European Commission

Creating a METIS model for Fit for 55 scenarios

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2022

Joint Research Centre

EU Science Hub
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Contents

Acknowledgements

The author is particularly grateful for the comments and contributions received from the following colleagues: Konstantinos KANELLOPOULOS, Andreas ZUCKER, Sebastian BUSCH, Derck KOOLEN

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Abstract

This document describes the methodology followed and the datasets used to create a model based on the Fit for 55 scenarios published by the European Commission. We also discuss the assumptions made to create the hourly model using the METIS tool, based on Fit for 55 data from PRIMES tool.

The model extends the EU data by including seven neighbouring countries using the data provided by ENTSO-E. The availability of renewable sources (wind, solar, water) and the hourly electricity demand are based on a set of different climatic conditions derived by the observed weather in the period 1982-2015.

The model reproduces the most important features of European power systems, simulating hourly electricity generation, demand, and cross-border exchanges of electricity, providing insight on the operations of power systems: the levels of storage, the marginal costs, the availability of renewable energy, etc.

The developed model can be used to carry out accurate simulations on the behaviour of 2030 power systems and it can easily be extended to add additional energy carriers or adapted to other scenarios from Fit for 55. The METIS model described in this report and the associated data are available with open license.

1 Introduction

This report describes the methodology used to create the JRC-FF55-MIX-2030 scenario, a METIS context[1] based on PRIMES data for the Fit for 55 MIX scenario. This report will focus on the MIX scenario [1] but the presented methodology can easily be extended to cover all the other PRIMES Fit for 55 scenarios.

The work described in this report is one of the results from the modelling support provided by the Joint Research Centre to the Directorate-General for Energy on all the topics related to the European Green Deal. The aim of this report is to describe the methodology used to create all the METIS contexts used in this activity. Moreover, this document may provide as description for the model inputs and outputs that will be publicly available on the JRC Data Catalogue.

The European Green Deal is a set of policy initiatives approved at the beginning of 2020 with the aim of reaching the carbon-neutrality in EU by 2050. In July 2021, the European Commission presented the "Fit for 55" package, revising and proposing policy measures to support the EU climate targets. To analyse the impacts of the proposed initiatives on the energy systems, a set of policy scenarios has been developed using PRIMES tool[2].

The MIX scenario [1] is one of the European Commission's core policy scenarios, produced to serve as common tools for analysis across the impact assessments of various initiatives in the European Green Deal policy package. This scenario is the central policy scenario used in various impact assessments for the policy package. It assumes an extended Emissions Trading System (ETS) in road transport and buildings, and medium to high ambition for energy efficiency and renewable energy policies[3]. It delivers emission reductions of 55% compared to 1990, reducing 2030 energy demand by around 9% compared to the REF 2020 scenario and reaching a share of renewables of 38.4%.

To reach the ambitious target of climate neutrality in Europe set by the Climate Target Plan[4], energy modelling is a fundamental tool to enable the design and assessment of effective policy measures. Scenarios such as Fit for 55 MIX are created by energy models focusing on investment pathways across decades. The subsequent assessment of such scenarios, with dedicated sectoral models focusing on the power and gas systems at a high temporal resolution, can provide significant insights into the operation of future systems and markets and the challenges that operators, suppliers and consumers could face. The present report documents the data, assumptions and methodologies used in creating a METIS context based on the Fit for 55 MIX scenario.

METIS is a tool that focuses on the short-term operation of the energy system and markets [2] and provides rapid and robust insights on complex energy issues. In METIS, each node represents a country and can be linked to other nodes via interconnectors. Exchanges of energy between nodes are limited by interconnectors' predetermined fixed capacity, defined as Net Transfer Capacity (NTC). The simulation performed by METIS consists of optimising the operation of the system assets over a year, minimising the overall cost of the system to maintain supply/demand equilibrium in each node. The optimisation problem is linear and is solved over an entire year using a rolling horizon approach. A detailed description of the tool is provided in [3].

(1) A context is the set of input data and parameters defining the mathematical problem used to simulate the power and gas systems within the specified scenario. It includes all the input data and the model results.
(2) More details here: https://energy.ec.europa.eu/data-and-analysis/energy-modelling/policy-scenarios-delivering-european-green-deal_en
(3) COM(2021) 555 final (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52021PC0555)
(4) COM/2020/562 final (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0562)

2 From PRIMES to METIS

PRIMES (Price-Induced Market Equilibrium System) [4] is a large-scale energy system model able to calculate optimal market partial equilibrium volumes for medium- and long-term projections. The tool is able to carry out analytical cost estimations by sector in demand, supply, and infrastructures. It includes all the member states of EU plus UK covering the horizon up to 2070 with 5-year intervals.

METIS [2] is able to simulate the hour-by-hour operations of power, gas and heat systems. The model performs both economic dispatch and capacity expansion planning at national or regional scale.

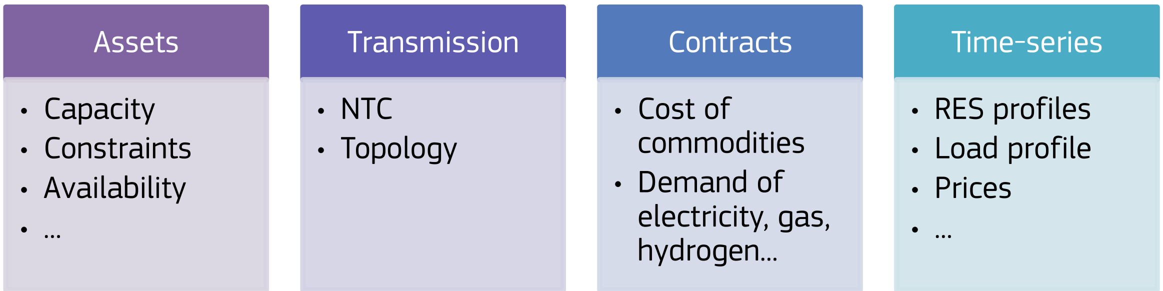
The two tools are designed to solve different problems: PRIMES is focused on long-term transitions of energy systems driven by technology changes, economics and policy measures, while METIS provides insights on short-term dynamics of energy systems (marginal costs, energy flows, adequacy issues, etc.)

A METIS context is defined as the set of all input variables describing the problem to be studied. It is formed by a set of input files (Figure 1): a file with the details on all the electricity generating assets, one on the transmission network and another one specifying the prices and the details on all the contracts modelled in the model (natural gas, electricity, fuels, etc.). The input files are supported by a database containing all the time-series used in the model (e.g., renewable energy profiles).

The approach followed here to create a METIS context based on PRIMES results is the simplest as possible: whenever possible the data in PRIMES is used to define the components needed by the context (e.g., the installed capacity for a specific technology), in case of missing information we used other data sources. In the following sections we explained for each component of the context our assumptions and the used data sources.

The data needed to create a METIS context for the Fit for 55 scenarios include the PRIMES results and additional data sources used to model all the aspects outside the scope of PRIMES. A description of all the data sets used for the creation of the context is given in the following section.

Figure 1. Visual summary of the main components of a METIS context



Source: JRC

2.1 Data sources

The creation of a METIS context based on the Fit for 55 MIX scenario requires several datasets in order to define all the parameters and the inputs needed by METIS.

2.1.1 PRIMES files

For reporting, PRIMES results are stored into spreadsheet files in Microsoft Excel format. The results for each country are stored in two files:

1. Detailed Analytical Results: from this file we extracted information about the net installed capacity, gross electricity generation, electricity demand-side load factor, electricity consumption and the cost of CO_2 emissions for the ETS sectors
2. Additional information: this file has been used to obtain information on the fuel prices for power generation, the capacity of storages, the useful and final energy per use for tertiary and residential sectors

2.1.2 ENTSO-E

ENTSO-E[5] within their mandate of coordinating the development of the European electricity markets and improving the security of the pan-European power system publishes several datasets[6] and for the creation of this context we used the following two:

1. Power Statistics: a dataset (discontinued in November 2019) providing hourly, monthly and yearly historical data. We used the monthly aggregated hourly load by country[7]

2. Pan-European Climate Database (PECD): this dataset contains time-series of capacity factors, hydropower inflows and electricity demand based on past weather conditions. It is used to introduce the impact of climate variability in renewable generation in the outlooks and adequacy assessments

The PECD used in this report is the version 2021.3 released with the European Resource Adequacy Assessment (ERAA) 2021[8]. The dataset has been used to model the following inputs:

1. Inflow for hydropower plants, power generation and storage capacities
2. Availability of run-of-river hydropower, wind (onshore and offshore) and solar plants
3. Electricity demand for the modelled countries not included in PRIMES (Albania, Bosnia-Herzegovina, Montenegro, North Macedonia, Norway, Serbia, Switzerland)
4. Detailed information on the operation of hydropower plants: weekly minimum storage, minimum and maximum generation

Additionally, the power generation capacity for the countries not covered by PRIMES has been obtained by using the National Estimates 2030 scenario for the ERAA 2021.

