European Commission

METIS 2

Technical Note T1

Methodology for the integration of the European Commission's Long-Term Strategy scenarios into METIS

Prepared by

Luiza Lacombe Da Rocha
Anthony Vautrin
Paul Barberi

Contact: metis.studies@artelys.com

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E-mail: ENER-METIS@ec.europa.eu

European Commission
B-1049 Brussels

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1 ABBREVIATIONS AND DEFINITIONS

1.1 ABBREVIATIONS

Abbreviation	Definition
CCGT	Combined cycle gas turbine
CCS	Carbon capture and storage
EFLH	Equivalent full load hours
EV	Electric vehicle
HHV	Higher heating value
HP	Heat pump
LTS	Long-Term Strategy
NTC	Net transfer capacity
OCGT	Open cycle gas turbine
P2X	Power-to-X
PHS	Pumped hydro storage
PV	Photovoltaics
RES	Renewable energy sources
RoR	Run-of-river
SMR	Steam methane reformation
V2G	Vehicle-to-grid
vRES	Variable RES

1.2 METIS CONFIGURATION

The configuration of the METIS model used to evaluate the impacts of the MDI policy measures is summarised in Table 1.

Table 1 - METIS Configuration

METIS Configuration	
Version	METIS v2.0 Beta (non-published)
Modules	Energy system integration module
Scenario	METIS 2050 scenario
Time resolution	Hourly (8760 consecutive time-steps per year)
Spatial granularity	Member State

2 INTRODUCTION

This technical note aims at providing information on how the energy scenarios of the European Commission's Long- Term Strategy were integrated into METIS. It describes the different datasets that were used to model the full European power system, and the calibration steps that were performed in order to get a consistent set of assumptions for the METIS energy system model.

The METIS model

The METIS[1] model is being developed by Artelys on behalf of the European Commission. METIS is a multi-energy model covering in high granularity (in time and technological detail) the entire European energy system, representing each Member State of the EU and relevant neighbouring countries, each as a single node.

METIS includes its own modelling assumptions, datasets and comes with a set of pre-configured scenarios. These scenarios usually rely (at least partially) on the inputs and results from the European Commission's projections of the energy system, for instance with respect to the capacity mix (for selected technologies, others being subject to capacity optimisation) or annual demand. Based on this information, METIS allows to perform the hourly capacity expansion and dispatch optimisation (over the duration of an entire year, i.e., for 8760 consecutive time-steps per year). The result consists of the capacity mix and the hourly utilisation of all national generation, storage, conversion and cross-border capacities as well as demand side response assets.

Structure of this Technical Note

The present document is organised as follows. **Section 3** provides an overview of the EC's Long-Term-Strategy scenarios integrated into METIS. **Section 4** is dedicated to the description of the calibration methodology.

[1] See https://energy.ec.europa.eu/data-and-analysis/energy-modelling/metis_en

3 Description of the LTS scenarios

3.1 Three scenarios adapted from the EC's Long-Term Strategy

The EC Long-Term Strategy (LTS) has analysed different pathways that can lead the European Union's economy to reach the Paris agreement target of keeping the temperature increase since the pre-industrial era "well below 2°C by 2100"[2].

A first pathway called **Baseline** includes the recently agreed policies, such as a reformed EU emissions trading system and different target for energy efficiency and renewable production. In 2050, this pathway reaches a 60% reduction of greenhouse gas emissions, which is not sufficient to meet the objectives of the Paris Agreement.

Five pathways have been considered to meet the objectives of the Paris Agreement, each of them being based on diverse technological choices on how to decarbonise the EU economy:

- **Energy efficiency (EE):** Pursuing deep energy efficiency in all sectors, with higher rates of building renovation.
- **Circular economy (CIRC):** Increased resource and material efficiency, with lower demand for industry thanks to higher recycling rate and circular measures.
- **Electrification (ELEC)**: deep electrification in all sectors, with large deployment of heat pumps for building heating and faster electrification of all transport modes
- **Hydrogen (H2):** Hydrogen is used in all sectors, and injected into the distribution grids to be used in the building for heating, and for freight transport.
- **Power-to-X (P2X):** Large development of e-gas and e-fuels to decarbonise the different vectors without changing the energy supply type

Based on these different options, three additional pathways are described in the LTS. The first one, **COMBO**, is a cost-efficient combination of the five options described above.

The two additional ones are more ambitious, with a goal of keeping the temperature increase to "around 1.5°C by 2100". Including carbon sinks, these two scenarios reach carbon neutrality by 2050. The **1.5TECH** scenario combines the technologies used in the five different pathways defined above to reach net zero greenhouse gases emissions in 2050. The **1.5LIFE** scenario is also based on different technological pathways, yet with a stronger focus on lifestyle changes leading to a lower energy consumption.

Figure *1* provides an overview of the power generation capacities for each scenario at the 2030 and 2050 time horizon.

[2] For more information about the Long term strategy, please refer to the available documentation on the EC website : https://ec.europa.eu/clima/policies/strategies/2050_en

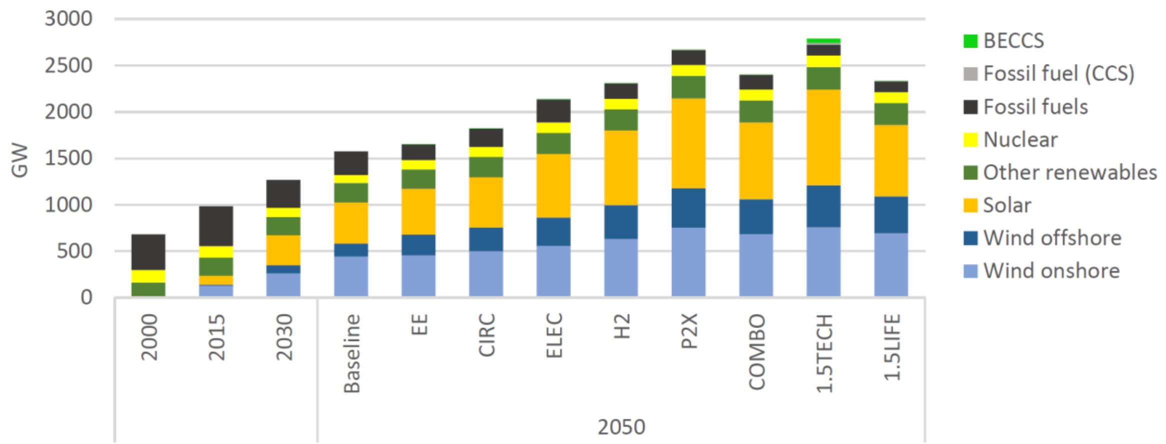

Figure 1 - Power installed capacities in the different pathways of the Long-term Strategy. Source: EC LTS

Three scenarios at different time horizons have been selected to be integrated in METIS:

- **Baseline** (year 2030)
- **1.5TECH** (year 2050)
- **P2X** (year 2050)

The rationale behind this choice was to have a first 2050 scenario that reaches carbon neutrality in 2050. **1.5TECH** scenario was selected against 1.5LIFE since it was more conservative in terms of behavioural change. **P2X** was then selected because it was the most ambitious pathway in terms of storage potential according to the modelling exercise realized for the definition of these different scenarios. Finally, the **Baseline** scenario was selected for the year 2030 since it reflects the currently agreed policies, allowing a comparison of the energy mix between 2030 and 2050[3].

3.2 Evolution of the energy mix in 2030 and 2050

In the Long-Term Strategy pathways, the decarbonisation of the EU energy system mainly results from a large integration of renewable power energy sources, such as solar and wind capacities, that enable direct and indirect electrification of end-uses. As can be seen on Figure *1*, solar and wind capacities increase to 2140 GW in Europe in 2050 in the P2X scenario and 2240 GW in the 1.5TECH scenario, starting from 670 GW in 2030 in the Baseline scenario.

This important increase in decarbonised power production capacities is crucial to switch away from fossil power generation and to facilitate the increasing use of electricity, both in a direct way and via indirect electrification (i.e. via power-to-gas technologies and end-uses using decarbonised gases and fuels). Between today and 2030, this fossil-to-RES switch is driven by direct electrification leading to an increase of the total power production from 2750 TWh in 2015 to 3030 TWh in 2030. From 2030 onwards, the Long-Term Strategy considers an important development of P2X technologies for indirect electrification, leading

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[3] At the time of writing, the impact assessment of the 50 to 55% reduction of GHG emissions by 2030 was not available. This scenario has therefore not been included in this analysis.

to the production of synthetic fuels such as e-gases[4] and e-liquids[5] from electrolysis, replacing their fossil counterparts in the industry, heating and mobility sectors (cf. Figure 2).

