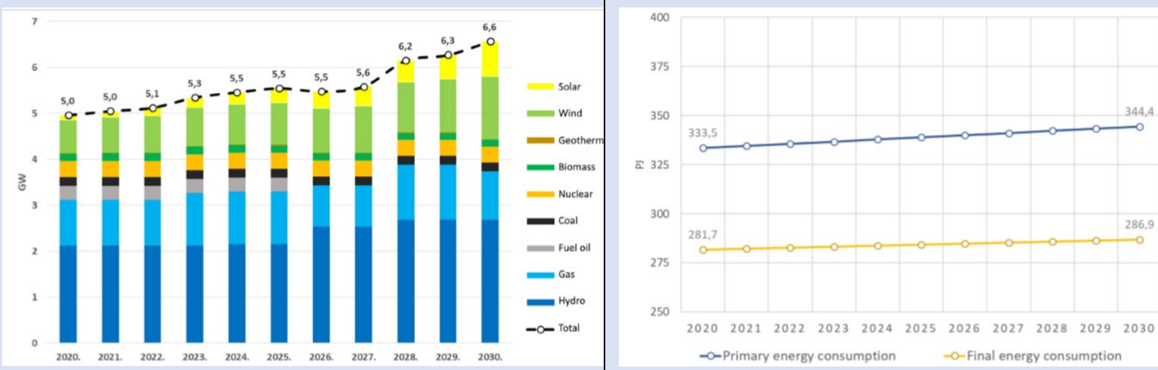


Figure 18: Development of RE capacity and consumption under the Croatian NECP [42]

8.3.2 Rules, standards, and criteria

Another potential source of information includes rules, standards, and criteria at a national or international level. Examples include local market rules, the grid code or similar documents at a national scale, NERC standards in the U.S., or the EU Network Codes within the European Union and the Energy Community.

In many cases, there will be no direct relation between these rules and the detailed model setup. Nevertheless, it may be possible to rely on the definition of mandatory reliability standards, or grid code requirements may be used to derive suitable assumptions on reserve types and requirements, or the minimum capability of different resources (present and future) for providing such services.

Implicitly, market rules – as well as current arrangements – are also a key source for the definition of the basic market structure (compare section 8.2.1).

8.3.3 Use of system operator, market operator, and stakeholder data

Where market simulations are carried out by the (transmission) system operator, the operator of the (national) wholesale electricity market or similar entities, the corresponding entities can often rely on a large volume of information that is already available to them. Prime examples include information on cross-border capacities (or detailed data where applicable), standing technical data of existing power

[41] Republic of Croatia - Ministry of Environment and Energy, "Integrated National Energy and Climate Plan for the Republic of Croatia for the Period 2021-2030," 2019, https://ec.europa.eu/energy/sites/ener/files/documents/hr_final_necp_main_en.pdf.

[42] Republic of Croatia - Ministry of Environment and Energy.

plants and similar assets, reserve requirements, historic load and, in many cases, production profiles, mandatory security and reliability targets etc.

When simulating the present market, much information may thus be readily available already. Similarly, the data needs for future market and/or generation plans and studies are closely related to similar exercise on the network side, and vice versa. Depending on the sequence and coordination of these activities, it may thus be possible to utilize information that is available already.

Another possible data source for modeling inputs is data collection from market stakeholders. The data can be obtained through surveys or by a mandatory data provision. Such data may for instance be collected from present or prospective generators, (large) consumers, and retail suppliers. In many cases, information is collected by the appropriate network or system operators at the transmission (TSO) or distribution level (DSO) and then passed on by the DSOs to the TSO where applicable.

Depending on the data needs, typical data to be collected from stakeholders may include, for example:

- Type, peak capacity, annual consumption of consumption sites (present and future), including distribution offtakes from the transmission grid where applicable (i.e., for DSOs);
- Type, location, capacity, and other relevant technical characteristics of existing and/or planned generation and/or storage facilities, including larger facilities in distribution networks and /or information / estimation by DSOs on the corresponding volumes (to be) connected to their networks;
- Historic production and/or load profiles, including forecast values (VRE) for transmission-connected facilities, larger plants connected to distribution networks, or on aggregate basis for distribution networks;
- Flexibility available from large consumers (e.g., demand response); and
- Present or expected operating constraints (i.e., in a similar way as exchange for operational planning).