2.1.3 ERA5 temperature

The Copernicus Climate Change Service (C3S) has produced a climate reanalysis – an hourly snapshot of land and atmosphere variables from 1979 onwards – called ERA5 [5]. A climate reanalysis is a reconstruction of the past values of several meteorological variables, including air temperature (at 2m height), and it is commonly used to model the weather-derived aspects of energy systems.

While the original reanalysis data is gridded, in the creation of this context we have used the time-series generated at regional level, following the NUTS2 classification as available in the JRC ERA-NUTS dataset [6].

The JRC ERA-NUTS dataset provides eight meteorological variables aggregated at NUTS0, NUTS1 and NUTS2 levels. The aggregation is performed spatially using a latitude-weighted mean (with the exception of run-off, which is aggregated using a sum) and temporally using a simple arithmetic mean.

2.1.4 HOTMAPS data

HOTMAPS[9] is a European Union's Horizon 2020 research project on the development of an open source toolbox on local, regional and national heating and cooling systems.

A code & data repository associated to the project[10] contains several datasets, including hourly profiles for heating and cooling for various sectors. The profiles consist of a table containing the heating & cooling load for each hour of the day, day of the week and value of air temperature. This table is available for each European region (NUTS2) and allows to create climate-informed time-series of heating & cooling load.

The datasets are described in the WP2 report of the project [7] and for the creation of this context we used the following data sets:

([5]) ENTSO-E (European Network of Transmission System Operators for Electricity) is an association of 42 European electricity transmission system operators (TSOs) with the mission of coordinating the development of the European electricity markets and improving the security of the pan-European power system.
([6]) See https://www.entsoe.eu/data/
([7]) Available at this webpage: https://www.entsoe.eu/data/power-stats/ [accessed December 2021]
([8]) Data and documentation can be downloaded at this webpage: https://www.entsoe.eu/outlooks/eraa/eraa-downloads/ [accessed January 2022]
([9]) The project has been funded by the H2020 programme under the grant agreement 723677. The home page is available at this address: https://www.hotmaps-project.eu/ [accessed December 2021]
([10]) https://gitlab.com/hotmaps

1. The typical day hourly profiles for space cooling in the residential sector (*load_profile_residential_cooling_generic*)
2. The typical day hourly profiles for domestic hot water demand in the residential sector [8]
3. The typical day hourly profiles for space cooling in the tertiary sector [9]
4. The typical day hourly profiles for space heating demand in the tertiary sector [10]

2.1.5 JRC Power Plant Database (JRC-PPDB-OPEN)

The JRC's open database with detailed information for all the power plants in Europe [11] is used as the basis to define generator fleet performance parameters. The dataset contains the performance parameters and other technical features of individual power plants, including ramping capacity, efficiency, installed capacity and coordinates. For each country power plants are grouped in fleet classes according based on their age or equipment class (i.e. gas turbines). The power plant classes used are detailed in [12] and in the subsequent Section 3.

3 Power generation assets and commodities

The first step for the creation of a context based on PRIMES data is to map the generation technologies used in PRIMES to the classification used in METIS (Table 1). The mapping procedure is needed to be sure that the generation capacity defined by PRIMES is consistently associated to the same technology in METIS.

Table 1. Mapping of generation technologies between PRIMES and METIS.

METIS	PRIMES	PRIMES MIX EU capacity 2030 (GW)
Solar	Solar	383
Wind onshore	Wind on-shore	361
CCGT, OCGT	Natural gas	177
Nuclear	Nuclear	93.9
Hydro	Lakes	89.5
Pumped storage (open- and closed-loop)	Hydro pumping	71.8
Wind offshore	Wind off-shore	66.4
Coal, Lignite	Solids fired	63.4
Hydro RoR	Run of river	41.9
Lithium Ion battery	Batteries	41.4
Biomass	Biomass-waste fired	40.6
Oil	Oil fired	13.5
Derived gasses	Derived gasses	4.93
Electrolysis	Electrolysers	3.11
Geothermal	Geothermal heat	0.9
-	Other RES	0.24
-	Hydrogen plants	0

source: JRC

PRIMES data specifies only the generation capacity (MW), the rest of the parameters are obtained from the JRC Power Plant Database (see Section 2.1.5). In case a parameter is not specified in the JRC-PPDB-OPEN, the METIS default value is used.

The data for the countries not included in PRIMES are taken from ENTSO-E ERAA 2021 (see Section 2.1.2).

3.1 Gas generation

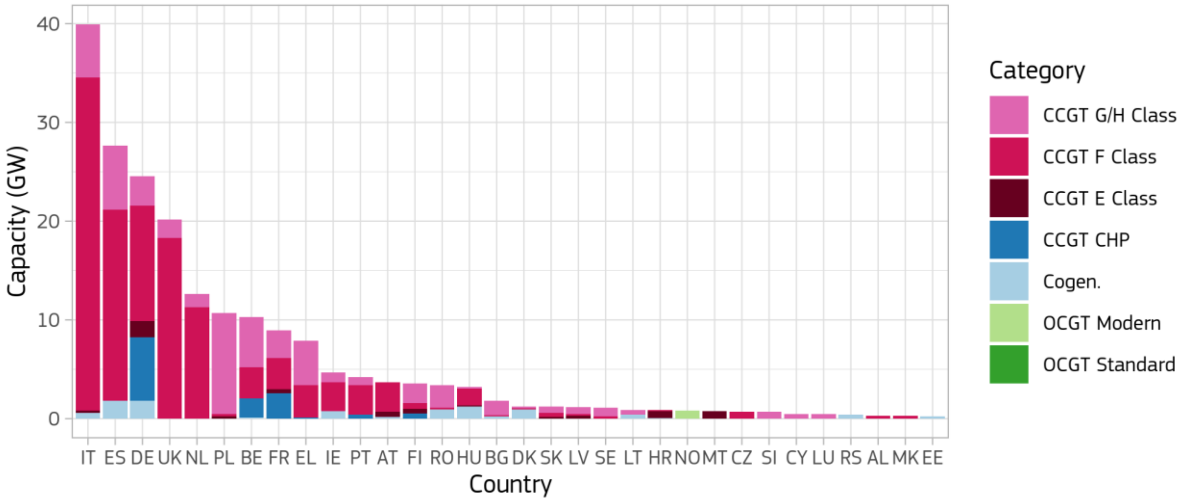
The natural-gas fired generation in METIS is modelled using the following sub-categories:

- CCGT E class
- CCGT F class
- CCGT G-H class
- CCGT CHP
- CCGT Rest cogeneration
- OCGT Standard
- OCGT Modern

The characteristics of each sub-category can be found in the Table 2 of [12]. Given that PRIMES data does not include any sub-categorisation (see Table 1), we derived it starting from the data in the JRC Power Plant Database (see Section 2.1.5), which provides a snapshot of the generation capacity in Europe in 2019. Starting from this, we assume that all the new capacity in the 2030 scenario is of the most efficient technology type (e.g. CCGT G-H class for CCGT turbines).

The total gas-fired generation (2030) per country in the METIS context is shown in Figure 2.

Figure 2. Gas-fired generation per country and per generation technology (2030)



Source: JRC

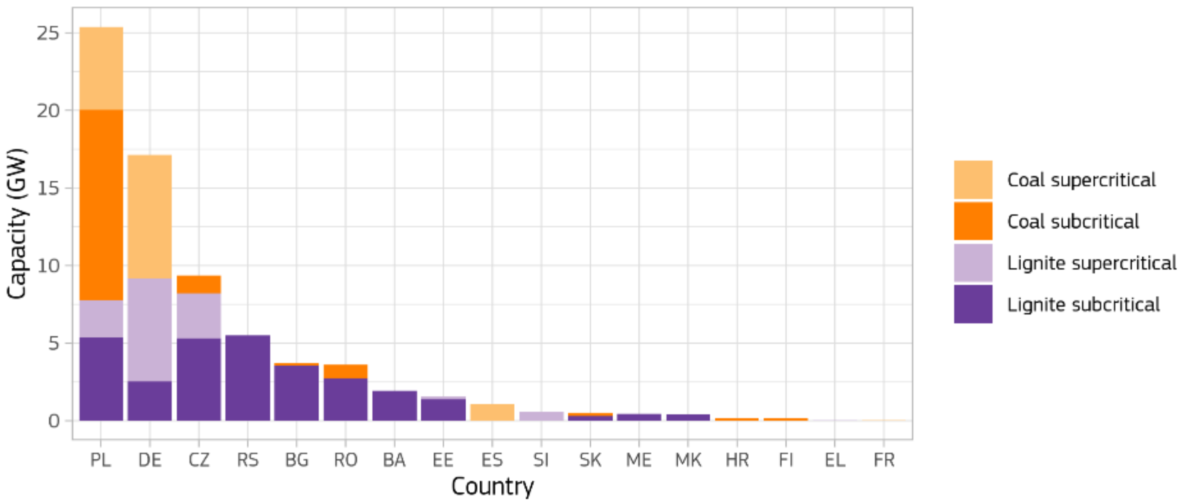
3.2 Coal & lignite

The power plants are clustered in two technology classes (subcritical and supercritical[11]) on the basis of the assessed thermal efficiency, which was in turn based either on real efficiency calculated from actual generation and CO_2 emissions reported on the Transparency Platform of ENTSO-E and IPCC respectively [12].