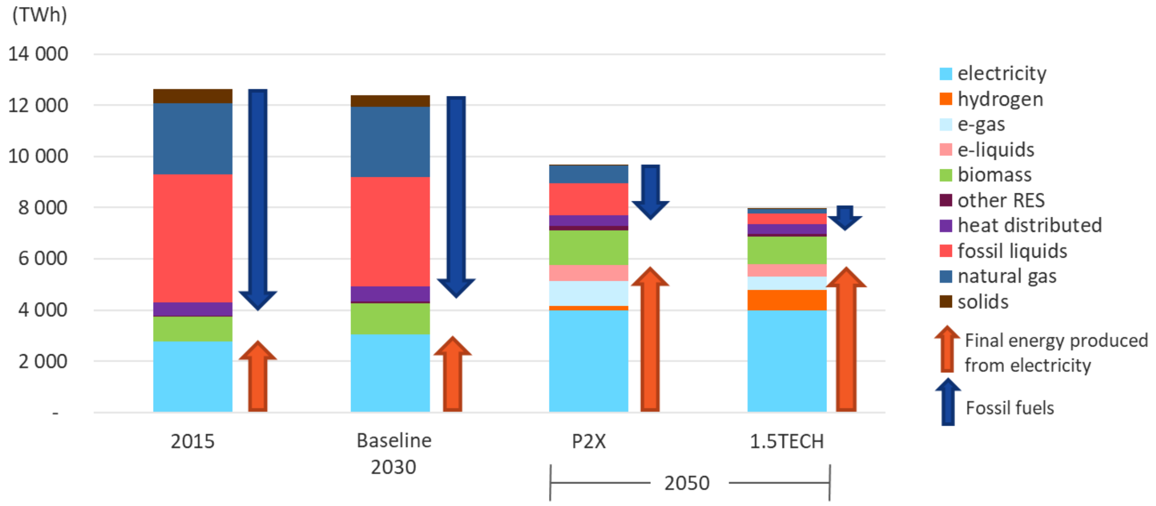

Figure 2 - Share of energy carriers in final energy consumption (TWh). Source: EC LTS

As a consequence of the large volumes of e-gases and e-liquids being required to decarbonise these sectors, the demand for electricity drastically increases between 2030 and 2050. In 2050, more than a third of the power production is dedicated to electrolysis, in order to produce carbon free fuels (hydrogen, e-gas and e-liquids). Direct electrification also contributes to an increase of the total power demand, raising above 4 000 TWh in both P2X and 1.5TECH scenarios. The combination of direct and indirect electrification leads to a total power demand that will be more than twice as high in 2050 as in 2030 (cf. Figure 2). The demand in the 1.5TECH scenario is a little higher than the one of the P2X scenario, since the more ambitious target in terms of reduction of greenhouse emissions requires a deeper decarbonisation of the energy sector.

3.3 Implementation of the LTS scenarios in METIS

The translation of the LTS scenarios into METIS scenarios relies mostly on assumptions from the Long-Term Strategy scenarios. In particular, the following datasets are directly based on the LTS scenarios:

- Installed capacities of most power generation technologies (solar, wind, nuclear, lignite and coal, geothermal generation, biomass and waste, hydrogen, oil, other renewables) and load factors of RES-E plants.
- Power demand
  - Final electricity demand, with a specific distinction of electric vehicles and heat pumps consumption
  - Indirect power demand (i.e., electricity dedicated to P2X, in order to produce synthetic hydrogen, e-gas and e-fuels)
- Commodity prices

[4] e-gas refers to e-CH_4, which can be used instead of natural gas in all its applications

[5] e-liquids refers to a large range of complex synthetic hydrocarbons, that could be used instead conventional fuels derived from petrol (gasoline, unleaded, oil, kerosene, etc.)

  - Fuel prices (gas, coal, oil)
  - EU-ETS carbon price

These assumptions are gathered at national level for all Member States of the European Union (EU27).

In METIS, in addition to the Member States, 7 major neighbouring countries have also been modelled to capture their interactions with the EU Member States. These 7 countries include:

- Bosnia-Herzegovina
- Montenegro
- Norway
- North Macedonia
- Serbia
- Switzerland
- United Kingdom

While the UK follows the same modelling process as the EU countries since they are included in the LTS scenarios, the main assumptions of power production capacities and demand for the 6 remaining countries are based on exogenous scenarios from the ENTSO-E's TYNDP2018. In particular, the following scenarios have been selected, as they were assessed to be the closest to the selected EC pathways:

- Baseline (2030): "Sustainable Transition" (ST) 2030 scenario has been selected, as it was in line with the 2030 objectives of the European Union
- 1.5TECH and P2X (2050): "Global Climate Action" (GCA) 2040 has been selected, since it relies as the LTS scenario in large-scale power renewable for both direct and indirect electrification of the EU energy system

4 DESCRIPTION OF THE DATA COMPLETION PROCESS TO CONFIGURE THE METIS SCENARIOS

The three "METIS scenarios" (implementations in METIS of LTS Baseline, 1.5TECH and P2X) are based on the pathways elaborated in the context of the EC Long-Term Strategy. For the 27 European countries and the UK, the data completion process of parameters needed to model all different assets in METIS was mainly based directly on the data from the EC Long-Term Strategy scenarios. Additionally, data for the remaining 6 neighbouring countries modelled in METIS were based on the different ENTSOE-E TYNDP 2018 scenarios mentioned on the previous section. Additional sources, such as the ASSET database (E3Modelling, Ecofys, Tractebel, 2018), were also used, e.g., for techno-economic parameters, such as capital costs, potential, fuel prices, etc.

Furthermore, while installed capacities for most technologies are based directly on the EC's LTS scenarios, investments in flexibility solutions are optimized with METIS, benefiting from a more detailed representation of the power system's dynamics thanks to an hourly resolution. The flexibility solutions' portfolio is composed of gas-fired plants (OCGTs and CCGTs), storage technologies (batteries and pumped hydro storage), P2X technologies and cross-border interconnectors. The resulting optimized capacities for these technologies may then differ from the original installed capacities in the LTS scenarios.

This section explains the detailed methodology used to calibrate all assets included in the three METIS scenarios.

4.1 ENERGY DEMAND

From 2030 onwards, the Long-Term Strategy considers an important development of P2X technologies for indirect electrification, leading to the production of synthetic fuels such as hydrogen, e-gas[6] and e-liquids[7] from electrolysis, replacing their fossil counterparts in the industry, heating and mobility sectors. As a consequence, in the LTS scenarios, the demand for electricity drastically increases between 2030 and 2050. The P2X chain will be responsible for more than a third of the power demand as electrolysis takes an essential role on the production of carbon free fuels. The production of hydrogen and its derivatives (e-gas and e-liquids) can provide an important flexibility to the system, as hydrogen can be produced using excess electricity of vRES via electrolysis for direct use or be later converted into e-gas and e-liquids.

The 2050 scenarios also assume an important flexibility of end-uses on the P2X side (hydrogen and e-fuels), that can be provided by hydrogen storage (enabling a flexible operation of electrolysers) but also via some flexibility in the end-uses' consumption (for

[6] e-gas refers to synthetic methane, which can be used as a substitute for natural gas.

[7] e-liquids refers to a large range of complex synthetic hydrocarbons, that could be used instead conventional fuels derived from petrol (gasoline, unleaded, oil, kerosene, etc.)

example for the supply of vehicles with e-liquids, consumption is flexible thanks to current infrastructure for petrol).

In order to better capture the coupling between the different energy vectors and the flexibility provided by the P2X chain, the energy demand is separated into two main categories:

- direct power demand, represented by hourly time series and decomposed in 5 end-uses (electric vehicles, heat-pumps, air conditioning, thermosensitive remainder and non-thermosensitive remainder)
- indirect power demand dedicated to P2X: electricity dedicated to P2X, in order to produce synthetic hydrogen, e-gas and e-fuels, represented by an annual demand volume.

4.1.1 POWER DEMAND

The direct power demand is modelled with the following end-use decomposition:

- Electric vehicles
- Heat-pump
- Air conditioning
- Thermosensitive remainder
- Non-thermosensitive remainder

Each end-use is modelled via an hourly profile, from the METIS database[8]. For thermosensitive end-uses (heat-pump, air conditioning and thermosensitive remainder) three hourly time series are considered, which reflect three different years of historical temperature data. The generation of the demand time series sensitive to temperature is described in detail in METIS Technical Notes T1 (Artelys, 2016) and T8 (Artelys, 2018).