To facilitate this process, it is desirable to establish a clear mandate for the TSO, and/or other relevant parties (like DSOs) to request such data from stakeholders, provide for a clearly defined process and to develop and implement standardized templates and/or data formats. As in the case of Great Britain, this may, for instance, be achieved through the grid code (compare Text box 5) or similar documents. Alternatively, similar standards or documents may be drawn up by the TSO itself, potentially subject to final approval by the regulator, i.e., as a means to create an obligation on concerned stakeholders.

With a growing penetration of distributed resources, it is increasingly important to also involve facilities connected to distribution networks in this process. Within the Energy Community, corresponding obligations can partially rely on the applicable stipulations of the EU Network Codes, such as the requirements under the Requirements for Generators (RfG) by ENTSO-E. [43] Similarly, it will become increasingly important to establish and ensure a well-coordinated data exchange between the TSO and DSOs as explained under the Primer on Load Flow Analysis in the context of grid planning.

[43] ENTSO-E, "Requirements for Generators," 2016, https://www.entsoe.eu/network_codes/rfg/.

Text box 5: Collection of planning data under the British Grid Code [44]

The Planning Code as part of the British Grid Code includes detailed provisions on the scope and process for data to be provided by relevant stakeholders to the TSO National Grid for long-term network planning. The corresponding requirements apply to parties with present or prospective assets (to be) connected with the transmission grid. For connected assets, "connected planning data" must be provided. Depending on the planning stage of future projects, stakeholders must first provide less detailed "preliminary project planning data" and then "committed project planning data", when the project moves to a more concrete stage. Each of these data sets have a standardized set of information which need to be made available to National Grid according to a defined time schedule. The data requirements are also documented in the Planning Code.

In the following, typical data requirements for generators and large consumers and are briefly described:

- **Generators:** Generators, which want to be connected to the electricity system, need to provide data on technical characteristics such as the maximum and minimum power output, reactive power dispatch limitations, or classification of the generating unit (e.g., fossil brown coal/lignite, geothermal, marine, or wind offshore). Generators must also provide information on the expected connection date, connection entry capacity and transmission connection capacity. Moreover, generators must provide forecasts of their expected power production. For some technologies, such as offshore wind, there are special information requirements such as the preparation of the Offshore Development Information Statement.
- **Industrial and large-scale consumers:** Industrial and large-scale consumers must provide information to the system operator when connecting to the grid or altering the connection (e.g., increase capacity). For the example of the UK, new electricity consumers must provide the standard planning data (e.g., detailed demand forecast), the planned date of connection and the maximum power demand. Consumers which are already connected to the grid must make historic, current, and forecast demand data available to National Grid, explicitly stating expected peak demand and the anticipated days of peak and demand.

8.3.4 Use of publicly available studies, reports, or databases

Some of the key sources for future modeling assumptions are publicly available studies, reports, or databases, including delivery of tailor-made reports by commercial service providers. In practice, modelers can rely on a vast range of possible sources. For the purpose of this primer, the following categories appear particularly relevant:

- Projections of future energy or electricity demand and supply;
- Projections of future technology development and costs;
- Commodity price forecasts; and
- Information on resource availability and profiles.

Projections of future energy or electricity demand and supply

Many (international) organizations regularly develop and publish general forecasts of how national, regional, or even the global energy or power system will develop over time. Examples include the World Energy Outlook by International Energy Agency (IEA),[45] the World Energy Scenarios by World Energy Council (WEC),[46] the International Renewable Energy Agency (IRENA) roadmaps, the EU

[44] National Grid, "Planning Code" (National Grid, 2020), https://www.nationalgrideso.com/document/33871/download.
[45] *WORLD ENERGY OUTLOOK 2019.* (S.l.: IEA, 2019).
[46] World Energy Council, "World Energy Scenarios | 2019: European Regional Perspectives," 2019, https://www.worldenergy.org/publications/entry/world-energy-scenarios-2019-european-regional-perspectives.

forecasts, and a large number of separate studies by academic or research organizations, industry associations and others. Depending on the regional scope of a given study, these sources may be used to derive (consistent) assumptions on other / neighboring countries, or to put one's own assumptions into a larger context (see also the discussion under chapter 4 above).