The methodology applied to classify the generation is the same used for gas in Section 3.1.

A summary of the coal & lignite generation in the context is provided in Figure 3.

Figure 3. Coal-fired generation per country and per technology (2030)



Source: JRC

3.3 Nuclear

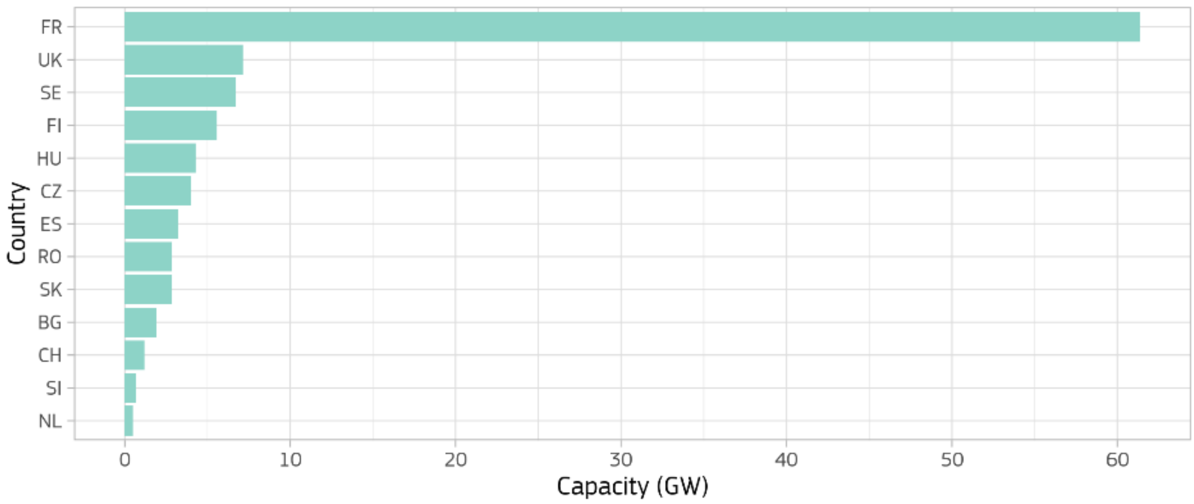
The nuclear capacity is derived from PRIMES data without further classification. In our modelling approach, we assume only one type of nuclear technology without differences in technical parameters. However, as

[11] Units with higher thermodynamic efficiency due to steam parameters above the critical point for water (250 bar 600ºC) and reheat.

described in Section 5, we use different availabilities for the countries with nuclear capacity (based on historical observations).

Figure 4 shows a visual summary of the nuclear generation capacity in the context.

Figure 4. Nuclear generation capacity (2030) by country



Source: JRC

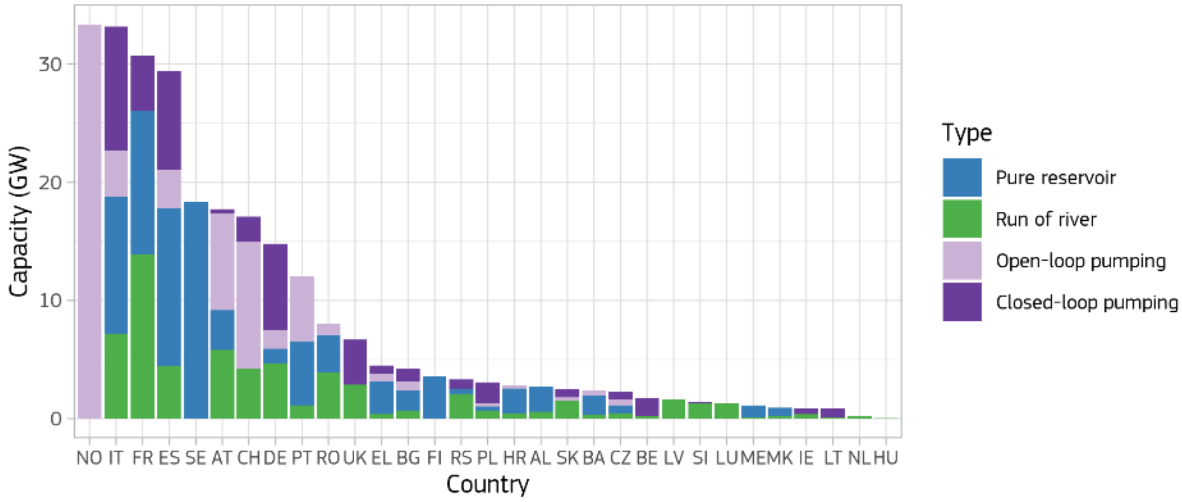
3.4 Hydropower

Hydropower plays an important role in providing flexibility to power systems both in today's systems and in the one envisioned by the FF55 MIX scenario. In the latter, in fact, there is 203 GW of hydropower capacity (including pure reservoirs, run of river and pumped storage).

As mentioned in Section 2.1.2, we used the hydropower information (inflow, availabilities, storage and generation capacities) provided by the ENTSO-E ERAA 2021. For each country we used the generation capacities and storage volumes of the four modelled technologies (run-of-river, pure reservoir, open- and closed-loop pumping) in the ENTSO-E hydropower data and then we corrected the total hydropower generation capacity for each country in order to match the numbers reported by PRIMES. Basically, we used the PRIMES hydropower (all technologies) generation capacity but the 2030 technology split described by ENTSO-E.

For the countries not covered by PRIMES we have used the values reported in the National Estimates 2030 scenario from ENTSO-E ERAA 2021. The final capacities used in the METIS context are illustrated in Figure 5.

Figure 5. Hydropower capacity by country and by typology (2030). The countries are sorted by total capacity.

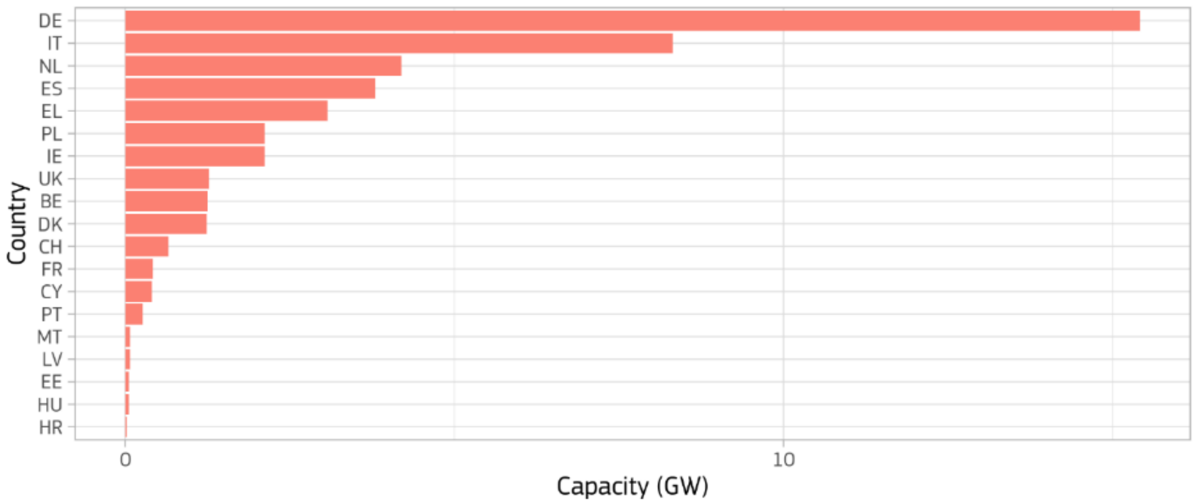


Source: JRC

3.5 Lithium-ion batteries

We model the batteries specified in the PRIMES formulation as lithium-ion batteries. The MIX scenario specifies the power capacity of the batteries but not the storage, that we assume being two hours (discharge time). This means that in the entire modelled domain we have 42.7 GW of batteries (the sum of all the capacities shown in Figure 6) and 85.4 GWh of storage.

