METIS Technical Note T1

Methodology for the integration of PRIMES scenarios into METIS

METIS Technical Notes
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1 INTRODUCTION

METIS is an on-going project[1] initiated by DG ENER for the development of an energy modelling software, with the aim to further support DG ENER's evidence-based policy making, especially in the areas of electricity and gas. The software is developed by Artelys with the support of IAEW (RWTH Aachen University), ConGas and Frontier Economics as part of Horizons 2020 and is closely followed by DG ENER.

This technical note aims at providing information on how the Consortium integrated PRIMES data into METIS. The methodology was used to calibrate METIS EUCO27 scenario, based on the PRIMES EUCO27 scenario projections, but the same approach can be used for other PRIMES scenario, even other energy system models in general.

The present document is organised as follows:

Section 2 provides an overview of PRIMES data used for METIS scenario calibration.

Section 3 is dedicated to the description of the calibration methodology. In particular, it details how PRIMES data are completed using ENTSO-E published data.

Section 4 provides a comparison of PRIMES EUCO27 and METIS EUCO27 scenarios.

This document only considers data related to power systems. Later versions will also include gas and heat sectors.

[1] (METIS) http://ec.europa.eu/dgs/energy/tenders/doc/2014/2014s_152_272370_specifications.pdf

2 PRIMES-EUCO27 DATA

2.1 DEMAND, INSTALLED CAPACITIES, YEARLY GENERATION

Power demand, installed capacities and yearly generation data were provided at EU level and at country level (for each of the 28 European countries). Power installed capacities and yearly generation are defined at fleet level. These data do not specify the technology used for natural gas fired (CCGT or OCGT) and solid-fired (coal or lignite).

2.2 CCGT/OCGT AND COAL/LIGNITE DECOMPOSITION

The decomposition by country between CCGT and other gas unit fleets (corresponding to all other gas/steam turbines using gas as fuel), as well as the split between coal and lignite fleets, were provided separately.

2.3 ASSET TECHNOLOGY PARAMETERS, NTC VALUES AND FUEL PRICES

Technical fleet parameters, net transfer capacity values and fuel prices were provided. In particular, the following technical parameters were provided associated with each fleet, considering - when relevant - several options or age classes:

- Investment costs (for net power output)
- Fixed O&M Costs
- Variable costs
- Fuel-consumption rate
- Net Efficiency
- Amortisation and Technical Lifetime
- CO2 em. Factor

For each of the EU28 countries, the values of its Net Transfer Capacity (ie. maximal capacity for commercial power exchange) with each of its EU28 neighbouring countries were provided.

Fuel prices were given in €'13 per boe for the following energy carriers:

- Oil
- Gas (NCV)
- Coal

The price for CO2 emissions in PRIMES-EUCO27 was 38.5 €/tCO2.

2.4 END-USER FUEL PRICES

End-user fuel prices depend on the transportation cost and thus vary from one country to another. Transportation cost data for coal and wood, which tend to be more significant compared to other fuels, were assessed from PRIMES data and used in METIS EUCO27.

3 DESCRIPTION OF THE DATA COMPLETION PROCESS NEEDED TO CONFIGURE METIS-EUCO27

This chapter describes the data completion process needed to configure the METIS-EUCO27 scenario. Since data supplied by PRIMES only include the 28 European countries, different data processing were used for the 28 European countries and the 6 other countries[2] included in the METIS-EUCO27 scenario. Power exchanges outside of these 34 countries are not modelled.

3.1 POWER DEMAND

Fifty power demand hourly time series are considered. They are driven from ENTSO-E TYNDP 2014[3] hourly profiles (vision 1)[4] and 50 years of temperature data history. The generation of the 50 years of demand time series sensitive to temperature is described in 0.

EU28 countries

In order to build a scenario consistent with PRIMES-EUCO27 data, the power demand time series are adjusted, so that on average (over the 50 realizations) the power demand by country corresponds to the sum of the following data taken from the PRIMES-EUCO27 scenario:

- "Final energy demand"
- Demand for "Refineries & other uses"
- "Transmission and distribution losses"

METIS system module does not model network losses. As a result, it is necessary to include them ex-ante.

Other countries

For the 6 other countries the power demand time series are driven from ENTSO-E 2030 vision 1, as vision 1 was the closest to PRIMES-EUCO27 in terms of annual power demand.

3.2 POWER GENERATION

3.2.1 WIND, SOLAR AND RUN-OF-THE-RIVER FLEETS

In METIS wind, solar and run-of-the-river fleets can produce a maximum energy equal to the product of their installed capacity and a capacity factor (percentage of the installed capacity that can be used at a given time depending on the weather conditions).

Capacity factor time series

To run consistent simulations at an hourly time step, it is necessary to provide METIS with capacity factor time series (8760 hourly values) for wind, PV and run-of-the-river (RoR) fleets. For both the EU28 and the 6 other countries, the capacity factor time series for wind and PV (10 weather data realizations per country) were computed by IAEW using the methodology described in 0. For run-of-the-river capacity factor time series, 2008-to-2013 historical generation data from ENTSO-E TYNDP 2014 were averaged to obtain a unique year-long realisation per country.

Installed capacity

[2] The 6 other countries included in the METIS-EuCO27 scenario are Bosnia (BA), Switzerland (CH), Montenegro (ME), FYROM (MK), Norway (NO) and Serbia (RS). Including these countries enables to capture most of the power exchanges on the European continent making results more accurate.

[3] In this document, all references to ENTSO-E 2030 projections concerns the TYNDP 2014.

[4] Note that a unique flat demand profile has been used for Malta.

To be consistent with the "Net Electricity generation" indicated in the PRIMES-EUCO27 scenario, installed capacities, for the EU28 countries, are computed as the "Net Electricity generation"[5] indicated in the PRIMES-EUCO27 scenario divided by the average annual load factor (the average is taken over all available weather data realizations, that is over the 10 realizations for wind and PV generation, and considering the unique realization for run-of-the-river generation). For the 6 other countries the installed capacities for wind, PV and RoR fleets are taken from the ENTSO-E 2030v1 scenario.

Table 1 and Table 2 compare PRIMES-EUCO27 annual load-factors for 2030 with the mean load factors used in METIS, for wind onshore and solar fleets respectively. Whenever possible, the location of RES units were selected, so that the average load factors matched. More information on the methodology can be found in Appendices.

[5] For some EU28 countries, the split between hydro lake and hydro run-of-the-river has been reviewed according to historical data from ENTSO-E, changing the annual electricity generation and as a consequence the installed capacity for the run-of-the-river fleet (see 0B).