Another relevant category includes national energy strategies, long-term network developments, and similar documents of other countries, or for wider regions, such as the ENTSO-E TYNDP.

Projections of technology development and costs

Either in the context of future energy supply studies or on a stand-alone basis, many organizations also prepare (regular) reports on the future development and costs of different technologies, including for conventional generation, renewable energies, battery energy storages, and others. Likewise, some industry associations, commercial services providers, or international organizations also provide information on the costs and reliability of existing technologies.

Relevant examples in this category include for instance:

- *Technology reports*: Technology reports typically contain current and anticipated developments of technical characteristics and price levels for one or more technologies. Examples include the IEA's Energy Technology Perspectives (see Text box 6), the "Renewable Power Generation Costs" report and similar publications and databases by IRENA (e.g.,[47] or similar publications from national institutions like NREL in the U.S. (e.g.,[48]) or the Fraunhofer institutes in Germany. In addition, modelers may rely on surveys and forecasts by commercial service providers, such as Bloomberg New Energy Finance or Lazard for renewable energies or storage.
- *Operation and maintenance cost:* Costs for operation and maintenance for individual power plants are often unknown, even to the stakeholders. Cost assumptions for market modeling are thus often based on typical cost assumptions which are published by different institutions, such as NREL in the U.S.[49] Some reports also contain projections for the future development of the operation and maintenance cost for energy technologies.
- *Reliability statistics*: Proper market simulations require adequate assumptions on the reliability of existing and new plants, including plants that may not yet be present in the local market. In these cases, it may be necessary to rely on external statistics, such as those managed by VGB PowerTech in Europe, NERC in the U.S. and a variety of other institutions and companies at a national level. Alternatively, relevant estimates may also be taken from similar studies, such as those prepared by ENTSO-E, on behalf of the European Commission, or various other international, national, academic, or private organizations.

[47] IRENA, "Future of Wind," 2019, /publications/2019/Oct/Future-of-wind; International Renewable Energy Agency, *Electricity Storage and Renewables: Costs and Markets to 2030* (International Renewable Energy Agency, 2017), /publications/2017/Oct/Electricity-storage-and-renewables-costs-and-markets; IRENA, "Renewable Power Generation Costs in 2018," 2018, /publications/2019/May/Renewable-power-generation-costs-in-2018.

[48] Laura Vimmerstedt et al., "2019 Annual Technology Baseline ATB Cost and Performance Data for Electricity Generation Technologies" (National Renewable Energy Laboratory (NREL), Golden, CO (United States); Oak Ridge National Laboratory (ORNL), Oak Ridge, TN (United States), 2019), https://doi.org/10.11578/1544562.

[49] NREL, "Distributed Generation Energy Technology Operations and Maintenance Costs | Energy Analysis | NREL," 2020, https://www.nrel.gov/analysis/tech-cost-om-dg.html.

When applying inputs from other countries or geographies, especially in case of studies with a more global scope, it may be necessary to carefully review and adjust the corresponding values as they may not be directly applicable to the region under study.

Text box 6: Energy Technology Perspectives by IEA [50]

The Energy Technology Perspectives are a technology report by the IEA which highlights how technology can help to achieve the carbon emission reduction objectives. It contains an outlook on the energy system of the world until 2050, predicting the cost and penetration of generation technologies such as PV and offshore wind. Figure 19 shows an example for typical information on electricity generation technologies: It illustrates the historic and the predicted development of solar PV levelized cost of energy (LCOE) and underpin this prediction based on tendered prices in various projects across the world. Besides electricity generation technologies, the report also covers demand side of the energy system, by giving insights into expected improvements in energy efficiency and an outlook on how the high-energy industrial sectors in different parts of the world are going to develop (e.g., aluminum and chemical industry). The report even covers the developments of technologies and processes in the industrial sector and discusses for example how the energy intensity of aluminum production is likely to change in different parts of the world. Lastly, the report also discusses various energy storage technologies and contains forecasts including price levels and expected deployment.