Figure 6. Lithium-ion battery capacity (2030) per country



Source: JRC

3.6 Commodities

3.6.1 CO_2 price

The carbon price of the Emission Trading System is specified by PRIMES as described in Section 2.1.1. The value used is then 48 EUR/ton.

3.6.2 Fuel prices

The METIS model is able to simulate energy systems with multiple energy fuels and carriers. Although METIS allows time-dependant fuel prices, we assume constant values across the simulated period.

The fuel prices used in the context are extracted from the PRIMES data as described in Section 2.1.1. Fuels prices that are mapped and transformed to METIS inputs are: fuel oil, natural gas, hard coal, lignite, and biomass. Fuel prices for METIS are calculated as the aggregate of pre-tax prices and excise taxes for the year 2030, and then subsequently divided by the factor 11.63 to transform the denominator from toe to MWh.

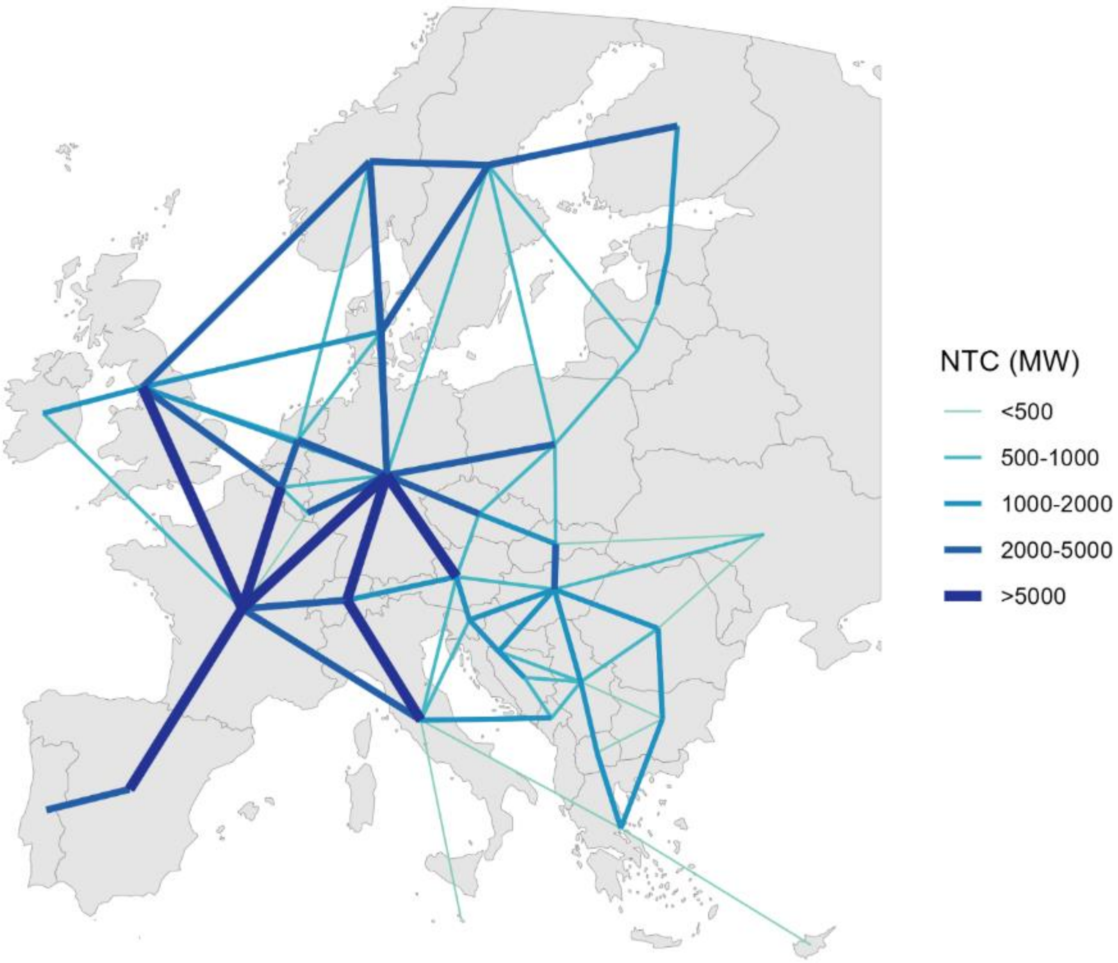
The public version of the JRC-FF55-MIX-2030 model use the same fuel prices for all the modelled countries, because the fuel prices in PRIMES data are not publicly available.

4 Transmission infrastructure

The PRIMES scenario data do not specify the configuration of the electricity transmission network. Thus, we use the power grid used in the TYNDP 2020 – the Europe's network development plan published by ENTSO-E every two years – in particular the Global Ambition scenario[12] for year 2030.

The Global Ambition scenario has been chosen as the one most similar to the MIX scenario. In this scenario, the Net Transfer Capacity (NTC) is defined for each interconnector as a constant value during the year.

Figure 7. The net transfer capacity (NTC) used in this context and based on the Global Ambition Scenario for the year 2030 developed in the TYNDP 2020



Source: JRC based on ENTSO-E TYNDP 2020

[12] All the reports and the scenario data can be accessed at the following URL: https://2020.entsos-tyndp-scenarios.eu/ [accessed 29/11/2021]

5 Profiles and time-series

The METIS model can simulate power systems at hourly resolution and for this reason most of the inputs can be defined as time-series with hourly resolution.

5.1 Climatic variability

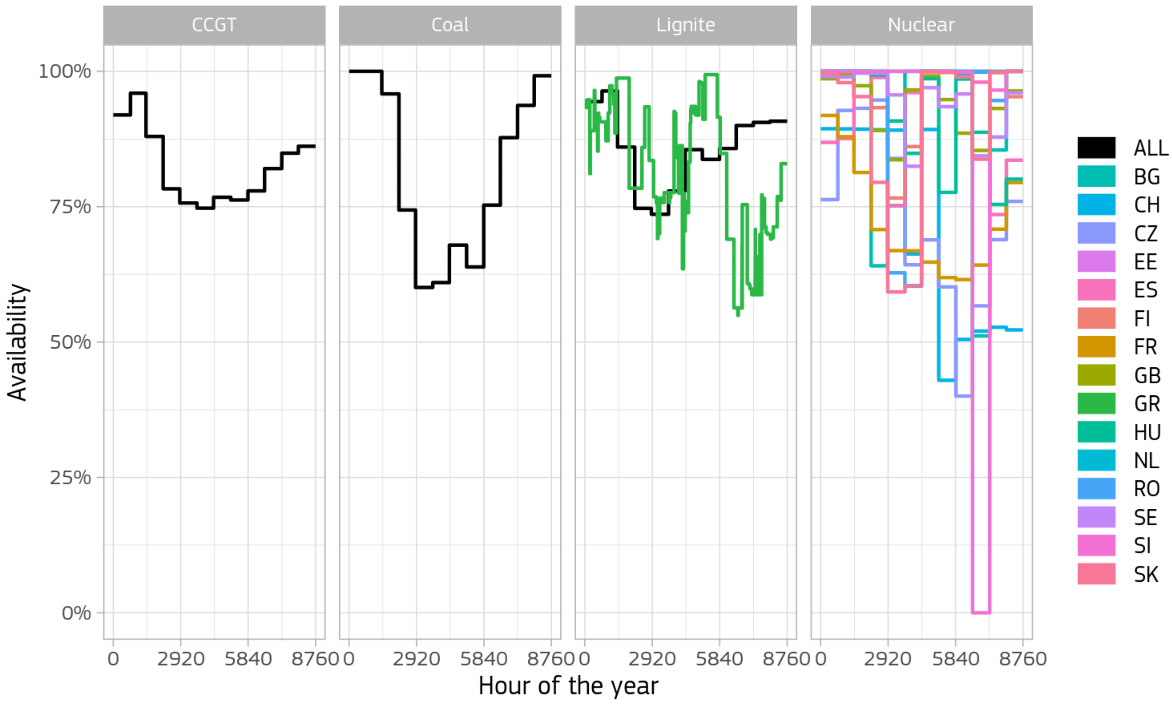
Where weather is a driving factor, multiple time-series for a single input are used to simulate different climatic conditions. This is the case of renewable energy profiles or electricity demand time-series. We have created a set of time-series associated to the climatic conditions based on past years: a set of inputs (solar, wind, demand, etc.) based on the conditions for 1982, another one for 1983 and so on and so forth. In METIS, each set of inputs is called *test case* and the associated year is called in this report *climate year* to make clear that we are not simulating the power system conditions for that year but only the weather-induced effects. In this context, we have simulated the climate years ranging from 1982 to 2015.