	METIS database											PRIMES-EuCo27 data
Zone	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10	10-years mean	
AT	26%	25%	25%	27%	26%	25%	26%	27%	26%	24%	26%	26%
BA	25%	23%	23%	24%	25%	25%	27%	27%	26%	24%	25%	_
BE	27%	26%	28%	29%	29%	27%	25%	28%	29%	25%	27%	27%
BG	30%	30%	28%	30%	29%	27%	30%	32%	30%	28%	29%	30%
CH	15%	13%	14%	15%	15%	14%	14%	16%	15%	14%	14%	_
CY	*32%*	*31%*	*32%*	*31%*	*32%*	*31%*	*31%*	*34%*	*28%*	*33%*	*31%*	24%
CZ	25%	23%	22%	26%	24%	22%	22%	23%	24%	21%	23%	19%
DE	19%	18%	19%	21%	20%	18%	17%	18%	19%	17%	19%	19%
DK	31%	30%	28%	33%	32%	30%	28%	28%	30%	27%	30%	29%
EE	24%	26%	25%	27%	29%	23%	23%	25%	24%	25%	25%	25%
ES	28%	28%	28%	28%	29%	30%	31%	31%	30%	29%	29%	28%
FI	29%	32%	30%	31%	31%	28%	27%	30%	27%	31%	30%	30%
FR	28%	28%	28%	30%	29%	28%	28%	30%	30%	27%	29%	27%
GR	32%	31%	32%	31%	32%	31%	31%	34%	28%	33%	31%	31%
HR	20%	19%	19%	20%	20%	20%	20%	22%	20%	20%	20%	20%
HU	21%	21%	19%	21%	22%	20%	21%	23%	22%	21%	21%	23%
IE	34%	34%	33%	32%	35%	33%	27%	30%	34%	33%	33%	33%
IT	24%	23%	22%	24%	24%	25%	26%	26%	23%	24%	24%	24%
LT	21%	20%	20%	23%	24%	20%	20%	21%	23%	22%	21%	22%
LU	20%	18%	20%	21%	20%	19%	18%	21%	21%	18%	19%	20%
LV	28%	27%	27%	30%	32%	27%	26%	27%	29%	28%	28%	24%
ME	27%	24%	23%	25%	25%	25%	27%	28%	25%	26%	26%	_
MK	13%	12%	11%	12%	12%	12%	13%	13%	12%	12%	12%	_
MT	*24%*	*23%*	*22%*	*24%*	*24%*	*25%*	*26%*	*26%*	*23%*	*24%*	*24%*	17%
NL	30%	29%	30%	32%	32%	29%	26%	29%	29%	26%	29%	29%
NO	30%	32%	31%	32%	30%	30%	26%	28%	28%	29%	30%	_
PL	25%	23%	22%	27%	26%	23%	24%	24%	26%	23%	24%	24%
PT	28%	29%	29%	28%	29%	30%	33%	33%	31%	30%	30%	28%
RO	30%	29%	28%	30%	29%	26%	29%	31%	30%	28%	29%	29%
RS	17%	16%	14%	16%	17%	15%	18%	18%	17%	15%	16%	_
SE	31%	32%	30%	33%	32%	30%	29%	31%	30%	31%	31%	31%
SI	16%	16%	16%	17%	17%	17%	17%	18%	16%	16%	17%	17%
SK	16%	15%	14%	16%	16%	15%	15%	16%	16%	15%	16%	16%
UK	31%	33%	31%	32%	34%	31%	26%	29%	31%	29%	31%	30%

Table 1 – Onshore wind generation load factors: Comparison between IAEW and PRIMES-EUCO27 data

	METIS database											PRIMES-EuCo27 data
Zone	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10	10-years mean	
AT	13%	13%	13%	13%	13%	13%	12%	13%	13%	14%	**13%**	**13%**
BA	_	_	_	_	_	_	_	_	_	_	**_**	
BE	12%	12%	12%	12%	12%	12%	12%	12%	12%	13%	**12%**	**12%**
BG	15%	15%	15%	15%	15%	15%	14%	15%	15%	15%	**15%**	**15%**
CH	10%	10%	10%	10%	9%	10%	9%	9%	9%	10%	**9%**	
CY	*18%*	*18%*	*18%*	*19%*	*18%*	*18%*	*18%*	*19%*	*18%*	*18%*	*18%*	**21%**
CZ	11%	11%	11%	11%	11%	11%	11%	10%	11%	12%	**11%**	**11%**
DE	11%	11%	11%	11%	11%	11%	11%	10%	11%	12%	**11%**	**11%**
DK	10%	11%	10%	10%	11%	11%	10%	10%	10%	11%	**10%**	**10%**
EE	9%	10%	10%	10%	9%	9%	9%	9%	10%	9%	**10%**	**10%**
ES	22%	23%	22%	22%	22%	22%	22%	22%	22%	22%	**22%**	**22%**
FI	8%	9%	9%	8%	8%	9%	8%	8%	9%	8%	**9%**	**9%**
FR	18%	19%	18%	18%	18%	19%	18%	18%	18%	19%	**18%**	**18%**
GR	18%	18%	18%	19%	18%	18%	18%	19%	18%	18%	**18%**	**18%**
HR	16%	16%	16%	17%	16%	16%	16%	17%	16%	17%	**16%**	**16%**
HU	10%	10%	10%	11%	10%	10%	10%	10%	10%	11%	**10%**	**10%**
IE	10%	10%	10%	10%	9%	10%	10%	10%	10%	10%	**10%**	**9%**
IT	16%	16%	16%	16%	16%	16%	15%	16%	15%	17%	**16%**	**16%**
LT	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	**10%**	**10%**
LU	10%	10%	10%	10%	10%	10%	10%	10%	10%	11%	**10%**	**11%**
LV	10%	10%	10%	10%	9%	10%	10%	10%	10%	10%	**10%**	**10%**
ME	_	_	_	_	_	_	_	_	_	_	**_**	
MK	15%	15%	15%	15%	15%	14%	14%	15%	14%	15%	**15%**	
MT	*16%*	*16%*	*16%*	*16%*	*16%*	*16%*	*15%*	*16%*	*15%*	*17%*	*16%*	**20%**
NL	10%	10%	10%	10%	10%	10%	10%	10%	10%	11%	**10%**	**10%**
NO	_	_	_	_	_	_	_	_	_	_	**_**	
PL	10%	10%	10%	10%	10%	10%	10%	9%	10%	11%	**10%**	**10%**
PT	21%	22%	21%	21%	21%	21%	21%	21%	20%	21%	**21%**	**22%**
RO	15%	15%	15%	16%	16%	16%	15%	15%	15%	16%	**15%**	**15%**
RS	12%	12%	12%	13%	13%	12%	12%	12%	12%	13%	**12%**	
SE	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	**10%**	**10%**
SI	12%	12%	12%	13%	12%	12%	12%	12%	12%	13%	**12%**	**12%**
SK	10%	10%	11%	11%	10%	10%	10%	10%	10%	11%	**10%**	**11%**
UK	9%	9%	9%	9%	9%	9%	9%	9%	9%	10%	**9%**	**9%**

Table 2 - Solar generation load factors: Comparison between IAEW and PRIMES-EUCO27 data

Remark: For Malta and Cyprus, as there is no data available providing onshore wind and solar power at hourly time step, load factors of respectively Italy and Greece (neighbor countries) are used.

3.2.2 *HYDRO LAKE FLEET*

Note: For some of the EU28 countries, the split between hydro lake and hydro run-of-the-river of the PRIMES-EUCO27 scenario has been reviewed according to historical data from ENTSO-E (see 0).

In METIS, a hydro lake fleet is modelled with a generation asset (turbines), a storage asset and water inflows (time series in MWhe).
The sum of the hourly water inflows (over a year) determines power generation globally over the year. The water inflow profiles and the storage parameters (Storage capacity, Storage weekly minimum level, and Storage initial level) determine how this power generation is spread over the year.
Water inflow profiles as well as storage parameters are the result of an important reconciliation work which combines data from ENTSO-E and several TSOs[6].

EU28 countries

For the EU28 countries, it is necessary to scale the water inflow time series by the ratio between the "Net Electricity generation" indicated in PRIMES-EUCO27 and the total annual water inflows (sum of the hourly values) indicated in the time series obtained from the reconciliation work. This ratio is labeled *correctiveRatioHydroPRIMESMETIS*. Similarly storage capacities obtained from the reconciliation work are also scaled by the *correctiveRatioHydroPRIMESMETIS* ratio to avoid any computation infeasibilities due to storage-related values.

6 other countries

For the 6 other countries, water inflow levels and storage parameters obtained from the reconciliation work are considered without any further adjustement.

Table 3 and Table 4 detail the parameters defining the assets representing the hydro lake fleet.

Turbines

	Installed capacity	Abatement rate[7]
Turbines	Net Installed Power Capacity[8] (PRIMES-EUCO27 or ENTSO-E 2030v1)	Based on historical generation data

Table 3 - Hydro-turbines parameters: data completion

[6] Weekly or monthly data on storage level are often available, in which case, the reconciliation process consists in combining storage level and generation data to assess monthly inflows and storage management strategy.

[7] The abatement rate is a multiplying coefficient applied to an installed capacity in order to factor in that all turbines cannot generate power simultaneously (because of reservoirs in cascade, maximum river flows…). It has been calibrated on historical generation data.

[8] For some EU28 countries, the split between hydro lake and hydro run-of-the-river has been reviewed according to historical data from ENTSO-E, changing the turbines installed capacity and the total annual water inflows ("Net Electricity generation") for the Hydro lake fleet (see 0). Differences are mainly due to the different statistical definitions used by the TSOs and EUROSTAT (with which PRIMES complies).