EU27 countries

In order to build a scenario consistent with the LTS pathways, the power demand time series are adjusted, so that on average (over the 3 weather years, for thermosensitive end-uses) the total power demand of each end-use by country corresponds to the annual volume from the LTS data.

The total power demand by country corresponds to the sum of the following data taken from the LTS scenarios:

"Final energy demand" + "Transmission and distribution losses" + "Refineries & other uses" – "Annual Electricity Consumed for Fuel Production"

In the METIS scenarios described in this document, network losses are included ex-ante (total network losses are added to the final power demand) and are not explicitly modelled. The "Annual Electricity Consumed for Fuel Production" is accounted for in the P2X demand explained in the next section, therefore it is deducted from the direct power demand.

The total power demand for each end-use corresponds to the following data from the LTS scenarios:

[8] https://energy.ec.europa.eu/metis-scripts-and-data_en

- Electric vehicles: final energy demand in electricity for "Passenger transports" in road transport
- Heat-pump: energy consumption of heat pumps
- Air conditioning: final energy demand for air conditioning, for the residential sector
- Thermosensitive remainder: the thermosensitive remainder is considered to be the Final electricity demand of residential and tertiary less the electricity demand for air conditioning (already accounted for) and less the final energy demand of electric appliances and lighting (which is non thermosensitive).
- Non-thermosensitive remainder: all the other end-uses are considered to be non-thermosensitive. The total power demand for non-thermosensitive end uses corresponds to the total power demand less the sum of the end-uses listed above.

The annual power demand for electric vehicles is converted to a number of vehicles per Member State, used as input in the EV model in METIS[9]. EVs are optimised by modelling the smart charging patterns of two categories of battery EVs depending on the user profiles (home charging/work-charging). A ratio of 50% of EVs at home and at work is assumed for the scenarios. The charging of EVs is optimised for all vehicles connected to the charging point, depending on hourly arrival and departure time series. For more details on the modelling and data used for EVs see METIS Technical Note T8 (Artelys, 2018) and METIS Study S13 (Artelys, 2018).

Electricity demand from heat pumps is aggregated at national level and converted to useful heat demand. The hourly operation of heat pumps in order to meet the heat demand is optimised in METIS, with flexibility being provided by a heat storage unit. The use of an electric or gas back-up heater can also be optimised. Heat pumps' operation is based on several parameters, such as the coefficient of performance (COP), heat storage capacity, and the heating demand. The heat pump's coefficient of performance (COP) varies as a function of the outside temperature, hence depending on the individual weather year considered. For further details on heat-pump's modelling in METIS see METIS Study S6 (Artelys, 2018).

Both EVs and heat pumps can be modelled as flexible assets in METIS, their consumption can be jointly optimised with the rest of the system's operation. More details on the EVs and heat pumps modelling in the METIS scenarios will be detailed in Section 4.3.

Other countries

The dataset for power demand in the UK has been built following the same approach than for the 27 EU countries.

For the 6 other neighbouring countries, the annual power demand is derived from the corresponding ENTSO-Es TYNDP 2018 scenarios:

- "Sustainable Transition" (ST) 2030 for Baseline (2030).
- "Global Climate Action" (GCA) 2040 for 1.5TECH and P2X (2050).

[9] More details on the Electric Vehicles modelling in METIS can be seen on METIS Technical Note T8 (Artelys, 2018)

The decomposition of the consumption into end-uses is assumed to be proportional to the decomposition in end-uses of the closest EU neighbouring country, following the mapping shown in Table 2.

Table 2 - Mapping for non-EU countries power demand decomposition

Country	EU corresponding country
Bosnia-Herzegovina	Croatia
Switzerland	Austria
Montenegro	Bulgaria
North Macedonia	Romania
Serbia	Romania
Norway	Sweden

Based on this association, power demand time series of the non-EU countries are built so that on average the total power demand of each end-use by country corresponds to the annual volumes given in the ENTSO-E scenario.

4.1.2 P2X DEMAND

In the METIS 2050 scenarios the whole P2X demand (hydrogen, e-gas and e-liquids) is represented by an aggregated hydrogen demand. Hydrogen can either be consumed as such or converted further along the P2X chain in its derivatives, namely e-gas and e-liquids. For complexity purposes, e-liquids and e-gas end-use demands are factored in the hydrogen end-use demand. An annual inelastic hydrogen demand is modelled in the 2050 scenarios and accounts for all the exogenous end-uses of hydrogen, either in the industry, transport or building sectors.

Since the flexibility on the end-user side is difficult to predict (possible storage of hydrogen, refurbishment of existing network and storage to be compatible with e-gases, flexibility of the fuel supply for vehicles, etc.), it is assumed that there is a large flexibility on the demand-side of hydrogen, e-gas and e-fuels, implying that only the annual volume has to be met, in line with the values of the Long-Term Strategy pathways, whereas no daily, weekly or seasonal operational constraints are considered.

The assumption for annual hydrogen demand is based on the electricity demand for power-to-X, considering the electrolyser conversion efficiency (for hydrogen).

For each of the EU27 countries[10], the annual electricity demand used by electrolysers, power-to-CH4 and power-to-liquids was estimated as the sum of the following data from the LTS scenarios:

"Electricity Consumed as Losses in Storage and for Fuel Production": Electrolysers, Power-to-gas and Power-to-Liquid

Then, consumption for hydrogen that is reused for the power sector (reflecting the power-to-gas-to-power conversion chain) is subtracted from the total, since it is not part of the final hydrogen demand:

[10] For the other 6 non-European countries (with the exception of the UK) no P2X demand is considered

"Energy storage": Hydrogen

Hydrogen production is considered to include the demand of hydrogen for direct use as well as hydrogen used as an input for e-gas and e-fuels production. The total P2X demand of each country is then converted to a hydrogen demand, using the conversion efficiency of alkaline electrolysers of 85% (E3Modelling, Ecofys, Tractebel, 2018).

The resulting volume is used as an inelastic hydrogen demand coupled to a perfect storage, that models an annual hydrogen demand-side flexibility. This capacity can be further parameterized to represent either weekly or monthly demand-side flexibility ((Artelys, 2022)).

In these scenarios, the hydrogen production to meet this demand can be supplied by either electrolysis or by hydrogen produced by SMR (steam methane reforming) combined with CCS (carbon capture storage), for times when RES generation is not high enough to produce all the required hydrogen.

4.2 Power generation

4.2.1 Wind and Solar fleets

In METIS, wind and solar fleets can produce a maximum energy equal to the product of their installed capacity and a capacity factor (percentage of the installed capacity that is available at a given hour, accounting for weather conditions).

To represent the variability of the wind and solar production, in consistency with what was done for the thermosensitive end-uses in power demand, 3 different climatic years have been considered: a cold year, a warm year and a year with an average temperature profile. These years define the hourly capacity factor time series (8760 hourly values) which are used for wind and PV fleets. For both, the EU27 and the 7 neighbouring countries, the capacity factor time series for wind and PV were computed using generation profiles from METIS database[11].

EU27 countries

The profiles were adjusted so that on average, over all climatic years, the capacity factor matches the average capacity factor from the Long-Term-Strategy pathways. The average capacity factor used for the rescaling is based on data provided by the LTS scenarios:

Average capacity factor = "Net Electricity generation" / "Net installed Power Capacity"

For 2030, the average capacity factor was extracted from the LTS Baseline scenario, whereas for both 2050 scenarios, (1.5TECH and P2X), the average capacity factor is derived from the COMBO scenario. For the 2050 scenarios, this choice was made in order to avoid having different time-series for each country to represent the same climatic year. The COMBO scenario was selected for being a scenario in between 1.5TECH and P2X, well suited for representing both 2050's scenarios vRES generation profiles.

[11] https://ec.europa.eu/energy/data-analysis/energy-modelling/metis/metis-scripts-and-data_en

As a consequence, for both 1.5TECH and P2X, the installed capacities of wind and solar fleets had to be adjusted so that the final generation matches the net electricity generation indicated in each LTS scenario (1.5Tech and P2X, respectively):

*"Net Electricity generation" = "Adjusted installed capacity" * "Average capacity factor"*

Remark: for Malta, Cyprus and Romania no hourly data for wind and solar power generation is available in the METIS database, hence capacity factors hourly profiles from neighbouring countries were used as shown in Table 3.

Table 3 - Mapping for renewable generation profiles

Country	Reference country for vRES time series
Malta	Italy
Cyprus	Greece
Romania	Bulgaria

Other countries

The dataset for the UK is built following the same approach as for the EU27 countries.