Figure 19: Evolution of LCOE and contract prices for solar PV [51]

Commodity price forecasts

For commodity and fuel costs, modelers usually rely on the following types of sources:

- Especially in the absence of market prices, short-term studies will often rely on regulated prices or tariffs.
- Conversely, in liberalized markets or for commodities traded in global markets, it is often possible and/or desirable to use forward quotations of selected commodities. Depending on the countries concerned, this may be particularly relevant for oil, gas, or coal prices, i.e., at least for imported fuels. Similarly, in the EU, commercial forecast for carbon prices in the ETC are available.

[50] IEA, "Energy Technology Perspectives" (Paris, 2017), https://www.iea.org/reports/energy-technology-perspectives-2017.
[51] IEA.

- Similar to technology development and costs, long-term price projections can often be obtained from publicly available reports. The IEA's World Energy Outlook [52] represents one of the most widely used sources, but similar estimates are also available from the World Bank and other organizations. For Europe, the scenario framework for the Ten-Year Network Development Plan by ENTSO-E and ENTSO-G represents another possible source.[53]

When international sources are used, it is necessary to ensure that the prices are adjusted to reflect the situation in the modeled market.

Information on resource availability and profiles

For existing hydropower, wind, and solar plants, resource availability can be modeled based on historic information and measurements. However, especially for wind and solar plants, historic time series do not usually cover sufficient periods to allow for proper representation of stochastic variability over several years. Moreover, measurements are not available for future plants.

In these cases, resource-specific reports and studies may provide insights into the availability of the resource, at least on average load factors and energy yields. Besides specific forecast for individual sites, it is often more appropriate for national or regional studies to utilize sources of a similar regional scope, such as a wind or solar atlas. Relevant information is available from commercial service providers, but also from international organizations like IRENA.

The situation is different with regards to more detailed time series. Again, certain inputs are available for free, such as the EU-JRC's PV-GIS platform or a similar web-service by NREL from the U.S. In many cases, however, the time resolution or period covered is strongly limited, such as in the case of the global wind[54] or solar atlas[55] made available by the World Bank. For instance, the solar atlas provides for virtually global coverage on the overall availability of wind and solar irradiation, respectively, including Europe (see Figure 20). In addition, time series can be extracted at the level of selected sites, but only for a single year.

[52] *WORLD ENERGY OUTLOOK 2019.*
[53] ENTSO-E and ENTSO-G, "TYNDP2020 Scenario Methodology Report," 2020, 134.
[54] "Global Wind Atlas," Global Wind Atlas, accessed April 21, 2020, https://globalwindatlas.info.
[55] "Global Solar Atlas," accessed April 22, 2020, https://globalsolaratlas.info/map?c=11.523088,8.4375,3.

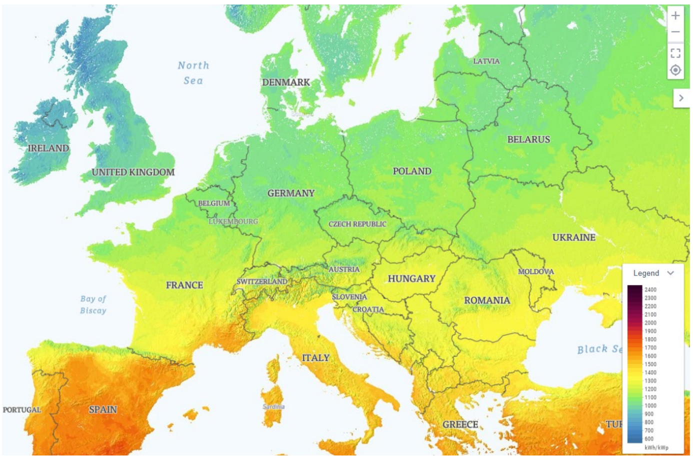


Figure 20: Overview of the availability of solar irradiation for Europe [56]

As an alternative, more detailed information and time series can be purchased from national meteorological bureaus or similar, or commercial service providers. Whilst many of the corresponding companies originate from Europe or the U.S., including Energy & Meteo (22), DNV GL,[57] Meteomatics,[58] Meteonorm,[59] or Solargis,[60] many of them offer their services on a global scale. Nevertheless, it should be noted that the corresponding data is not free but may come at significant costs.