Storage

	Storage capacity = Smax	Storage min level (% Smax)	Storage initial level (% Smax)
Storage	Smax (reconciliation work) * *correctiveRatioHydroPRIMESMETIS (only for the EU28 countries)*	Guide Curve[9] (reconciliation work)	Initial level[10]

Table 4 - Hydro-reservoir parameters: data completion

3.2.3 Pumped storage fleet

In METIS, a pumped storage fleet is defined by two installed capacities (in MW) and a storage capacity (in MWh). The first installed capacity (Pmax-in) represents the maximum loading capacity and the second installed capacity (Pmax-out) represents the maximum discharge capacity.

Provided data did not include values for pumped storage fleets. Therefore, their installed capacities and storage capacities were computed for all the countries according to (RENEAWABLE AND SUSTAIABLE ENERGY REVIEWS).

	Loading capacity	Discharge capacity	Storage capacity
Pumped storage fleet	Pmax-in	Pmax-out	Smax

Table 5 - Pumped hydro storage parameters: data completion

Table 6 presents the detailed parameters by country used in METIS EUCO27 scenario for pumped hydro storage.

	Pmax-in (MW)	Pmax-out (MW)	Smax (GWh)	Discharge time (h)
AT	3 246	4 051	132 410	*33*
BA	930	1 399	11 130	*8*
BE	1 196	1 301	5 710	*4*
BG	930	1 399	11 130	*8*
CH	1 512	2 291	311 480	*136*
CZ	1 145	1 119	5 720	*5*
DE	6 417	6 805	39 120	*6*
ES	5 859	6 358	70 000	*11*
FR	4 317	5 512	83 370	*15*
GB	2 650	2 788	26 700	*10*
GR	735	735	4 970	*7*
HR	246	281	2 340	*8*
IE	292	292	1 800	*6*
IT	7 640	7 833	68 270	*9*
LT	880	900	10 800	*12*
LU	1 050	1 296	4 920	*4*
NO	892	1 273	399 390	*314*
PL	1 647	1 757	7 960	*5*
PT	1 279	1 279	40 770	*32*
RO	200	285	10 200	*36*
SE	91	91	72 120	*793*
SI	180	185	500	*3*
SK	790	1 016	3 630	*4*

Table 6 - Pumped hydro storage parameters by country

[9] Weekly guide curves in METIS are based on historical hydro power generation, published by TSOs. They are assumed to remain constant for the studied scenario.
[10] The initial level is equal to the first value of the guide curve.

3.2.4 FUEL-BASED THERMAL FLEETS

Below is the list of fuel-based thermal fleets considered in the METIS-EUCO27 scenario:

- Solid-fired fleet, split between Hard coal fleet and Lignite fleet (see 0).
- Natural gas fleet, split between CCGT fleet and OCGT fleet (see 0).
- Oil fleet
- Biomass fleet, split between wood-based and waste (see 0).

Installed capacity and availability

To run simulations at an hourly time step, fuel-based thermal fleets require availability profiles (representing maintenance schedules) along with installed capacities.

Table 7 presents the parameters used for each fuel-based thermal fleet.

	Installed capacity	Availability
Hard coal fleet	Net Installed Power Capacity (PRIMES-EUCO27 or ENTSO-E 2030v1)	Time series[11]
Lignite fleet	Net Installed Power Capacity (PRIMES-EUCO27 or ENTSO-E 2030v1)	Time series
CCGT fleet	Net Installed Power Capacity (PRIMES-EUCO27 or ENTSO-E 2030v1)	Time series
OCGT fleet	See section 3.6	Constant value: 96%
Oil fleet	Net Installed Power Capacity (PRIMES-EUCO27 or ENTSO-E 2030v1)	Constant value: 90%
Biomass fleet	Net Installed Power Capacity (PRIMES-EUCO27 or ENTSO-E 2030v1)	Constant value: Net Electricity generation (PRIMES-EUCO27) / Net Installed Power Capacity (PRIMES-EUCO27)

Table 7 – Fuel-based thermal fleets' parameters: data completion

Figure 1, Figure 2 and Figure 3 show the availability time series common to all 34 countries for hard coal, lignite and CCGT fleets.

[11] For hard coal, lignite and CCGT fleets, an availability profile common to all countries has been computed using historical generation data from ENTSO-E. Figure 1, Figure 2 and Figure 3 show the profile used for each fleet.