For the 6 other non-EU countries the installed capacities and capacity factor time-series were derived from the corresponding ENTSO-E TYNDP 2018 scenario.

4.2.2 Hydro reservoir and run-of-River

In METIS, run-of-river hydro (RoR) can produce energy up to the product of their installed capacity and a capacity factor time series (as wind and solar) which reflects hydro power availability.

Hydro reservoir is modelled as a storage of energy, whose generation depends on water inflows (hourly time series in MWh), the generation capacity (characteristic of the turbine) and storage. The sum of the water inflows over a year determines the yearly power generation. The water inflow profiles and the storage parameters (such as storage capacity, weekly storage minimum level, initial storage level) determine how this power generation is spread over the year.

In order to more accurately capture the storage dynamics of hydro lake fleets, hourly water inflow profiles and storage parameters were based on historical data[12]. These profiles are used to better model the hourly operation and seasonal variations of inflow and storage availability throughout the year. More details are available in the Annex: Review Of The Annual Hydro Generation Parameters of METIS.

Historical water inflow time series are rescaled so that the annual water inflow matches the *"Net Electricity generation"* indicated in the Long-Term-Strategy scenarios.

Inflow rescaling ratio = "Net Electricity generation" / Annual water inflow from historical data

12 (ENTSO-E, 2022)

Storage capacities and installed capacities are also scaled by this same ratio to avoid any computation infeasibilities due to storage-related constraints.

For all other non-EU countries (with the exception of the UK): all parameters for both hydro lake fleets and RoR fleets are derived directly from the TYNDP 2018 scenarios without any further adjustment.

4.2.3 THERMAL GENERATION

The following thermal generation fleets are considered in the METIS scenarios:

- Solid-fired fleet (Coal and Lignite).
- Natural gas fleet (CCGTs and OCGTs)[13]
- Oil fleet
- Biomass fleet
- Waste fleet
- Nuclear fleet

To run simulations at an hourly time step, fuel-based thermal fleets require availability profiles (representing maintenance schedules) along with installed capacities. Further details on the availability profiles or values used for each thermal fleet can be found in the METIS Technical Note T1 (Artelys, 2016).

The installed capacity of nuclear and oil fleets derives directly from the LTS data: "Net installed Power Capacity".

The installed capacity for biomass- and waste-fired fleets are divided using a ratio of 22% of total capacity for waste fleet capacity and 78% for conventional biomass capacity (METIS Study S1 (Artelys, 2018)). For biomass, a fixed availability of 96% is used to represent maintenance.

For the 2030 Baseline scenario, the solids-fired fleet capacity is divided into a hard coal and a lignite fleet based on assumptions from the TYNDP 2018 scenario. For the 2050 scenarios the installed capacity is assumed to be solely coal fleet as lignite is assumed to be phased-out.

Installed capacities for non-EU countries derive from TYNDP 2018 scenarios.

For fuel-based thermal fleets, METIS takes into account maximum gradient constraints. A detailed description of the data used for all technical parameters can be found in METIS Technical Note T1.

While the operation of other thermal fleets is optimised in METIS, waste fleets are modelled as "must-run" using a fixed capacity factor estimated to match the total generation from the LTS scenarios, given by:

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[13] CCGT and OCGT fleets are part of the flexibility portfolio and will have their capacities optimized in METIS.

Capacity factor = "Net Electricity generation" / "Net Installed Power Capacity"

4.2.4 OTHER FLEETS

The remaining fleets (that are not part of the flexibility portfolio), composed of other renewables (tidal etc.), derived gasses, hydrogen turbines, and geothermal, are represented as "must-run" fleets in METIS. Their capacity factor is a constant value given by:

Capacity factor = "Net Electricity generation" / "Net Installed Power Capacity"

The installed capacity is the "Net Installed Power Capacity", which ensures that over a year, the total generation outcome is equal to the "*Net Electricity generation*" indicated in the LTS data.

For non-EU countries, the installed capacities and capacity factors derive from the corresponding TYNDP 2018 scenario.

4.2.5 CO_2 EMISSIONS

LTS data includes carbon price projections for different years and scenarios. The values used for the METIS scenarios were:

- Baseline (2030): 28 €/tCO2
- 1.5TECH (2050) and P2X (2050): 350 €/tCO2

The CO_2 consumed by methanation plants is modelled in METIS by a CO_2 supply to be provided by Direct Air Capture (DAC).

In 2050, the price was estimated based on the CO_2 carbon price minus the cost of DAC from the LTS data, of 200 €\MWh. For further details on the modelling of methanation plants, see (Artelys, 2022).

The CO_2 content (in t_{CO2}/MWh_{HHV}) for each fuel is detailed in Table 4, based on (ADEME, Updated in 2021).

Table 4 - CO_2 content by energy carrier

Fuel	CO2 content (t_{CO2}/MWh_{HHV})
Natural gas	0.185
Oil	0.262
Coal	0.345
Lignite	0.364

4.2.6 FUEL PRICES

International commodity prices

International commodity prices were provided in the LTS data in €/toe. In order to be integrated to METIS, they were converted to €/MWh_{HHV}. These prices are common to all EU27 and neighbouring countries and can be seen in Table 5.

Table 5 - International fuel prices

Fuel	Price (€/MWh_{HHV}) - 2030	Price (€/MWh_{HHV}) - 2050
Gas	38.4	43.7
Oil	63.3	72.7

Hydrogen production from electrolysis can be complemented by SMR combined with CCS, which is modelled in METIS by a hydrogen supply, with an associated production cost of 90€/MWh.

Coal and lignite end-user prices

End-user fuel prices depend on the transportation cost and thus vary from one country to another. For coal and lignite individual prices per country were used, since they national price variation tends to be more significant compared to other fuels. The data is derived from the end-user fuel prices from the LTS scenarios for most of EU27 countries.

For the 2050 scenarios, for countries without a coal or lignite end-user price, the EU28 price from Baseline 2050 was used as default.

4.2.7 BIOENERGY POTENTIAL

Biogas

The biogas potential is defined at the European level. It is modelled as a maximum yearly biogas supply that can be used by all EU27 countries plus the Unite Kingdom. A production cost of 61.2 €/MWh of methane is considered[14].

The total biogas potential used for power production in the EU27 countries plus the United Kingdom for each scenario is given on below:

- Baseline (2030): 325.64 TWh
- 1.5TECH (2050): 558.24 TWh
- P2X: 453.57 TWh

The potential derives directly from the *"Consumption of biogas and gas from waste sector"* in the power sector data from the LTS scenarios (converted from Mtoe to tons to be integrated into METIS).

Biomass

The biomass fleet is modelled without any production costs and the operation is limited by the biomass potential, which gives an upper limit for the total annual generation. The biomass potential is estimated at country-level and is based on the *"Net Electricity generation"* for biomass in the LTS data[15], assuming an efficiency of 40%.

[14] Cost potential curve from the IEA World Energy Outlook 2019

[15] Considering the ratio for Biomass and Waste fleet split (Section 4.2.4)

4.3 FLEXIBILITY PORTFOLIO

All flexibility assets, listed below, are subject to capacity optimization:

- Gas-fired power plants: OCGT, CCGT, CCGT+CCS
- Storage capacities (pumped hydro storage and stationary batteries)
- Power-to-X technologies (electrolysers and methanation)
- Cross-border interconnectors

The equilibrium between the power demand (and P2X demand in the 2050 scenarios) and the power production is ensured by a joint optimisation of investments and operation with the objective of minimising the total costs of the European system[16]. The optimisation is performed at an hourly time step, jointly for the 3 weather years (modelled to capture the variability of wind and solar production and of power demand), in order to dimension a power system that is robust to the 3 weather years.

The flexibility of the power system can be provided by these additional capacities, but also by other flexible technologies whose capacities are directly coming from the LTS scenario (nuclear, hydropower, coal/lignite, biomass) or demand-side response (smart charging or V2G of electric vehicles and heat pumps with thermal storage).

The installed capacities of the flexibility portfolio are jointly optimized for all 34 countries modelled in METIS. Their techno-economic parameters will be detailed in this section.

Pumped hydro storage

Pumped Hydro Storage (PHS) is one of the most conventional storage solutions. Its potential is limited by the availability of sites and might therefore vary considerably from one country to another. For all scenarios, PHS were separated in two categories:

- Existing PHS: existing capacities and storage capacities are given by ENTSO-E's TYNDP 2018 scenario "Best Estimate" scenario for the year 2020
- New PHS:
  - maximum potentials for the METIS 2030 scenario are given by ENTSO-E's TYNDP 2018 Sustainable Transition capacities (+15 GW).
  - maximum potentials for both METIS 2050 scenarios are given by ENTSO-E's TYNDP 2018 Global Climate Action capacities (+30 GW)

The storage capacity of all added PHS capacities is assumed to be of 24 hours (i.e., storage capacity = generation capacity*24). All technical parameters are listed in Table 6 and Table 7. Figure 3 provides a breakdown of the existing and potential PHS capacities for each country.