5.2 Availability of power plants

METIS is able to define for each time-step the availability of any asset, i.e. the fraction of the capacity that can be used to generate energy. In our context, we have defined a set of availability profiles for each technology (Figure 8). In some cases, we differentiate the curve for a specific country, otherwise we use the same curve for all the modelled zones.

The time-series have been created based on the availabilities based on the operations of European power systems in 2016, the most recent dataset we have available.

Figure 8. Hourly availability of CCGT, coal, lignite and nuclear assets. When the availability profiles are differentiated by country we show each of them with a different colour.



Source: JRC

5.3 Hydro-power

5.3.1 Run of river

Run of river plants are modelled as non-dispatchable units and then their hourly generation is defined by the availability time-series in the ENTSO-E PECD (see Section 2.1.2).

5.3.2 Reservoir inflow

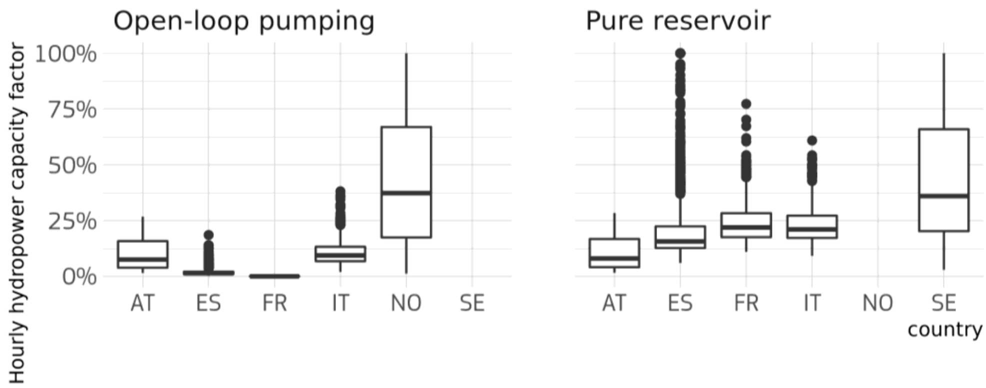
The hydropower inflow in METIS is defined as the hourly availability of water that can be stored and transformed in electricity.

We have used the hydropower time-series in the ENTSO-E PECD (see Section 2.1.2) for both pure reservoirs and open-loop pumping types. The inflows in the dataset are defined as capacity factors and, given that the METIS model needs the inflow as MWh, we have multiplied the capacity factors for the installed capacity of hydropower plants. The original temporal resolution is weekly, thus the final time-series have been obtained using the same weekly value for all the hourly time-steps.

In some countries (e.g. Italy), the PECD reports the inflows at bidding zone level. In these cases, the country inflow has been calculated as the weighted average of the capacity factors using the regional capacity (specified in the PECD database) as weight.

The distribution of the hourly capacity factors for hydropower is shown for the six countries with the highest installed capacity in Figure 9.

Figure 9. Hydropower boxplot inflow of hourly values between 1982 and 2015 for top 6 countries



Source: JRC based on ENTSO- E PECD

5.3.3 Storage guiding curves

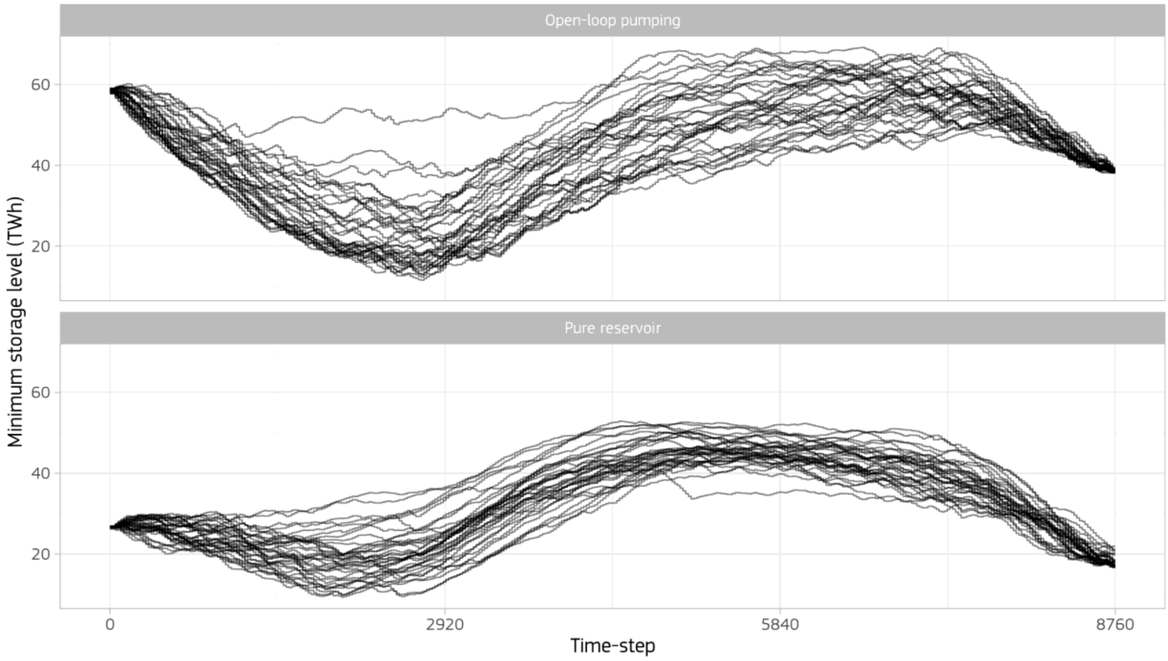
Hydropower generation in METIS is constrained by the level of the reservoir storage, which must be at each time-step above a guiding curve (*minStorageLevel* in the METIS formulation). This guiding curve has a fundamental role in defining a realistic dispatching of hydropower generation.

To create a feasible guiding curve consistent with the hydropower inflow, we used a version of the MIX scenario at daily resolution. Applying a daily resolution allowed us to solve the entire dispatching problem at once (perfect foresight), without applying the rolling-horizon approach (myopic foresight) used by default in METIS (see Section 2.3.2 of METIS Technical Note T6).

The daily model is launched aggregating all the input time-series to daily resolution. The storage levels resulting from the optimal dispatching are then collected and post-processed to be used as guiding curves for the hourly model.

The post-processing is needed to avoid infeasibilities caused by over-optimised guiding curves. In fact, the daily simulation, due to the perfect foresight of the optimiser, could generate guiding curves that would constrain too much the hourly simulation, which is using a rolling-horizon approach. Then, after a set of preliminary tests, we decide to lower the guiding curve, rescaling its value by a factor of 0.8. Also, all the values above 70% have been set to 70% in order to avoid having an hourly constraint too close to the maximum storage capacity. This approach has been chosen as the only available to deal with seasonal/annual storages using the METIS tool. More sophisticated methods (e.g., stochastic programming) are not implemented in METIS and then they were not considered for this work.

Figure 10. Cumulative storage guiding curve in all the countries modelled in the context. Each line represents a different climate year.



Source: JRC

To improve the realism of the storage curves, we took advantage of the data on hydropower available in the ENTSO-E PECD from ERAA 2021 (see Section 2.1.2). The dataset includes a variables named 'Minimum Reservoir levels at beginning of each week' that has been used to constrain the daily model and the generated final guiding curves.

Given the important role of hydropower and the challenges in creating a realistic and consistent characterisation, we have carried out a specific calibration procedure to match the PRIMES reported hydropower values. We corrected the inflows, the hydropower plants availabilities and the initial storage levels to make the average hydropower generation across all the test cases closer to the PRIMES values.

5.4 Wind and solar

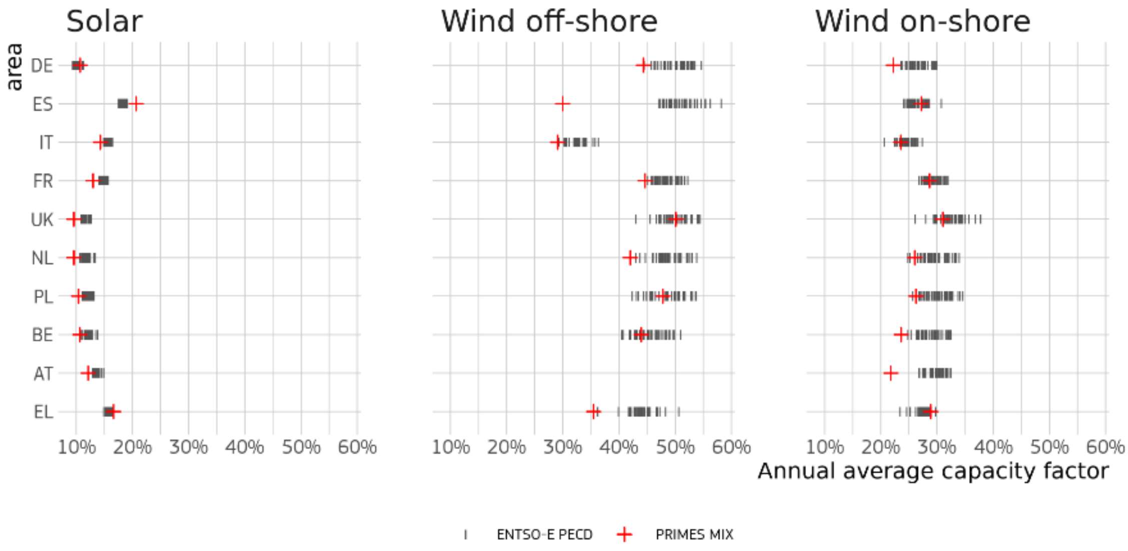
Solar and wind power are modelled in METIS through the definition of a profile specifying the capacity factor of the specific resource at each time step.