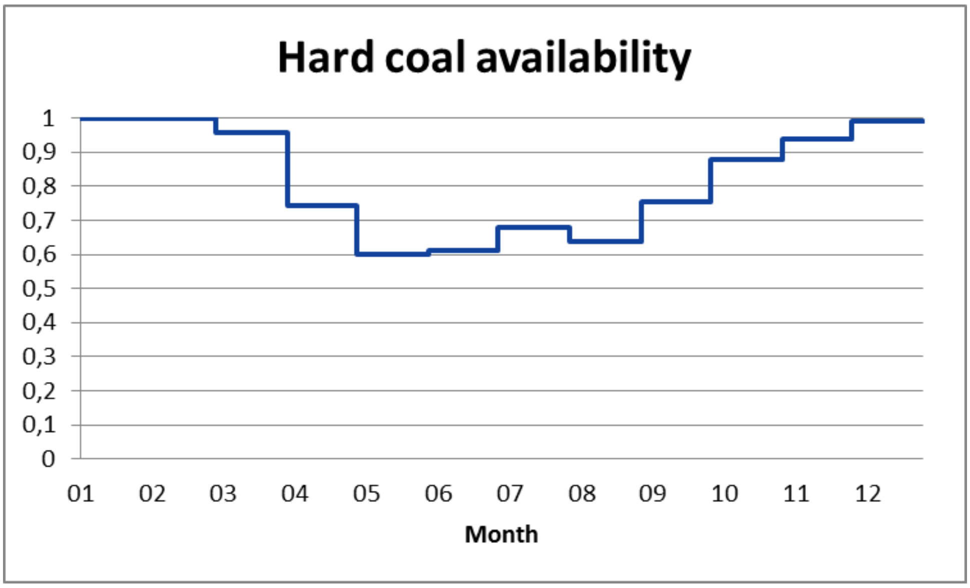

Figure 1 - Hard coal availability time series

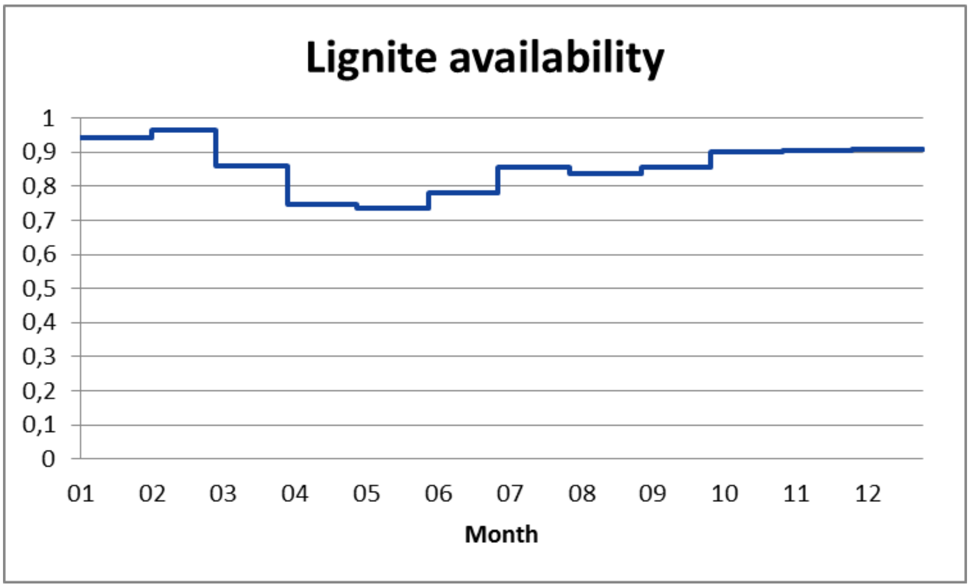

Figure 2 - Lignite availability time series

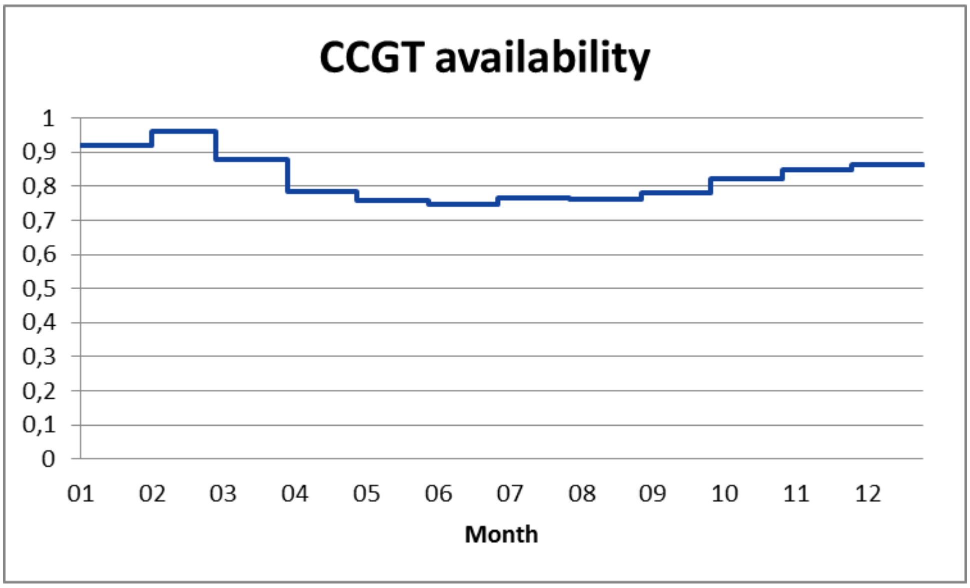

Figure 3 - CCGT availability time series

Starting and running costs

For fuel-based thermal fleets, METIS takes into account minimum off-time, minimum stable generation, maximum gradient and reserve supply constraints. Costs include starting, generation and running costs. A detailed description of how METIS models these constraints is provided in "METIS Technical Note T02: Power market models". Unit technical parameters are based on a literature review and are calibrated so that, when generating at maximum capacity, the cost corresponds to the net efficiencies indicated in PRIMES-EUCO27 data.

Table 8 sums up the main technical parameters used for thermal units (more details are provided in "METIS Technical Note T02: Power market models").

Parameter \ Unit type	Minimal generation level (% of Pmax)	Positive load gradient (% of Pmax)	Negative load gradient (% of Pmax)	Startup cost (€/MW)	Off-state minimal duration (h)	Efficiency (%) @Pmin/@Pmax
CCGT - oldest	50%	2%/min	5%/min	45	2	40% / 49%
CCGT - prevailing	50%	2%/min	5%/min	41	2	48% / 57%
CCGT – state of the art	40%	4%/min	5%/min	33	2	52% / 61%
Hard Coal – prevailing	40%	2%/min	5%/min	65	6	36% / 42%
Hard Coal – state of the art	25%	4%/min	5%/min	50	4	41% / 46%
Lignite – Prevailing	50%	2%/min	5%/min	25	6	34% / 38%
Lignite – State of the art	50%	2%/min	5%/min	25	4	38% / 42%
Biomass	20%	4%/min	5%/min	36	1	33% / 36%
Oil fired	50%	8%/min	8%/min	30	1	26% / 35%
OCGT - oldest	50%	8%/min	8%/min	30	1	27% / 36%
OCGT- state of the art	40%	12%/min	12%/min	21	1	32% / 42%

Table 8 - Thermal unit technical parameters

3.2.5 NUCLEAR FLEET

Installed capacity and availability profile

To run simulations at an hourly time step, nuclear fleets require availability profiles (representing maintenance schedules) along with installed capacities.

Table 9 provides the data sources of the nuclear fleet parameters.

	Installed capacity	Availability or Capacity factor
Nuclear energy	Net Installed Power Capacity (PRIMES-EUCO27)	Availability time series[12] (Based on historical generation data) Mean availability:

[12] Monthly historical generation data from ENTSO-E, scaled to be consistent with mean availability from PRIMES-EuCo27

	Net Electricity generation (PRIMES-EUCO27) / Net Installed Power Capacity (PRIMES-EUCO27)

Table 9 - Nuclear fleet parameters: data completion

Table 10 presents the averaged and maximal availabilities of nuclear fleets used for the EUCO scenario.

Country	BG	CH	CZ	ES	FI	FR	HU	LT	NL	RO	SE	SI	SK	UK
Max	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.91	0.99	0.99	0.99	0.99	0.99	0.99
Mean	0.87	0.9	0.85	0.9	0.93	0.81	0.86	0.91	0.93	0.94	0.85	0.97	0.9	0.89

Table 10 – Yearly average and maximum availabilities of nuclear fleets per country

3.2.6 Other fleets

The remaining fleets in the PRIMES-EUCO27 scenario, composed of other renewables (tidal etc.), derived gasses[13], hydrogen, and geothermal, are represented as "must-run" fleets in METIS. They have an installed capacity of 8.21 GW, which represent 0.5% of the total installed capacity in the 34 modelled countries.

The capacity factor is a constant value equal to the "Net Electricity generation" divided by the "Net Installed Power Capacity" and the installed capacity is the "Net Installed Power Capacity". This ensures that over a year, the generation outcome is equal to the "Net Electricity generation" indicated in PRIMES-EUCO27 data.

3.3 CO_2 emissions

PRIMES provided CO_2 emissions associated with fuels, which are expressed in tCO_2/toe fuel. As METIS uses "MWh GCV" as fuel units, PRIMES CO_2 emissions need to be converted.

Data and parameters used for the conversion are presented in Table 11.

	Coal	Lignite	Oil	Gas	Source
toe -> MWh NCV		11.67			(OREMIP) http://www.oremip.fr/modules/convertisseur/index.php
Yield GCV/NCV	1.05	1.05	1.1	1.1	(IEA) WEO
CO_2 emissions (tCO_2 / MWh GCV)	0.32	0.34	0.25	0.19	

Table 11 - CO2 emissions: data completion

Price for CO_2 emissions in PRIMES-EUCO27 was 38.5 €/tCO_2.

3.4 Fuel prices

3.4.1 International fuel prices

PRIMES provided international fuel prices. These prices are expressed in € per boe. As METIS uses "MWh GCV" as fuel units, PRIMES-EUCO27 prices are converted into € per MWh PCS using data and parameters presented Table 12. International fuel prices are common to all 34 countries.

[13] 'Other thermal fleet' from ENTSO-E 2030 v1 scenario is added to the 'Derived gasses fleet'.

	Coal	Lignite	Oil	Gas	Biomass[14]	Source
boe -> toe			0.14			(EIA) https://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=94&pid=57&aid=32
toe -> MWh NCV			11.67			(OREMIP) http://www.oremip.fr/modules/convertisseur/index.php
Yield GCV/NCV	1.05	1.05	1.1	1.1	1.05	(IEA) WEO
Fuel costs (€/MWh GCV)	11.67	2.29[15]	50.94	30.83	11.67	

Table 12 - Fuel costs: data completion

3.4.2 Coal and biomass end-user prices

As mentioned in paragraph 2.4, PRIMES also provided end-user fuel prices which include transportation cost.

For coal and biomass, end-user fuel prices have been used rather than the international fuel prices to provide a more accurate representation of the fuel cost in each country.

For the other fuel-based thermal fleets, international fuel prices have been used.

3.5 NTC values

NTC values for the METIS EUCO27 scenario are the same as the ones for the PRIMES EUCO27 scenario.

Table 13 summarizes the NTC values for METIS EUCO27 scenario.

[14] Coal parameters have been applied to the biomass fleet.

[15] Since no value was provided for lignite, the lignite price (€/MWh PCS) from the ENTSO-E 2030 V1 is used.