[16] The total costs of the system include annualised investment costs (for optimised capacities), fixed operation and maintenance costs, variable operation and maintenance costs, fuel costs and the carbon price.

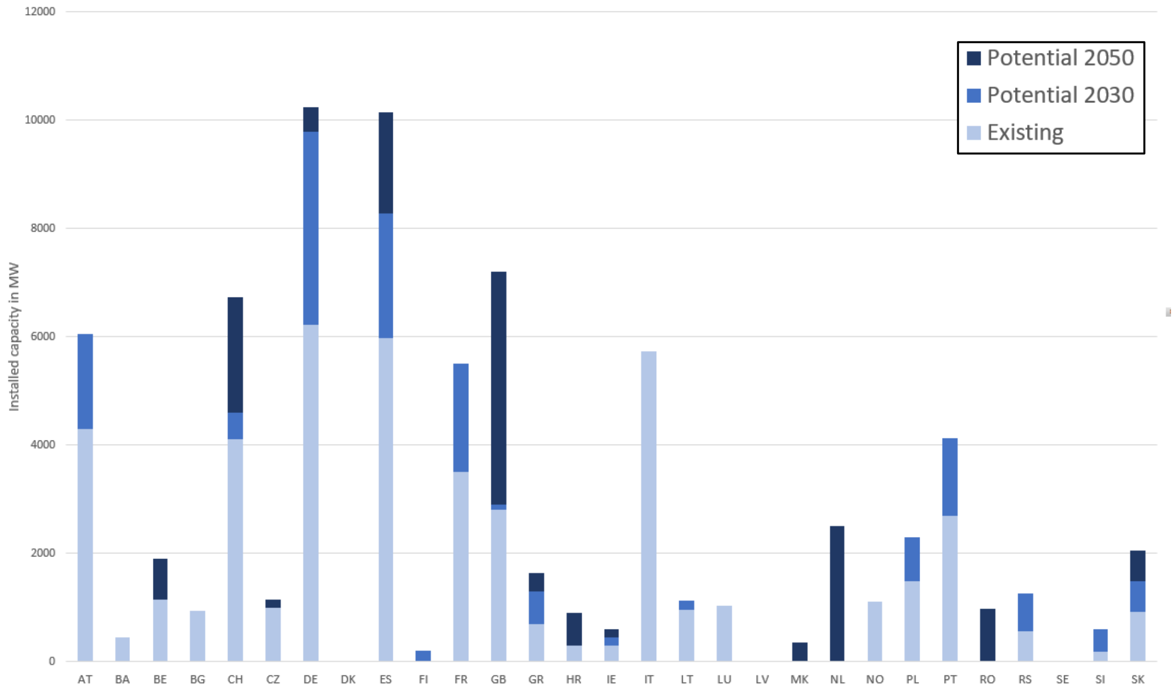

Figure 3 - Pumped hydro storage potential in 2030 and 2050, based on data from (ENTSO-E, 2018)

Batteries

Batteries can be used to provide short-term flexibility to the system. For all scenarios, four types of battery have been considered as potential investment options, with storage duration of 1, 2, 4 and 8 hours, respectively. No capacity limit is considered for these assets. Their CAPEX and other techno-economic parameters are specified in Table 6 and Table 7, derived from the ASSET study (E3Modelling, Ecofys, Tractebel, 2018).

Gas-fired plants

Both open-cycle gas turbines (OCGT) and combined-cycle gas turbines (CCGT) can provide additional flexibility. While OCGTs can provide a cheaper short-term response, they have lower efficiency than CCGTs. CCGTs with carbon capture and storage (CCS) are also considered, with a CO2 capture rate of 90%. All gas-fired plant capacities are optimised without any capacity limits. Their techno-economic parameters are listed in Table 6 and Table 7, based on (E3Modelling, Ecofys, Tractebel, 2018).

The LTS scenarios foresee limited amount of biogas being available for power production in 2050, but that amount is found to be sufficient to produce electricity with conventional gas-fired units during the hours where the power system is found to be needing such flexibility services.

Electrolysis and methanation

Electrolysers and methanation plants are investment options, without limitation on their potentials. The whole power-to-X chain has an important role in enhancing overall flexibility, as electrolysers can serve not only to directly supply hydrogen demand enabling the indirect electrification of a set of end-uses, but also convert the excess of renewable generation into hydrogen that can be stored and later converted to synthetic fuels. In this context, methanation completes the power-to-gas-to-power loop, allowing the production of synthetic gas that can fuel gas-fired plants. All techno-economic parameters of both electrolysers and methanation plants are listed below in Table 6 and Table 7, based on (E3Modelling, Ecofys, Tractebel, 2018).

Only one type of technology of electrolysers was considered in the modelling. The CAPEX and efficiency are equivalent to the Alkaline Electrolyser.

Interconnectors

Cross-border interconnectors enable exports and imports of energy between countries, thereby ensuring that the balance between supply and demand can be met at the lowest overall cost, reducing curtailment and better exploiting generation and storage technologies.

In all scenarios, interconnector capacities are optimised based on ENTSO-E's TYNDP 2018 Project List (PCI) data. The existing capacity is based on interconnectors from TYNDP 2018 BE for 2020 and the potential for additional capacities are based on TYNDP 2018 GCA 2040 scenario for scenarios P2X and 1.5TECH (170 GW potential) and on TYNDP 2018 ST 2030 for Baseline (74 GW potential)[17]. Figure 4 shows the existing installed capacities and the potential for additional capacity for each country.

For all transmissions in the TYNDP 2018 Project List, their CAPEX and OPEX are estimated at country-level, the price is weighted per country and the CAPEX corresponds to one direction of the interconnection. For transmissions that are not on the TYNDP 2018 Project List, their CAPEX and OPEX were estimated based on their type:

- Inland: average CAPEX and OPEX from all other inland transmissions in the Project List
- Offshore: average CAPEX and OPEX per kilometre estimated based on all other offshore transmissions in the Project List. The distance between the two countries used for costs is assumed to be the minimum distance between the shores of both countries.

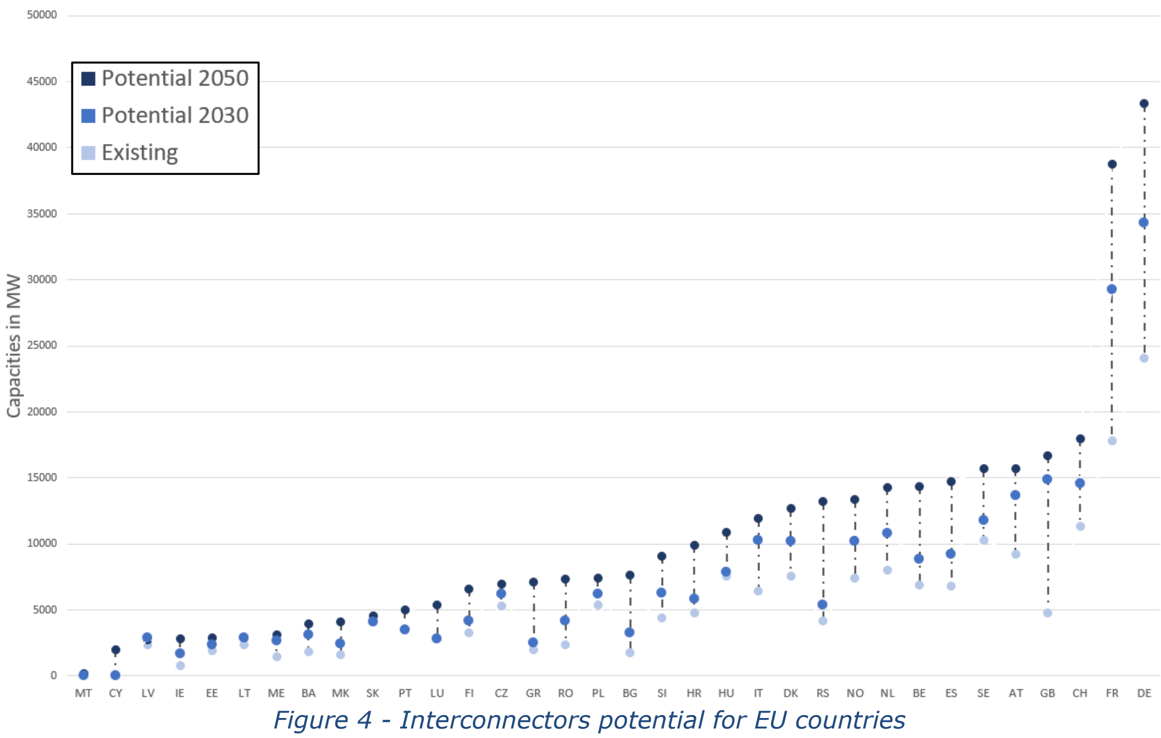

Figure 4 - Interconnectors potential for EU countries

[17] Please note that the capacity of a transmission is counted in this total for each direction of the interconnexion flow. Then, if an interconnexion has an NTC value of 1 GW in one side and 2 GW in the other side, the total capacity would be 3 GW.