In this study, we used the ENTSO-E PECD 2021.3 dataset (see Section 2.1.2) to define the hourly values of wind and solar capacity factors.

For both the technologies we used the data for the year 2030 (the PECD dataset provides both the data for the years 2025 and 2030).

We compare the annual average capacity factor between ENTSO-E PECD and PRIMES in Figure 11. PRIMES does not report directly the capacity factor but this has been calculated from the annual generation and the installed capacity.

Figure 11. Annual average capacity factors for the ten countries with the largest wind & solar fleet: the annual average for each climate year (black line) is compared with the capacity factor derived from PRIMES data (red cross).



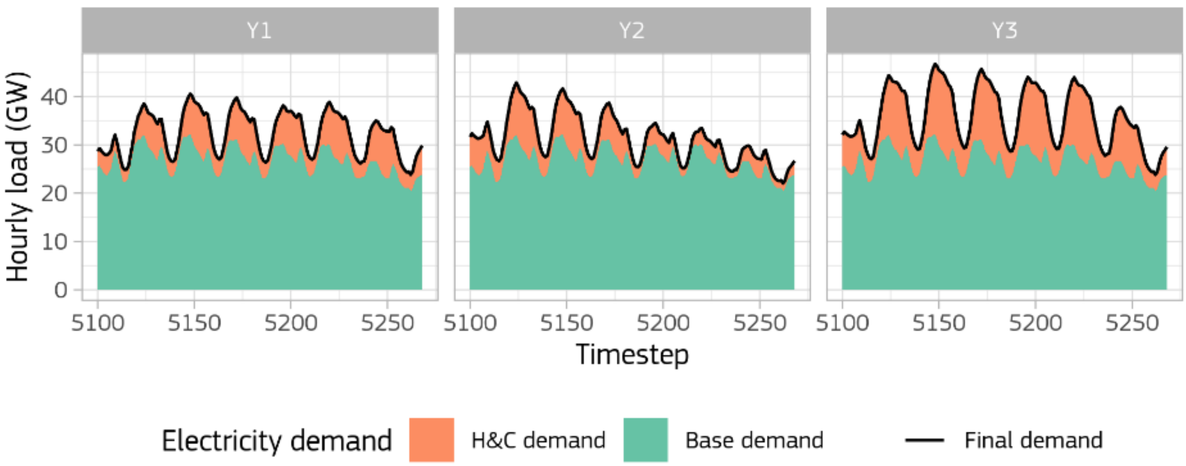
Source: JRC

5.5 Electricity demand

The electricity demand time-series used in the METIS model include the effect of weather variability (mainly driven by temperature) caused by the use of heating and cooling equipment in the residential and tertiary sectors.

The approach here described has been chosen as the only one satisfying the following requirements: 1) available for the entire European continent; 2) giving the possibility to model explicitly the link between climatic conditions and heating & cooling scenario data; 3) based on a solid and documented methodology (see Section 2.1.4).

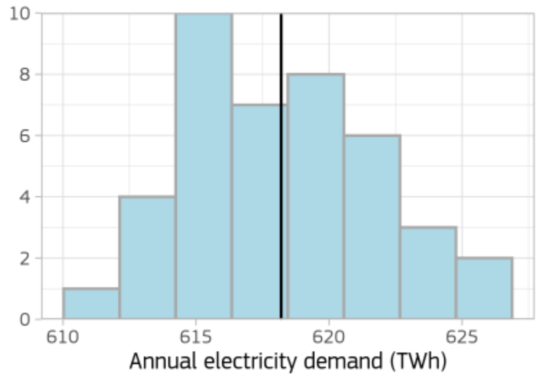
Figure 12. Example of Spanish electricity demand for three different climatic years. The light green area represents the part of the demand not affected by meteorological factors, while the orange is the heating & cooling part.



Source: JRC

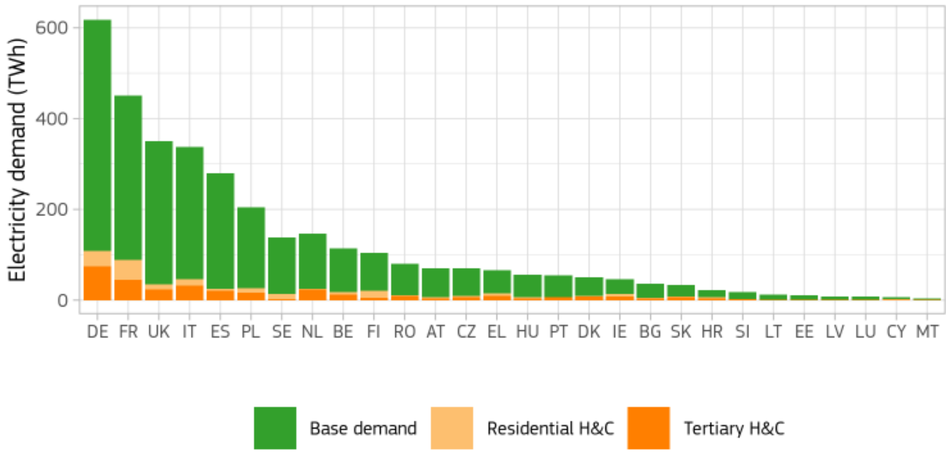
In each country, the final hourly demand time-series used in the simulation is created summing two time-series: a base demand which is not affected by meteorological factors and the electric heating & cooling part (see Figure 12). The impact of weather is simulated creating a set of different electric heating & cooling time-series based on a set of historical temperature hourly time-series for each country. The distribution of the total electricity demand time-series for each country is centred on the PRIMES values (example in Figure 13 and Figure 14). The distribution histogram for all the modelled countries is available in the Annex 2.

Figure 13. Distribution histogram of the German annual electricity demand compared with the value reported by PRIMES for the year 2030 (black vertical line)



Source: JRC

Figure 14. Average annual electricity demand for all the PRIMES countries in the MIX 2030 scenario



Source: JRC

5.5.1 Creating and H&C time-series

The first step in the methodology to calculate the electricity demand is the creation of the H&C time-series, which is based on the HOTMAPS methodology (see section 2.1.4) and the ERA5 temperatures (see section 2.1.3).

For each European region (NUTS2) and sector (residential and tertiary), we generated the following profiles:

- Hourly profiles of residential cooling at NUTS2 level based on ambient temperature
- Hourly profiles of residential heating at NUTS2 level based on ambient temperature
- Hourly profiles of tertiary cooling at NUTS2 level based on ambient temperature and day of the week
- Hourly profiles of tertiary heating at NUTS2 level based on ambient temperature and day of the week

The methodology to generate the time-series profiles needed by METIS based on PRIMES data is the following:

1. For each NUTS2 region we collected average temperature (based on ERA-NUTS[13]) and the HOTMAPS generic profiles[14]
2. The H&C load is generated using the HOTMAPS curves using temperature data (processed using a 3-hour rolling average to simulate building thermal inertia) and, when needed, the day type (Sunday/holiday, Saturday/day before holiday, or week day)
3. The NUTS2 time-series are aggregated at country level using NUTS2 population[15] as weight (we assume that the regions with larger populations have also the higher electricity consumption)
4. Data is rescaled to calibrate the distribution of annual demands obtained from the all the climate years to the PRIMES data for the year 2030

5.5.2 Creating the final time-series

As illustrated in Figure 12, the final demand is composed by H&C time-series and a base demand, independent from ambient temperature.

The base demand is created starting from a base hourly load time-series provided by ENTSO-E (see section 2.1.2) and rescaled to match the total electricity consumption specified in the PRIMES data. We used as base time-series the ENTSO-E total load for year 2016 which has been selected to derive the calendar effects for the heating & cooling time-series. The last day of the year has been removed to deal with the leap year. The year 2016 has been chosen as a trade-off between its representativeness of the current power systems (which are in turn considered a good approximation of 2030 power systems) and a reduced solar PV capacity which could reduce the effect on observed hourly load of behind-the-meter solar capacity (which is seen as negative demand).