	AT	BA	BE	BG	CH	CZ	DE	DK	EE	ES	FI	FR	GB	GR	HR	HU	IE	IT	LT	LU	LV	ME	MK	MT	NL	NO	PL	PT	RO	RS	SE	SI	SK
AT					1932	1800	7260									1458		1540														1512	
BA															3150							1518								2664			
BE												3700	1000							1000					2400								
BG														800									842						4200	1020			
CH	1932						7200					3696						4240															
CZ	2110						3200																				2000						2500
DE	7260				7200	3200		3450				3300								1911					4850	1500	3240				600		
DK							3450																		700	1700					2857		
EE											1000										1344												
ES												4000																3960					
FI									1000																	100					3150		
FR			3700		3696		3300			4000			3800					3750															
GB			1000									3800					1404								1290	1400							
GR				800														1000					1320										
HR		3150														2550		-												1020		2720	
HU	1458														2550														1100	700		800	2050
IE													1404																				
IT	1540				4240							3750		1000	-							1000		200								1316	
LT																					2145						1720				700		
LU			1000				1911																										
LV									1344										2145														
ME		1518																1000												1242			
MK				842										1320																788			
MT																		-															
NL			2400				4850	700					1290													2100							
NO							1500	1700			100		1400												2100						4968		
PL						2000	3240												1720												600		880
PT										3960																							
RO				4200												1100														1680			
RS		2664		1148											1020	700						1118	788						1680				
SE							600	2857			3150								700							4968	600						
SI	1512														2720	800		1316															
SK						2500										2050											880						

Table 13 - NTC values in METIS EUCO27 scenario

3.6 Security of supply modelling

METIS focuses in particular on the economics of security of supply, a key point is that installed capacity is consistent with peak demand. As more data were added in METIS to represent the hourly supply-demand equilibrium (METIS uses 50 years of hourly weather data versus typical days for PRIMES), it was necessary to optimize OCGT capacities by country (for given security of supply criteria) so that the generation capacities remain consistent with load and RES generation profiles.

To optimize OCGT capacities, cost parameters of "State of the art" OGCT were used. Capacities of "oldest" OCGT fleets remain fixed to the installed capacities in 2000 (see 0).

	CAPEX (€13/MW)	Annualized CAPEX (€13/MW)	FOC (€13/MW)
OCGT	550 000 (ETRI[16])	45 718[17]	15 200 (PRIMES-EUCO27, Natural gas OCGT Utility)

Table 14 - OCGT investment costs

	Cost (€13/MWh)
Loss of load	15 000

Table 15 - Loss of load cost

The resulting gas-fueled installed capacity is 190 GW, over all 34 modelled countries. The original gas-fueled installed capacity is 182 GW.

Table 16 presents the average (over the 50 weather realizations) yearly loss of load values per country after optimizing OCGT installed capacities.

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[16] Sources: ETRI, "CAPEX ref" for Open Cycle Gas Turbine advanced http://publications.jrc.ec.europa.eu/repository/handle/JRC92496

[17] Annualized OCGT CAPEX was computed based on the 8.5% discount rate considered by PRIMES for companies in competitive energy supply markets and the 35 years "Amortisation and Technical Lifetime" for Natural gas OCGT Utility indicated in PRIMES-EuCo27.

Country	Average loss of load on the 50 weather realizations (GWh)
AT	0
BA	0
BE	0,96
BG	0
CH	0
CZ	0
DE	1,44
DK	0,64
EE	0,2
ES	0,02
FI	0,76
FR	2,2
GR	0
HR	0
HU	0
IE	2,3
IT	0
LT	0
LU	0,4
LV	0,1
ME	0
MK	0
MT	0
NL	1,34
NO	0,46
PL	0,64
PT	0,18
RO	0
RS	0
SE	0,6
SI	0
SK	0
UK	1,8

Table 16 - Average loss of load on the 50 weather realizations after optimizing OCGT installed capacities

4 EUCO SCENARIO: MAIN CHARACTERISTICS

Chapter 3 presented the methodology to build METIS scenarios based on PRIMES data. A METIS scenario focuses on a given time horizon (2030 for this report) and includes 50 different weather data realizations. This chapter now presents the results obtained from simulating the power system optimal dispatch on these 50 realizations. In particular, the main characteristics of the EUCO27 scenario are highlighted and a comparison with the ENTSO-E TYNDP 2014 Vision 3 scenario is made[18].

In the remainder of this chapter, PRIMES-EUCO27 refers to the data provided by PRIMES (which for most of them serve as input to the simulations) and METIS-EUCO27 refers to the average (over the 50 realizations) output of the METIS optimal dispatch simulation.

4.1 POWER GENERATION DISTRIBUTION

In the PRIMES-EUCO27 scenario, renewable energies represent 49% of the total generation (36% for variable RES generation). Base-load fleets (nuclear fleet) generate 22% of the total power, while intermediate fleets (coal, lignite and CCGT) serve 26%. The remaining part is served by peak load generators (OCGT and oil fleets – 2.4% - 81 TWh) and the derived gasses fleet (0.7%).

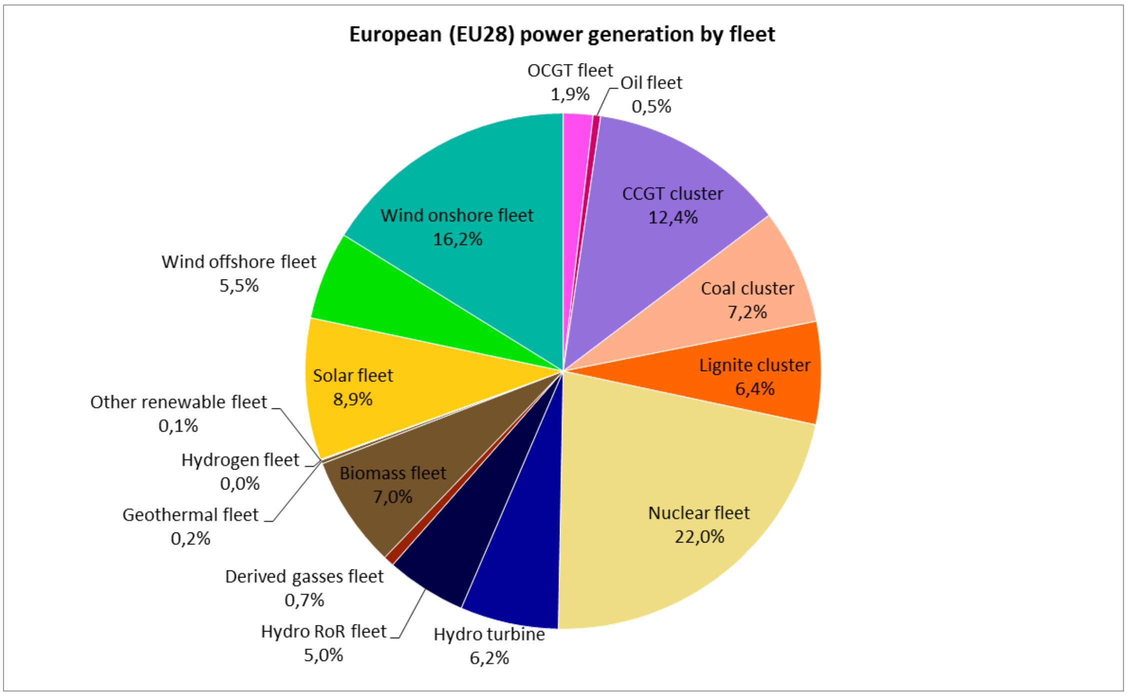

Figure 4 - EU28 generation by fleet - Total: 3371 TWh - PRIMES-EUCO27 scenario

In the METIS-EUCO27 scenario (average over the 50 weather data realization), renewable energies represent 49% of the total generation (35.5% for variable RES generation). Base-load fleets (nuclear fleet) generate 22.5% of the total power, while intermediate fleets (coal, lignite and CCGT) serve 27.5%. The remaining part is served by peak load generators (OCGT and oil fleets – 0.6% - 19 TWh) and the derived gasses fleet (0.7%).

[18] While Vision 1 is used for load profiles (as its annual power demand is closer to PRIMES data), the comparison is made here with Vision 3 which includes higher shares of renewable and is consequently more comparable to PRIMES EUCO27.