Table 6 - Technical parameters for flexibility solutions used for Baseline 2030

		Potential	Optimised capacity	Investment cost (€/kW)	Fixed O&M costs (% CAPEX)	Efficiency	Lifetime
Interconnectors	Additional capacities	+ 74 GW	✓	Based on line-by-line projects		-	50
Gas-fired power plants	OCGT	-	✓	700	3%	40%	25
	CCGT	-	✓	770	2%	63%	30
	CCGT with CCS	-	✓	1625	2%	49%	30
Storage capacities	Pumped Hydro	+ 15 GW	✓	1212	1,20%	81%	60
	Batteries	-	✓	120€/kW + 120€/kWh	4,30%	90%	10
Power-to-X technologies	Electrolysis	-	✓	300	6,50%	82%	20
	Methanation	-	✓	633	3,50%	79%	25

Table 7 - Technical parameters for flexibility solutions used for 2050 scenarios

		Potential	Optimised capacity	Investment cost (€/kW)	Fixed O&M costs (% CAPEX)	Efficiency	Lifetime
Interconnectors	Additional capacities	+ 170 GW	✓	Based on line-by-line projects		-	50
Gas-fired power plants	OCGT	-	✓	600[18]	3%	40%	25
	CCGT	-	✓	750	2%	63%	30
	CCGT with CCS	-	✓	1500	2%	49%	30
Storage capacities	Pumped Hydro	+ 30 GW	✓	1212[19]	1,20%	81%	60
	Batteries	-	✓	120€/kW + 120€/kWh[20]	4,30%	90%	10
Power-to-X technologies	Electrolysis	-	✓	180[21]	6,50%	82%	20
	Methanation	-	✓	263	3,50%	79%	25

Electric Vehicles and Heat Pumps

Electric vehicles and heat-pumps can play an important role in the provision of short-term flexibility. The behaviour of electric vehicles with smart charging or vehicle-to-grid capabilities, and heat-pumps combined with short-term storage (2 hours in the model), can be optimised in order to smooth the residual load profile.

At the 2030 horizon, 30% of all electric vehicles and heat pumps are considered as being able to offer flexibility services, while in 2050 this percentage is assumed to rise to 70%.

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[18] CAPEX source: "Technology pathways in decarbonisation scenarios", (E3Modelling, Ecofys, Tractebel, 2018)

[19] CAPEX source: ETRI (European Commission - Joint Research Centre, 2014) and METIS Study S8 (Artelys, 2018)

[20] Sources: ETRI (European Commission - Joint Research Centre, 2014) and METIS Study S8 (Artelys, 2018)

[21] CAPEX and efficiency sources: "Technology pathways in decarbonisation scenarios" (E3Modelling, Ecofys, Tractebel, 2018) and METIS Study S8 (Artelys, 2018)

EVs may also feature a configurable vehicle-to-grid (V2G) functionality, i.e., electricity may be reinjected from the EV battery into the grid.

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6 Annex: Review Of The Annual Hydro Generation Parameters of METIS

6.1 Methodology

The review of the annual hydro generation parameters is based on the Statistical Factsheets (SFS) that are published by ENTSO-E (see Figure 6-1 with an excerpt of the SFS 2018). The installed capacities and annual generation volumes reported in those factsheets are generally aligned to the annual numbers reported by Eurostat and national TSOs. ENTSO-E's Transparency Platform publishes accurate hourly production data for individual power generation units greater than 100 MW: *Actual Generation Output per Generation Unit [16.1.A]*. Nevertheless, the scope of the *Actual Generation per Production Type [16.1.B&C]* is not always clear, and may even change over time. That is why it is not advised to use those data to infer annual generation volumes per production type, as they can deviate significantly from reality. Also, the *Installed Capacity per Production Type [14.1.A]* from the Transparency Platform seems to be inconsistent with ENTSO-E's own Statistical Factsheets, and figures published individually by national TSOs.

ENTSO-E in figures – Electricity system data of member TSOs' countries

ENTSO-E Transmission network losses percentage of consumption: 1.77 %

Net generation 2018

Country	Non renewable net generation	Nuclear	Fossil fuels	Of which Fossil Brown coal/Lignite	Of which Fossil Coal-derived gas	Of which Fossil Gas	Of which Fossil Hard coal	Of which Fossil Oil	Of which Fossil Oil shale	Of which Fossil Peat	Of which Mixed fuels	Of which Other fossil fuels	Hydro pure pumped storage	Hydro mixed pumped storage (non renewable part)	Waste (non renewable part)	Other non-renewable
	TWh	TWh	TWh	TWh	TWh	TWh	TWh	TWh	TWh	TWh	TWh	TWh	TWh	TWh	TWh	TWh
AL	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
AT [2]	18.6	–	15.0	–	–	9.8	1.8	0.6	–	–	n.a.	2.7	–	3.6	–	–
BA	11.0	–	10.8	10.8	–	–	–	–	–	–	–	–	–	0.1	–	–
BE	53.5	27.0	24.3	–	2.1	22.1	–	0.1	–	–	–	–	1.0	–	1.0	0.2
BG [3]	34.3	15.3	18.7	16.8	–	1.7	0.3	–	–	–	–	–	0.3	0.0	–	–
CH	26.8	24.4	1.0	–	–	1.0	–	0.0	–	–	–	–	–	–	1.4	–
CY	4.8	–	4.8	–	–	–	–	4.8	–	–	–	–	–	–	–	–
CZ	73.0	28.3	43.6	34.2	1.6	4.4	3.2	0.0	–	–	–	0.1	1.1	–	–	–
DE [4]	384.7	71.9	300.9	134.8	–	87.3	72.9	3.2	–	–	2.6	–	5.6	1.1	5.2	–
DK	9.1	–	9.1	–	–	2.2	6.9	0.1	–	–	–	–	–	–	–	–
EE	8.8	–	8.8	–	–	–	–	–	8.8	–	–	–	–	–	n.a.	n.a.
ES	160.7	53.2	103.0	25.6	–	53.7	11.7	12.0	–	–	–	–	1.6	0.4	2.4	0.0
FI	35.8	21.9	13.0	–	–	3.9	5.8	0.2	–	3.0	–	–	–	–	n.a.	0.9
FR	439.9	393.2	39.5	–	–	31.4	5.8	2.2	–	–	–	–	–	5.1	2.1	–
GB [5]	207.4	60.7	146.7	–	–	129.9	16.8	0.0	–	–	–	–	–	–	–	–
GR	29.1	–	29.0	14.9	–	14.1	–	–	–	–	–	–	–	0.0	–	–
HR	3.2	–	3.2	–	–	1.9	1.3	–	–	–	–	–	–	–	–	–
HU	24.8	14.8	10.0	4.5	–	5.4	0.0	0.1	–	–	–	–	–	–	–	–
IE	19.8	–	19.3	–	–	14.9	2.1	0.1	–	2.2	–	–	0.2	–	0.3	–
IS	0.0	–	0.0	–	–	–	–	0.0	–	–	–	–	–	–	–	–
IT	170.3	–	158.7	–	2.2	124.0	28.8	3.6	–	–	–	–	1.9	0.5	2.1	7.2
LT	1.1	–	0.4	–	–	0.3	–	–	–	–	0.1	–	0.5	–	0.1	0.2
LU	1.6	–	0.2	–	–	0.2	–	–	–	–	–	–	1.2	–	0.1	–
LV	3.1	–	3.1	–	–	2.6	–	–	–	–	0.5	–	–	–	–	–
ME	3.5	–	1.4	1.4	–	–	–	–	–	–	–	–	–	2.0	–	–
MK	3.4	–	3.4	2.7	–	0.7	–	–	–	–	–	–	–	–	–	–
NL [6]	90.9	2.8	88.1	–	–	71.4	16.7	–	–	–	–	–	–	–	–	–
NO	3.2	–	3.2	–	–	3.2	–	–	–	–	–	–	–	–	–	–
PL [7]	136.6	–	136.0	44.8	1.9	12.4	75.2	1.6	–	–	–	–	0.4	0.0	0.3	–
PT	27.1	–	25.6	–	–	14.4	11.1	0.1	–	–	–	–	–	1.3	–	0.2
RO	34.7	10.4	24.3	13.0	–	5.0	1.0	–	–	–	5.2	–	–	–	–	–
RS	29.1	–	28.3	28.1	–	0.2	–	–	–	–	–	–	0.8	–	–	–
SE	69.5	65.8	2.8	–	–	0.6	0.5	0.2	–	–	1.5	–	–	–	0.9	–
SI	10.0	5.5	4.1	4.0	–	0.0	–	–	–	–	–	–	–	0.2	0.0	0.3
SK	19.2	13.8	5.1	1.3	0.5	1.8	1.2	0.3	–	–	–	0.0	0.3	0.0	0.1	–
TR	203.5	–	203.5	44.8	–	89.4	67.8	1.4	–	–	–	–	–	–	–	–
ENTSO-E [*]	2 351.8	808.8	1 488.8	382.0	8.3	710.0	330.9	30.7	8.8	5.3	9.9	2.9	14.8	14.4	16.0	9.0
%	64.27	22.10	40.69	10.44	0.23	19.40	9.04	0.84	0.24	0.14	0.27	0.08	0.40	0.39	0.44	0.25
EU [**]	2 071.4	784.4	1 237.1	294.0	8.3	615.5	263.1	29.3	8.8	5.3	9.9	2.9	14.0	12.3	14.6	9.0
%	67.68	25.63	40.42	9.61	0.27	20.11	8.60	0.96	0.29	0.17	0.32	0.09	0.46	0.40	0.48	0.30