After rescaling the base year using the PRIMES MIX 2020 electricity consumption, the base demand is calculated subtracting the H&C hourly time-series, using the climate year 2016 for consistency reasons. This time-series is then rescaled to match the base demand (the green part shown in Figure 14).

Then, as already illustrated in Figure 12, the final demand is created summing to the base demand the H&C time-series for each climate year.

The demand time-series for the countries not defined in PRIMES are based on the profiles defined by ENTSO-E for their ERAA 2021 "National Estimates" scenario.

After a set of preliminary simulations, the electricity demand time-series have been calibrated to match the PRIMES load-factors. The calibration consisted of a smoothing of temperature time-series used to calculate the final electricity demand.

$$t_{corrected}^{y,i} = t_{clim}^{i} + \alpha t_{deviation}^{y,i}$$

Firstly, for each time step (*i*) we calculate the average temperature (t_{clim}) across all the years and the deviation from this average.

Then the deviation (for the year *y* and the time step i) is rescaled using the parameter $\alpha \in [0.5,1]$ and summed again to the average temperature. Thus, this temperature has been used to recreate the electricity demand time-series and calculate the deriving demand-side load factor.

The demand-side load factor is here defined using the same definition from PRIMES:

Demand-side load factor = demand / (peak load x 8760 hours)

We tested a set of α values and we chose for each country the value with the median load factor (across all the climate years) closer to the PRIMES value.

We can see in Table 2 the minimum, median and maximum load factor values obtained with the corrected temperature compared with the value reported by PRIMES

[13] ERA-NUTS is a dataset containing a set of meteorological variables at hourly level based on Copernicus Climate Change Service ERA5 atmospheric reanalysis (https://data.jrc.ec.europa.eu/dataset/d0b4f69d-99c4-447b-9db2-c5b531c3555c)

[14] https://gitlab.com/hotmaps/load_profile

[15] Data from EUROSTAT from the database demo_r_d2jan: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=demo_r_d2jan

Table 2. Comparison between the demand-side load factors (LF) calculated on the METIS time-series (first three columns: statistics across all the test case) and the values reported in PRIMES.

country	Minimum LF	Median LF	Maximum LF	PRIMES
AT	0.681	0.693	0.703	0.732
BE	0.667	0.717	0.744	0.722
BG	0.594	0.623	0.645	0.635
CY	0.388	0.461	0.553	0.434
CZ	0.687	0.714	0.731	0.736
DE	0.666	0.711	0.728	0.718
DK	0.617	0.651	0.667	0.651
EE	0.551	0.602	0.632	0.652
EL	0.584	0.633	0.668	0.626
ES	0.684	0.727	0.744	0.715
FI	0.603	0.649	0.691	0.676
FR	0.536	0.617	0.659	0.594
HR	0.486	0.577	0.662	0.577
HU	0.685	0.728	0.749	0.738
IE	0.528	0.613	0.646	0.573
IT	0.635	0.65	0.669	0.664
LT	0.677	0.699	0.707	0.717
LU	0.612	0.659	0.696	0.560
LV	0.64	0.657	0.673	0.697
NL	0.588	0.659	0.715	0.635
PL	0.647	0.688	0.721	0.684
PT	0.663	0.69	0.705	0.693
RO	0.612	0.647	0.705	0.661
SE	0.603	0.637	0.666	0.674
SI	0.617	0.675	0.732	0.709
SK	0.595	0.671	0.728	0.703
UK	0.61	0.623	0.635	0.672

Source: JRC

6 Analysis

This section focuses on the calibration of the context and its comparison with the annual PRIMES values. The calibration is needed because the two models, PRIMES and METIS, have been created with different scopes and to address different issues, thus some aspects – as in this case the adequacy issues – are modelled in a different way in the two models.

6.1 Calibration

For the calibration, we launched a set of simulations with all the available test cases. A test case consists of a set of inputs representing a specific climate year: the first test case is formed by renewable profiles, hydropower inflows and electricity demand based on the meteorological variables observed in the year 1982, while the last test case is based on the year 2015.

The simulations showed that in all the test cases one or more countries experienced at least one hour of loss of load, with an average of 37.6 hours in the entire simulated area.

To reduce the amount of unserved energy, we solved a capacity expansion to optimise the fleet of OCGT turbines and batteries. The capacity expansion problem has been solved using test case associated to the climate year 1991, the year with the 4^{th} highest value in terms of number of loss of load hours.

The optimal deployment in the EU area found by the optimisation consists of 4.4 GW of additional gas turbines (+2% on the total gas generation capacity) and 15.7 GW of additional batteries (+36%).

With the additional capacity, we could observe a loss of load of more than 3 hours in 24% of the test cases. The countries experiencing loss of load are seven: Denmark, Estonia, Finland, Germany, Ireland, Netherlands and the United Kingdom.

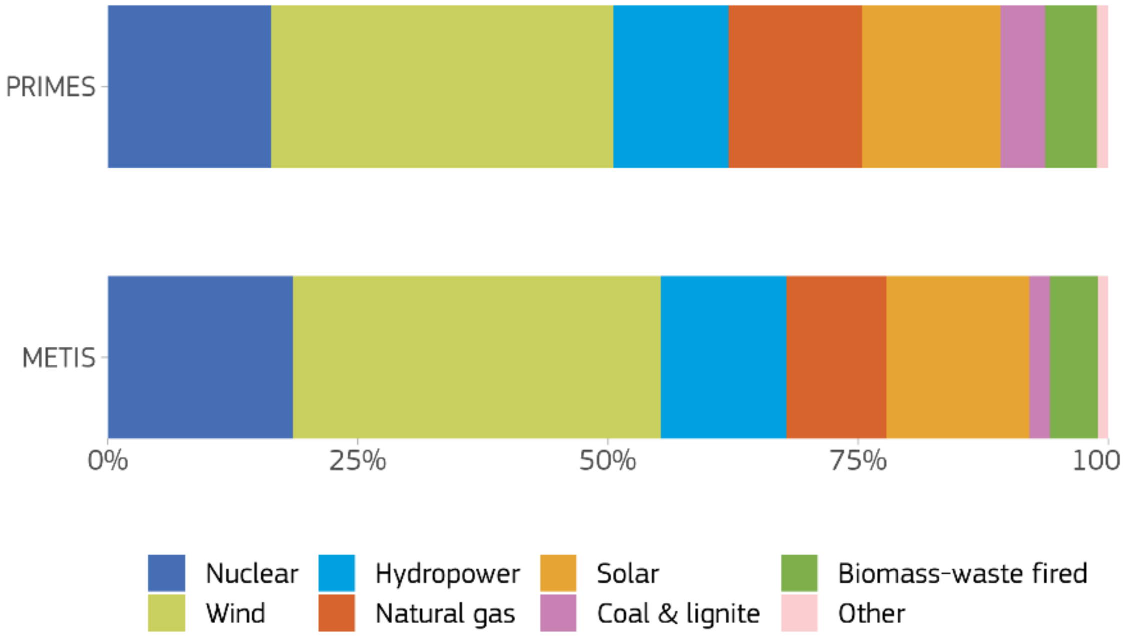
6.2 Comparing with PRIMES

The METIS context created with the methodology described in this document and after the calibration introduced in Section 6.1 is able to reproduce the energy mix reported in the PRIMES results (Figure 15).

The two main differences we can spot in the figure are the following:

1. PRIMES reports a lower nuclear generation in EU: this can be explained by the fact that the nuclear generation in PRIMES for France (a country with the 65% of the total EU nuclear capacity in the MIX scenario 2030) shows a low capacity factor compared to the standard availability profiles we used in METIS
2. METIS simulates higher generation from renewables: the wind, solar and inflow profiles used in the METIS context are based on observed meteorological variables while PRIMES data do not include any climatic information

Figure 15. Generation by source of electricity for the EU area expressed as percentage of the total annual production. For METIS we show the average of all the test cases.