8.3.5 Dedicated studies

Some input parameters for the modeling cannot simply be obtained from existing reports, but must be derived by separate studies or analysis.

In some cases, it may be possible to derive such information by means of parametric derivation or statistical regression analysis. In many cases, it may be necessary to account for the influence of multiple factors. For example, the load profile depends on the individual demand of different sectors, such as the residential and industrial sectors. Therefore, it depends on a variety of factors as well as the penetration of different technologies.

This type of variable can be approximated using external parameters and drivers, which typically include the expected GDP growth, population growth, urbanization, technology penetration (e.g., electrification of transport, heating, or cooling) and expected efficiency improvements. The load profile can be deduced using different methods, which vary in their level of effort. The simplest method is an extrapolation of historical data of load profiles. More advanced methods include a single- and multi-dimensional regression based on external parameters and historic data. For some analyses, sophisticated econometric models such as a partial or global equilibrium model are used. An example of how the future load profile was derived using a combination of external parameters and other methods is included in Text box 7.

56 "Global Solar Atlas."
57 DNV GL, "Virtual Met Data," DNV GL, 2020, https://www.dnvgl.com/services/virtual-met-data-3964.
58 Meteomatics, "Energy Market | Meteomatics," 2020, https://www.meteomatics.com/en/energy/.
59 Meteonorm, "Meteonorm Software - Worldwide Irradiation Data," Meteonorm, 2020, https://meteonorm.com/en.
60 Solargis, "Bankable Solar Data for Better Decisions," 2020, https://solargis.com/.

Text box 7: Estimation of future load profile for German network development plan [61]

The four TSOs in Germany consider different scenarios for development of the German network development plan. The TSOs determined both the overall consumption and the peak load using a bottom-up approach by adding up consumption from different segments. It should be noted that for some of the technologies (e.g., EV, electric heating) the load profile might be flexible. The TSOs distinguish between conventional electricity demand segments and new electricity demand segments, for which a different approach for the derivation of the load profile was chosen: The demand for conventional electricity demand segments was determined by parametric derivation and the electricity consumption of new demand segments was determined via other approaches (mainly stakeholder consultation). The classification of the segments into these categories is illustrated in Table 8, while Table 9 contains examples for the considered parameters for two demand segments.

Table 8: Classification of demand segments by German TSOs

Conventional electricity demand segments	New electricity demand segments
Determined via parametric derivation	Determined via other approaches
Residential sector	New battery, steel, aluminum, and chemical plants
Commercial sector	Data centers
Public transport	Electric mobility (EVs, heavy-duty vehicles)
Industry	Power to heat (both industrial and residential)
Conversion industry, fossil fuel mining	Power to gas

Table 9: Examples for parameters considered for parametric forecasting of load profiles

Demand segment	Parameters considered for the derivation
Residential sector	Current electricity demand from residential sector, population growth, number of households, income development, energy efficiency improvements
Industry	Current electricity demand from industrial sector, efficiency improvements, new processes and technologies, higher electricity demand due to digitalization and decarbonization

[61] Tim Drees et al., "Szenariorahmen Zum Netzentwicklungsplan Strom 2035, Version 2021" (Amprion, 50Hertz, TenneT, TransnetBW, 2020), https://www.netzentwicklungsplan.de/de/netzentwicklungsplaene/netzentwicklungsplan-2035-2021.

For questions regarding this publication, please contact Erin Hammel (ehammel@naruc.org).

National Association of Regulatory Utility Commissioners (NARUC)
1101 Vermont Ave, NW, Suite 200
Washington, DC 20005 U.S.
Tel: +1-202-898-2210
Fax: +1-202-898-2213
www.naruc.org