Net generation 2018 (continued) / Consumption 2018 [1]

Country	Renewable net generation	Wind offshore	Wind onshore	Solar PV	Solar Thermal	Biomass	Biogas	Geothermal	Waste (renewable part)	Hydro Pure storage	Hydro Run-of-river and pondage	Hydro mixed pumped storage (renewable part)	Hydro Marine (tidal/wave)	Other renewable	Not identified	Total net generation	Pumping	Consumption	Variation (compared with 2017)	Country
	TWh	TWh	TWh	TWh	TWh	TWh	TWh	TWh	TWh	TWh	TWh	TWh	TWh	TWh	TWh	TWh	TWh	TWh		
AL	8.1	–	–	–	–	–	–	–	–	5.9	2.2	–	–	–	–	8.1	–	7.2	0.5	AL
AT [2]	43.2	–	5.9	n.a.	–	n.a.	n.a.	n.a.	n.a.	n.a.	24.0	10.1	–	3.2	5.7	67.5	5.1	71.4	0.3	AT [2]
BA	6.3	–	0.1	–	–	–	–	–	–	5.8	–	0.3	–	–	0.1	17.3	0.1	12.6	–0.2	BA
BE	15.6	3.4	3.7	3.5	–	2.7	0.8	–	1.2	–	0.3	–	–	0.1	–	69.1	1.3	85.1	0.3	BE
BG [3]	8.0	–	1.4	1.4	–	0.3	–	–	–	2.7	1.6	0.7	–	–	–	42.3	0.4	34.1	–0.9	BG [3]
CH	40.7	–	0.1	1.2	–	0.3	0.4	–	1.3	20.5	16.9	–	–	–	–	67.6	4.0	62.3	–1.7	CH
CY	0.2	–	0.2	–	–	–	–	–	–	–	–	–	–	–	–	5.0	–	5.0	5.3	CY
CZ	8.9	–	0.6	2.3	–	2.0	2.4	–	–	0.7	0.9	–	–	–	–	81.8	1.4	66.6	0.4	CZ
DE [4]	212.9	19.0	88.2	41.2	–	40.1	n.a.	0.2	4.7	0.5	17.9	n.a.	–	1.2	–	597.6	8.3	538.1	–0.1	DE [4]
DK	19.8	4.6	9.3	1.0	–	3.1	0.5	–	1.3	–	0.0	–	–	–	–	28.9	–	34.1	–0.1	DK
EE	1.5	–	0.6	0.0	–	0.7	0.0	–	0.0	–	0.1	–	–	–	–	10.3	–	8.7	2.5	EE
ES	100.3	–	49.6	7.8	4.4	2.8	0.8	–	0.9	24.5	6.6	3.0	–	0.0	–	261.0	3.2	268.9	0.4	ES
FI	31.7	–	5.9	0.2	–	12.5	–	–	–	–	13.1	–	–	n.a.	–	67.5	–	87.4	2.3	FI
FR	108.8	–	27.8	10.2	–	2.8	2.4	–	2.4	–	32.3	30.9	–	–	–	548.6	7.3	478.3	–0.7	FR
GB [5]	78.4	16.7	25.6	11.8	–	17.8	0.1	–	0.4	2.5	3.4	–	–	–	–	285.8	3.4	304.0	–6.4	GB [5]
GR	16.3	–	5.6	3.5	–	0.3	–	–	–	4.4	0.7	0.6	–	1.1	–	45.3	0.0	51.6	–0.6	GR
HR	8.9	–	1.3	0.1	–	0.3	0.3	–	0.0	4.6	1.8	0.5	–	0.0	–	12.1	0.1	18.2	1.7	HR
HU	3.4	–	0.6	0.3	–	1.8	0.2	–	0.4	–	0.2	–	–	–	–	28.2	–	42.5	1.3	HU
IE	9.5	–	8.4	–	–	–	–	–	0.3	–	0.7	–	–	0.2	–	29.3	0.5	28.7	2.1	IE
IS	19.3	–	0.0	–	–	–	–	5.6	–	13.5	0.2	–	–	–	–	19.3	–	19.3	3.4	IS
IT	110.2	–	17.3	22.9	–	7.6	7.3	5.7	2.1	8.9	36.2	2.0	–	–	–	280.5	2.2	322.2	0.6	IT
LT	2.1	–	1.1	0.1	–	0.2	0.1	–	0.1	–	0.4	–	–	–	–	3.2	0.7	12.1	3.2	LT
LU	0.4	–	0.3	0.1	–	–	0.1	–	–	0.0	0.1	–	–	–	–	2.0	1.7	6.4	–2.1	LU
LV	3.4	–	0.1	–	–	0.5	0.4	–	–	–	2.4	–	–	–	–	6.5	–	7.4	1.8	LV
ME	0.2	–	0.2	–	–	–	–	–	–	–	–	–	–	–	–	3.6	–	3.4	1.3	ME
MK	1.8	–	0.1	0.0	–	–	0.1	–	–	1.4	0.2	–	–	–	–	5.2	–	7.1	–1.1	MK
NL [6]	17.6	3.5	7.4	3.1	–	3.5	–	–	n.a.	–	0.1	–	–	–	–	108.6	–	116.5	1.3	NL [6]
NO	141.4	–	3.4	–	–	–	–	–	–	138.0	–	–	–	–	1.1	145.7	n.a.	135.5	1.5	NO
PL [7]	20.4	–	12.5	0.3	–	4.9	0.8	–	–	0.4	1.3	0.2	–	–	–	157.1	0.6	162.2	1.8	PL [7]
PT	28.0	–	12.4	0.8	–	2.8	–	–	–	–	7.3	4.8	–	–	–	55.1	1.6	50.9	2.5	PT
RO	26.0	–	6.3	1.8	–	0.3	–	–	–	7.3	10.4	–	–	–	–	60.7	0.2	57.9	2.1	RO
RS	10.5	–	0.1	–	–	–	–	–	–	1.2	9.2	–	–	–	–	39.6	1.1	39.1	–1.4	RS
SE	88.8	–	16.6	–	–	9.8	–	–	1.3	61.0	–	–	–	–	–	158.3	–	141.1	0.7	SE
SI	5.0	–	0.0	0.2	–	0.1	0.1	–	–	–	4.6	–	–	–	–	15.0	0.3	14.4	1.2	SI
SK	5.8	–	0.0	0.6	–	1.1	0.5	–	–	0.5	2.9	0.1	–	0.0	–	25.1	0.4	28.5	–0.3	SK
TR	96.9	–	19.9	7.2	–	3.2	–	6.9	–	40.9	18.9	–	–	–	–	300.4	–	300.0	1.9	TR
ENTSO-E [*]	1 300.4	47.2	332.3	121.3	4.4	121.6	17.4	18.4	16.3	345.3	217.1	53.3	–	5.7	7.0	3 659.1	44.1	3 628.4	–	ENTSO-E [*]
%	35.54	1.29	9.08	3.32	0.12	3.32	0.48	0.50	0.45	9.44	5.93	1.46	0.00	0.16	0.19	100.00				%
EU [**]	983.3	47.2	308.5	112.9	4.4	118.1	17.0	5.9	15.0	124.0	171.7	52.9	–	5.7	5.7	3 060.5	39.0	3 049.2	–	EU [**]
%	32.13	1.54	10.08	3.69	0.14	3.86	0.55	0.19	0.49	4.05	5.61	1.73	0.00	0.19	0.19	100.00				%

Figure 6-1 : ENTSO-E Statistical Factsheet 2018

For the review of the hydro power modelling parameters, the three last available factsheets were used (2016, 2017 and 2018). Factsheets prior to 2016 do exist but do not provide any distinction between hydro production types (i.e. Run-of-River and Reservoir). In this technical note, only Hydro Run-of-River and Hydro Reservoir technologies are considered.