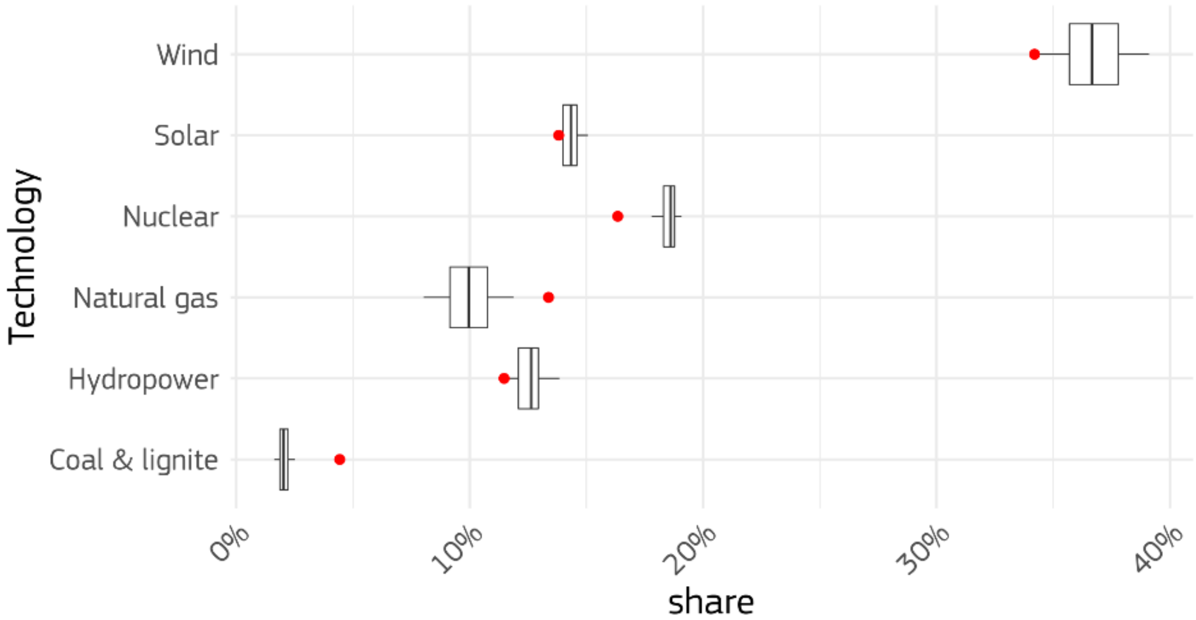
Source: JRC

The difference of energy mix in EU described by the two models is shown with more detail in Figure 16, where we show the entire range of generation in METIS that can be obtained by the results in all the 34 simulated test cases. The figure confirms that the MIX scenario implemented in METIS consistently show a generation from renewable sources larger than the value reported by PRIMES.

The thermal generation in the METIS model is lower than in PRIMES, this can be explained by the fact that in METIS there is more availability of cheaper sources of electricity (i.e. nuclear and renewables).

To summarise, both Figure 15 and Figure 16 show that the outputs from the JRC-FF55-MIX-2030 context are consistent with the PRIMES results, with the some significant differences due to the different availability factors for nuclear and renewables mentioned earlier in this section.

Figure 16. Boxplot of the share of generation for six technologies in METIS in all the 34 simulated test cases. The red dot represents the values reported by PRIMES.



Source: JRC

7 Conclusions

This report describes the methodology and assumptions behind the creation of a context for the METIS power system model based on the Fit for 55 scenario. The methodology has been applied for the MIX 2030 scenario but it may be used for any other Fit for 55 scenario or for other years.

The model developed with METIS, named JRC-FF55-MIX-2030, covers 34 countries, six more than the countries reported in PRIMES (EU and UK). The model is able to simulate the hourly dispatching of electricity under a set of 34 climate years, i.e. climatic conditions based on the observed weather in the years 1982-2015.

The JRC-FF55-MIX-2030 was created to approximate the PRIMES model results as closely as possible; however, the electricity mix obtained from the models shows some differences (see Section 6). These are due to the different scopes of the two models (PRIMES and METIS) and the different inputs used, with renewable and other generator availabilities being the most prominent among those.

The JRC-FF55-MIX-2030 model can be used to carry out accurate simulations of the behaviour of future power systems and it can easily be extended to add additional energy carriers or adapted to other scenarios (e.g. MIX scenario for 2050).

All the input data and the MIX 2030 context will be released in parallel with this report with open license.

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List of abbreviations and definitions

CCGT	Combined Cycle Gas Turbines
CHP	Combined heat and power
ENTSO-E	European Network of Transmission System Operators for Electricity
ERAA	European Resource Adequacy Assessment
ETS	Emission Trading System
IPCC	Intergovernmental Panel on Climate Change
OCGP	Open-cycle gas-turbine
NTC	Net Transfer Capacity
NUTS	Nomenclature of territorial units for statistics
PECD	Pan-European Climate Database
TYNDP	10-year network development plan

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Annex 1. Description of the dataset

The JRC-FF55-MIX-2030 model consists of three files and a folder containing all the time-series described in Section 5.

The files are inputs used by the METIS model:

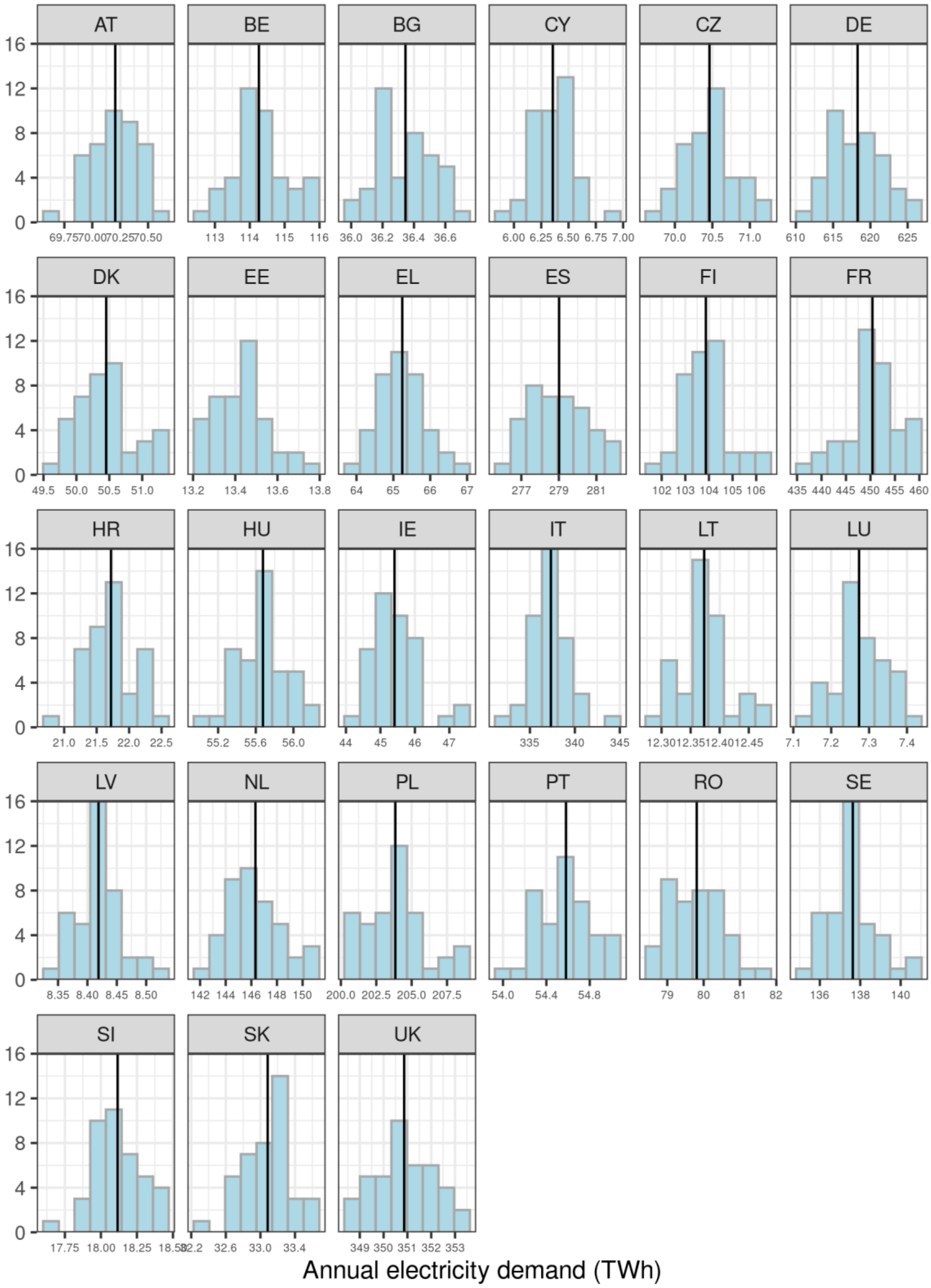
- assets.xlsx: it contains all the data for the generation assets
- contracts.xlsx: information about electricity demand and fuel prices
- transmissions.xlsx: information about interconnectors

In the shared data we also provide a copy of the METIS model documentation.

The time-series are contained in a compressed 7-Zip[16] archive which also include a file named "DB-Temporal.csv", providing the mapping between the METIS variables and the comma-separated files (CSV) containing the actual hourly time-series.

(16) 7-Zip is an open-source file archiver, the utility to compress and decompress can be found here: https://www.7-zip.org/ [accessed: February 2022]

Annex 2. Demand distribution for all countries



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