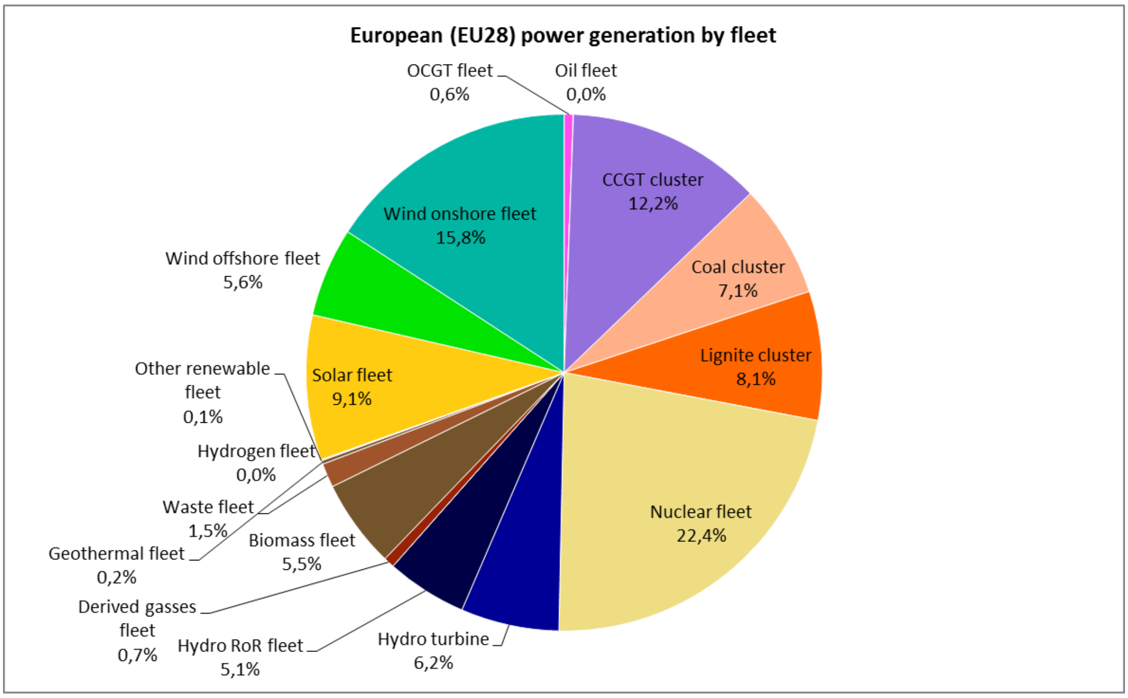

Figure 5 - EU28 generation by fleet - Total: 3337 TWh[19] - METIS-EUCO27 scenario, current market design

In the ENTSO-E TYNDP 2014 Vision 3 scenario, renewable energies represent 47% of the total generation (29% for variable RES generation). Base-load fleets (nuclear fleet) produce 19% of the total power, while intermediate fleets (coal, lignite and CCGT) serve 28%. The remaining part is served by peak load generators (oil – 0.06% - 2 TWh) and other non-renewable energy sources (6%).

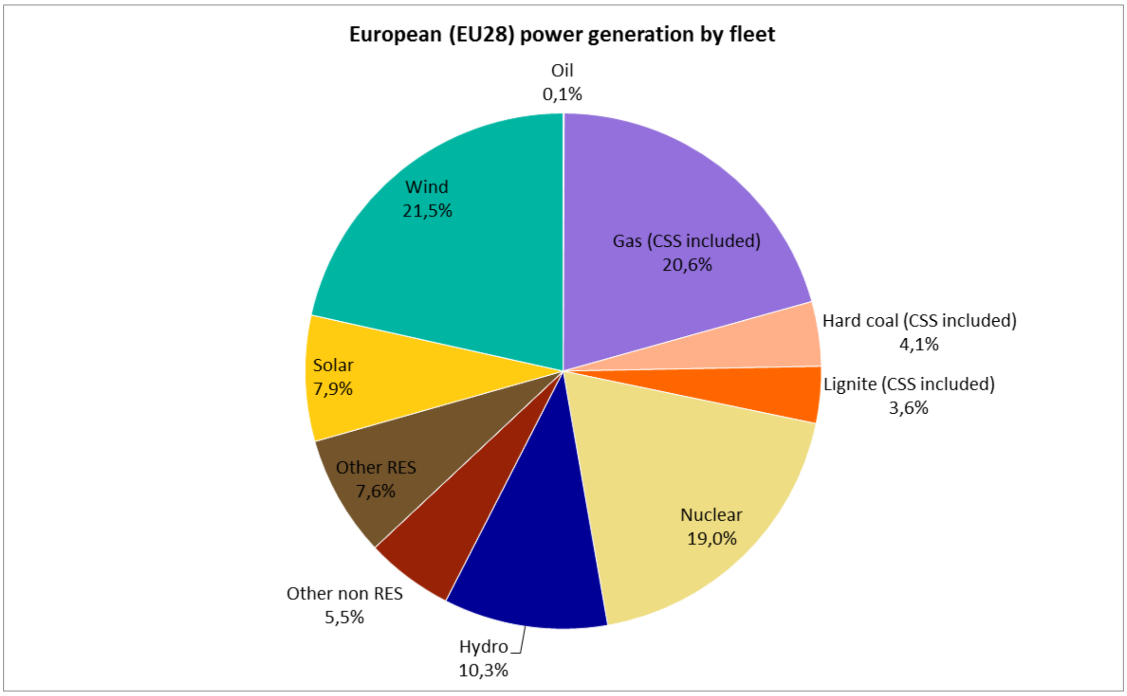

Figure 6 - EU28 generation by fleet – Total: 3 876 TWh - ENTSO-E V3 scenario (TYNDP'14)

Table 17 sums up the information from Figure 4, Figure 5 and Figure 6 to facilitate the comparison between PRIMES-EUCO27, METIS-EUCO27 and ENTSO-E Vision 3 scenarios.

[19] The difference in total generation, compared to PRIMES-EuCo27 comes from PHS management and exports to non-EU28 countries

	PRIMES-EUCO27	METIS-EUCO27	ENTSO-E Vision 3
Variable RES share (%)	36	35.5	29
Solar share (%)	9	9	8
Nuclear share (%)	22	22.5	19
Intermediate load share (%)	26	27.5	28
Peak load share (%)	2	0.5	< 0.1[20]

Table 17 - Comparison between power generation distributions

This Table shows that PRIMES EUCO27 and METIS EUCO27 RES shares are very close, which is a direct consequence of the calibration methodology. The use of flexible thermal units is however a result of the simulation. The slight differences between PRIMES and METIS come in particular from the following points:

- PRIMES uses typical days for optimal dispatch simulation while METIS uses hourly profiles for 50 years of weather data
- Presented results for METIS include only the power sector[21], while PRIMES models the whole energy system. Constraints in PRIMES on heat supply for cogeneration impact the merit order
- No information was provided on the age of 2030 thermal units built before 2000. Hence, differences may exist between PRIMES and METIS on the technical parameters of very old units.

[20] This figure does not include OCGT, as CCGT and OCGT are gathered in the gas fleet in the ENTSO-E Vision 3 scenario.

[21] This report is based on METIS power system module. Additional modules for gas and heat are currently under development.

Appendix A Hourly load profiles

The objective was to generate fifty hourly scenarios of demand for each country by means of a statistical model fitted to the following data sources:

- historical daily temperature data from years 1965 to 2014 for all countries from the European Climate Assessment & Dataset project (ECA, see http://eca.knmi.nl/);
- hourly demand data projections for 2030 provided by ENTSO-E TYNDP 2014[22] visions 1 and 3.

In this regard, each demand scenario is modeled as the sum of a thermo-sensitive component and a non-thermo-sensitive one. The thermo-sensitive component is computed using a piecewise linear model. This model is set up with one threshold and two slopes[23] and calibrated by getting recourse to a *Multivariate Adaptive Regression Splines* method[24] (ANNALS OF STATISTICS, PACKAGE 'MDA') that involves the computation of temperature gradients (MW of demand increase per °C increase) for each country.