The following indicators were retrieved from the Factsheets for RoR and Reservoir, per country:

- **Installed Capacity [GW]**: the latest available view (SFS 2018);
- **EFLOH [h]**: average value of the equivalent full-load hours over the SFS 2016-2018;
- **Annual Generation [TWh]**: calculated from the average EFLOH and Installed Capacity (2018).

A few exceptions were made to cope with missing or invalid data:

- *France:* the annual power generation of RoR and Reservoir have been corrected for 2017 to match the average shares for the years 2016 and 2018. The installed capacity has been aligned to the publications of RTE, the French national TSO.
- *Bosnia and Herzegovina, Great-Britain, Hungary, Latvia, Luxembourg, Montenegro, Norway and Portugal*: total annual hydro generation figures and installed capacities (RoR + Reservoir) are based on SFS, but the split between RoR and Reservoir was left as in the original METIS parametrization.

6.2 Impact of the Revision

The alignment to these new hydro envelope figures leads to considerable changes in the power generation mix. Overall, a hydro generation volume excess was present in the initial METIS power system model. It led to an overproduction of 91.2 TWh (39.7 TWh for RoR, and 51.5 TWh for Reservoir). The geographical distribution of this surplus is shown in Figure 6-2. In contrast to the annual generation, the installed capacity was underestimated prior to the revision: 52.3 GW were missing (56.9 GW underreported for Reservoir, and 3.9 GW overreported for hydro RoR). The geographical distribution of those differences is shown in Figure 6-3.

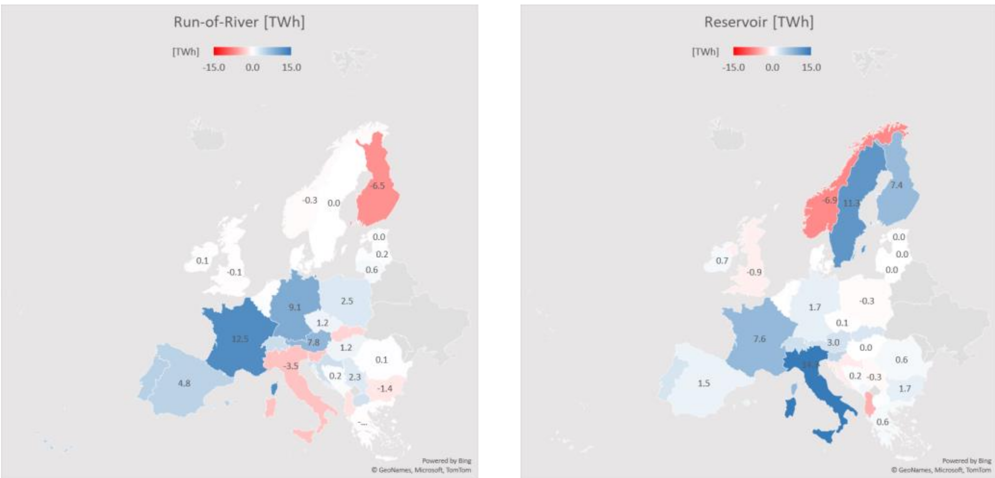

Figure 6-2: Hydro generation surplus (before revision)

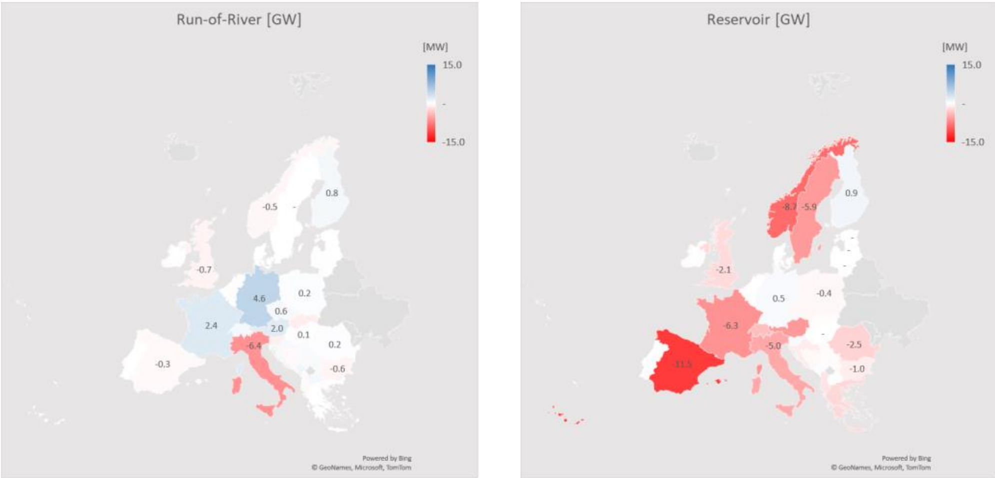

Figure 6-3: Hydro installed capacity surplus (before revision)

Prior to our proposed update, the combination of overestimated hydro power generation volume and underestimated installed capacity led to unrealistic (i.e., too high) annual load factors for hydro. The impact of the revision is shown in Figure 6-4, and can be summarized as follows:

- the average load factor over the full modelling scope decreased from 53% to 33%;
- the range of load factors over the different countries becomes tighter, and covers a more realistic range of [17% - 56%] instead of [13% - 84%].

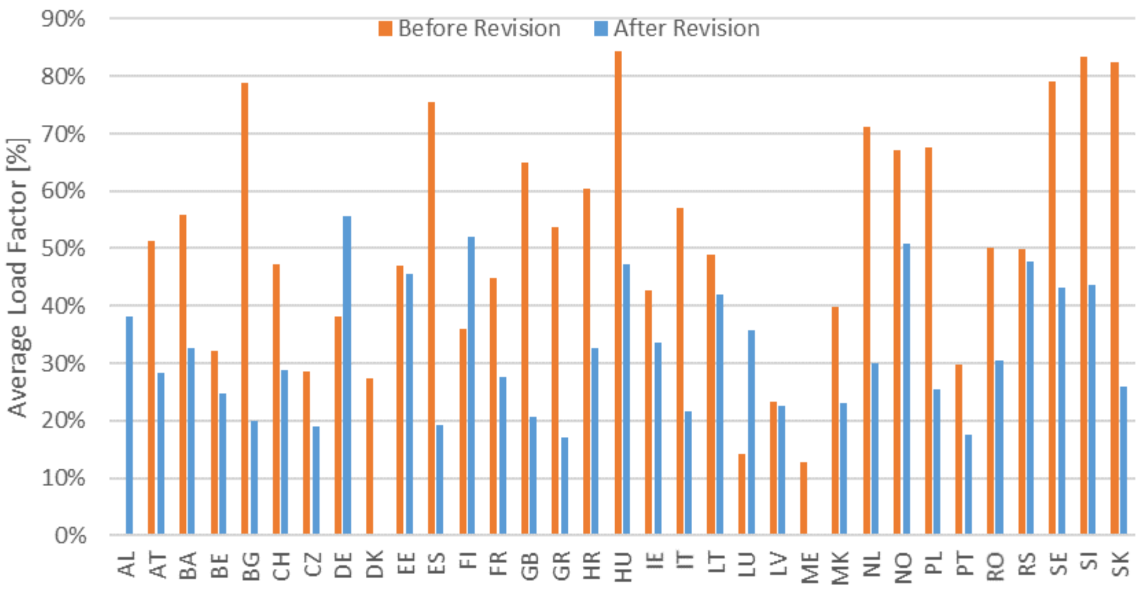

Figure 6-4: Impact of the revision on the load factor per country

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