As depicted in Figure 7 for Spain, the temperature scenarios of each country drive its thermo-sensitive demand scenarios by using the country temperature gradients. Then, thermo-sensitive and non-thermo-sensitive demand scenarios are added so as to complete the generation of the country demand scenarios.

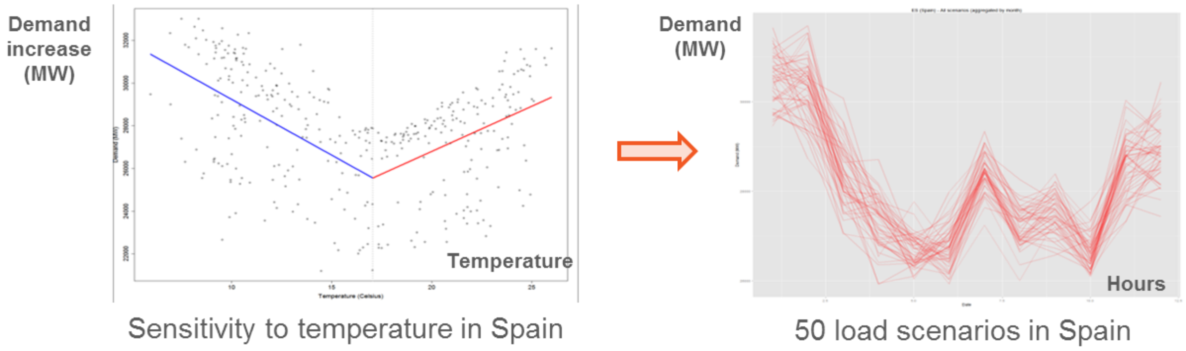

Figure 7 - Two gradients and one threshold accounting for heating and cooling effects on Spain demand

[22] Data is given as hourly time series for one year and average seasonal temperatures.

[23] The use of two slopes - one slope associated to low temperatures and one slope associated to high temperatures - allows for applying the same approach for each country, with the same number of parameters, although three slopes could have been used for countries with both heating and cooling gradients.

[24] See J. H. Friedman, « *Multivariate Adaptive Regression Splines* », *Annals of Statistics*, vol. 19, nº 1, 1991 (ANNALS OF STATISTICS) for the method and https://cran.r-project.org/web/packages/mda/mda.pdf for its R implementation (PACKAGE 'MDA').

Appendix B Solid-fired, natural gas, hydro fleet splits

Solid-fired

The solid-fire fleet is divided into a hard coal and a lignite fleet using the installed capacity split between hard coal and lignite fleets provided by PRIMES EUCO27.

Each fleet is then divided into two age classes, "State of the art" (built after 2015) and "prevailing" (built before 2015 and still operational in 2030), using the "Net Power Capacity Investment" from the PRIMES-EUCO27 scenario.

Natural gas

The natural gas fleet is divided into a CCGT and an OCGT fleet using the installed capacity split between CCGT and OCGT fleets provided by PRIMES EUCO27.

The CCGT fleet is then divided into three age classes, "State of the art" (built after 2015), "prevailing" (built between 2000 and 2015) and, "oldest" (built before 2000 and still operational in 2030), using the "Net Power Capacity Investment" from the PRIMES-EUCO27 scenario.

The OCGT fleet is then divided into two age classes, "State of the art" (built after 2000) and "oldest" (built before 2000 and still operational in 2030), using the "Net Power Capacity Investment" from the PRIMES-EUCO27 scenario.

Biomass

The biomass fleet is divided into a wood-based biomass fleet and a waste fleet using Eurostat 2013 figures. Based on the ratio of European municipal and industrial waste capacities over the total biomass capacities in 2013, the waste fleet capacity is assumed to be 22% of the total biomass capacity. The remaining 78% of biomass capacity correspond to conventional biomass fleets.

Hydro generation

As shown in Table 18 and Table 19, in the PRIMES-EUCO27 scenario, the split between hydro lake and hydro run-of-the-river with respect to the total hydro generation and the total installed capacity is quite different compared to historical data from ENTSO-E.

	PRIMES-EUCO27	ENTSO-E (Historical data)	PRIMES-EUCO27	ENTSO-E (Historical data)
Country	Hydro lake generation	Hydro lake generation	Hydro run-of-river generation	Hydro run-of-river generation
AT	50%	28%	50%	72%
BE	11%	0%	89%	100%
FR	85%	45%	15%	55%
IT	58%	45%	42%	55%
LV	0%	0%	100%	100%
LT	0%	0%	100%	100%
PT	51%	36%	49%	64%
RO	60%	41%	40%	59%
ES	60%	71%	40%	29%
SE	36%	100%	64%	0%

Table 18 - Share of hydro lake and hydro run-of-the-river generation with respect to the total hydro generation - Comparison between PRIMES EUCO27 and ENTSO-E (Historical data)

	PRIMES-EUCO27	ENTSO-E (Historical data)	PRIMES-EUCO27	ENTSO-E (Historical data)

Country	Hydro lake installed capacity	Hydro lake installed capacity	Hydro run-of-river installed capacity	Hydro run-of-river installed capacity
AT	63%	40%	37%	60%
BE	17%	0%	83%	100%
FR	91%	44%	9%	56%
IT	82%	66%	18%	34%
LV	0%	0%	100%	100%
LT	0%	0%	100%	100%
PT	69%	33%	31%	67%
RO	75%	59%	25%	41%
ES	73%	94%	27%	6%
SE	47%	100%	53%	0%

Table 19 - Share of hydro lake and hydro run-of-river installed capacity with respect to the total hydro installed capacity - Comparison between PRIMES EUCO27 and ENTSO-E (Historical data)

For the countries listed in Table 18 and Table 19, the METIS-EUCO27 scenario considers a mix of information from PRIMES-EUCO27 and historical data from ENTSO-E to compute new generation and installed capacities split values between hydro lake and hydro run-of-river fleets. These new values are computed as indicated in Table 20.

	Installed capacity	**Net generation**
Hydro lake	Total hydro installed capacity (PRIMES-EUCO27) * Hydro lake share of the total hydro installed capacity (ENTSO-E: Historical data)	Total hydro net generation (PRIMES-EUCO27) * Hydro lake share of the total hydro net generation (ENTSO-E: Historical data)
Hydro run-of-river	New hydro net generation / Hydro run-of-river capacity factor time series (ENTSO-E: Historical data)	New hydro net generation = Total hydro net generation (PRIMES-EUCO27) * Hydro run-of-river share of the total hydro net generation (ENTSO-E: Historical data)

Table 20 - Formulas to obtain the new values for hydro lake and hydro run-of-river generation and installed capacities

Appendix C PV and onshore wind generation profiles

Generation of ten historical yearly profiles for wind power and solar power has been performed by a model developed by IAEW. The model uses historical meteorological data, units' power curves and historical generation data as input parameters to determine RES generation profiles and calibrate the results for each region in the models scope.

The methodology is depicted in Figure 8.

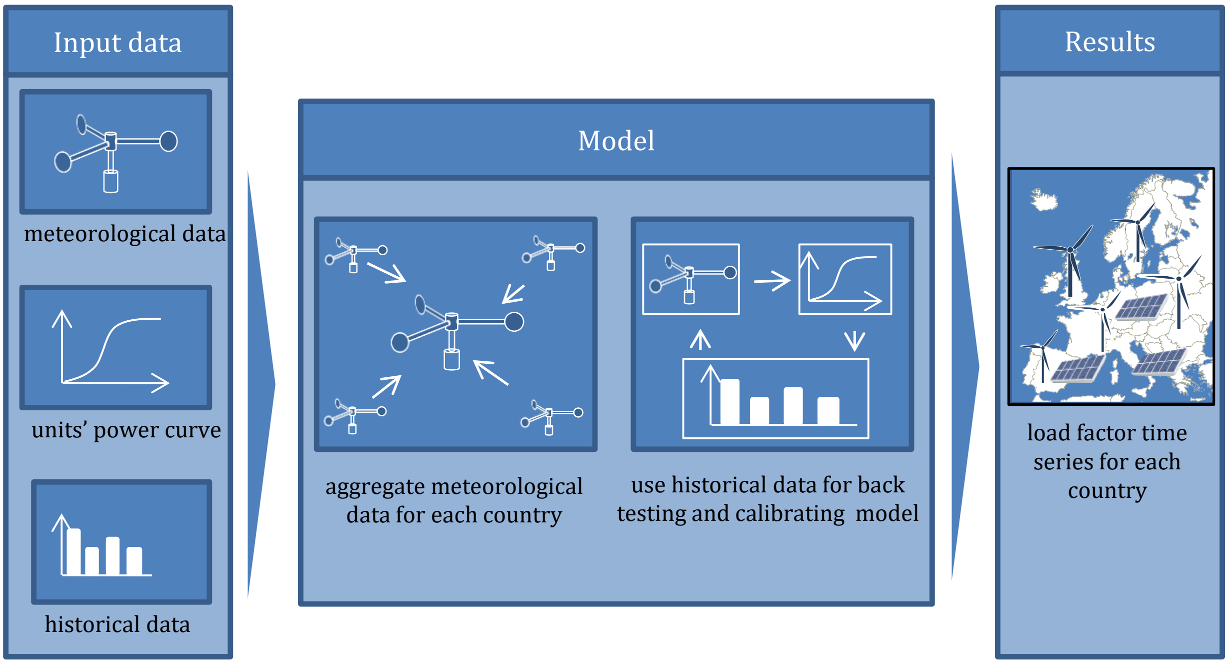

Figure 8 - Methodology

Input Data

Meteorological Data

The delivered time series of renewable feed-ins are based on fundamental wind, solar and temperature time series for 10 years (2001 to 2010) on a detailed regional level derived from the ERA-Interim data provided by Meteo Group Germany GmbH. From ERA-Interim's model, values for wind speed (m/s), global irradiation (W/m2) and temperature (°C) are derived for every third hour and interpolated to hourly values by Meteo Group. The regional resolution of the data is one hourly input series (wind, solar, temperature) on a 0.75° (longitude) times 0.75° (latitude) grid model, which ensures an adequate modeling accuracy. The regional resolution is shown in Figure 9, in which each blue dot represents one data point.

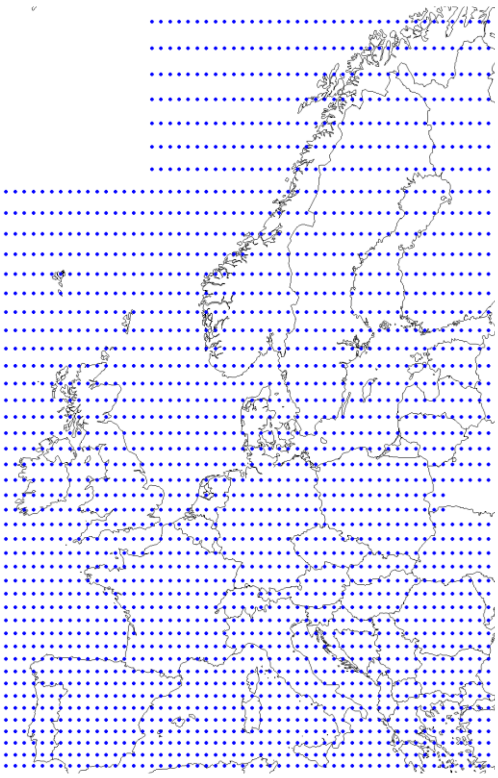

Figure 9 - Regional resolution of meteorological data

Historical Data

To generate realistic time series a calibration of the models is inevitable. Therefore information regarding the yearly full load hours for wind and PV generation in each country is necessary. To derive the yearly number of full load hours the installed capacities of wind and PV generation as well as the yearly energy production have been investigated for each country.
In case of unavailable data the full load hours were derived based on the data of a neighboring country. While the availability for data regarding installed wind generation capacities and generated energy is satisfying in almost every country, it is rather low for information regarding PV power. Only for a few countries reasonable full load hours could be derived from historical published data. For the other countries, data from the Photovoltaic Geographical Information System was used instead.

Model

In a first step, the high-resolution meteorological data are aggregated for each country and NUTS2 region. The aggregation is thereby based on the regional distribution of wind and PV capacities. The required distribution of wind and PV generation capacities is extracted from different databases and is aggregated at high voltage network nodes. In countries with no available information a uniform distribution is assumed.
Each high voltage network node is assigned the nearest meteorological data point and the data is weighted with the installed capacity at the network node. Thereby the wind-speed is weighted by the installed wind generation capacity whereas global irradiation and temperature are weighted with the installed PV generation capacity. The weighted time series for all nodes in each region are aggregated and divided by the overall installed wind respectively PV capacities. Subsequently, it is necessary to calibrate the generation models for each country by scaling the meteorological data accordingly. The process of calibration is display in Figure 10.

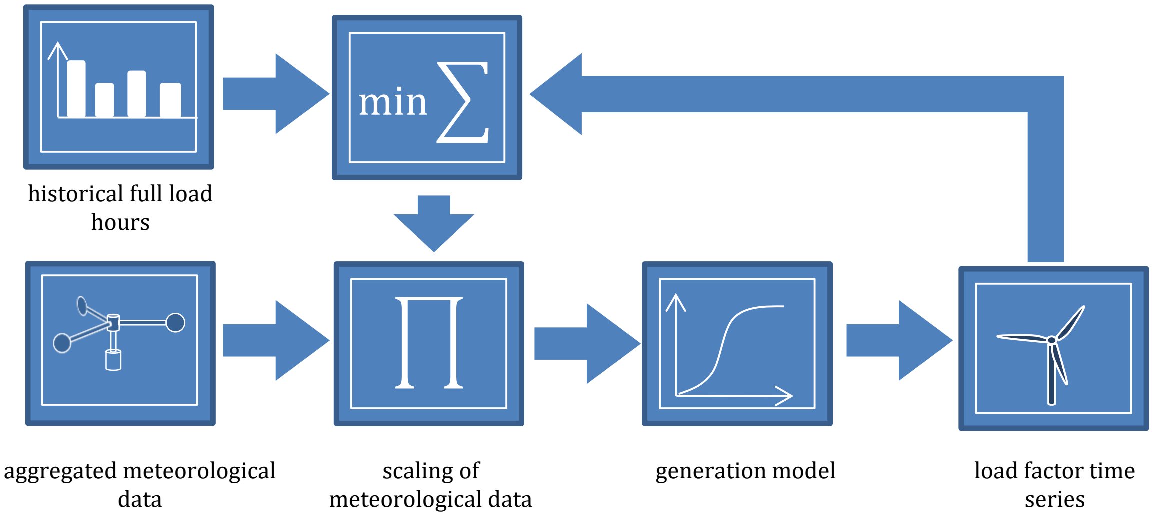

Figure 10 - Model calibration

The meteorological data is fed into generation models for PV and wind generation. The resulting load factor time series are compared with the historical full load hours for the specific country and the deviation between load factor time series and the historic full load hours in each year *i* is to be minimized by scaling the meteorological data accordingly. In this minimization process, the yearly deviation between time series full load hours (*FLH*) and historical data is weighted with the installed capacity (*IC*) in the specific year according to formula (1).

$$\min \sum_{i=1}^{10} (FLH_{i,time\ series} - FLH_{i,historical\ data}) \cdot IC_i \qquad (1)$$

The scaling factors are chosen independently for wind speed and global irradiation and are individual for each country.

Calibration to PRIMES load factors

In order to generate RES generation profiles for the 2030 PRIMES scenario, the installed capacities and full load hours for each country from PRIMES were used. From these data each NUTS2 region was assigned a share of the country's installed generation capacities for PV, onshore wind and offshore wind (if applicable) according to the region's average global irradiation and wind speed in comparison to the countries average global irradiation and wind speed, respectively. The model was then calibrated by minimizing the deviation between time series full load hours and PRIMES full load hours in 2030.

The resulting full load hours for both wind and PV for exemplary countries are shown in Figure 11.

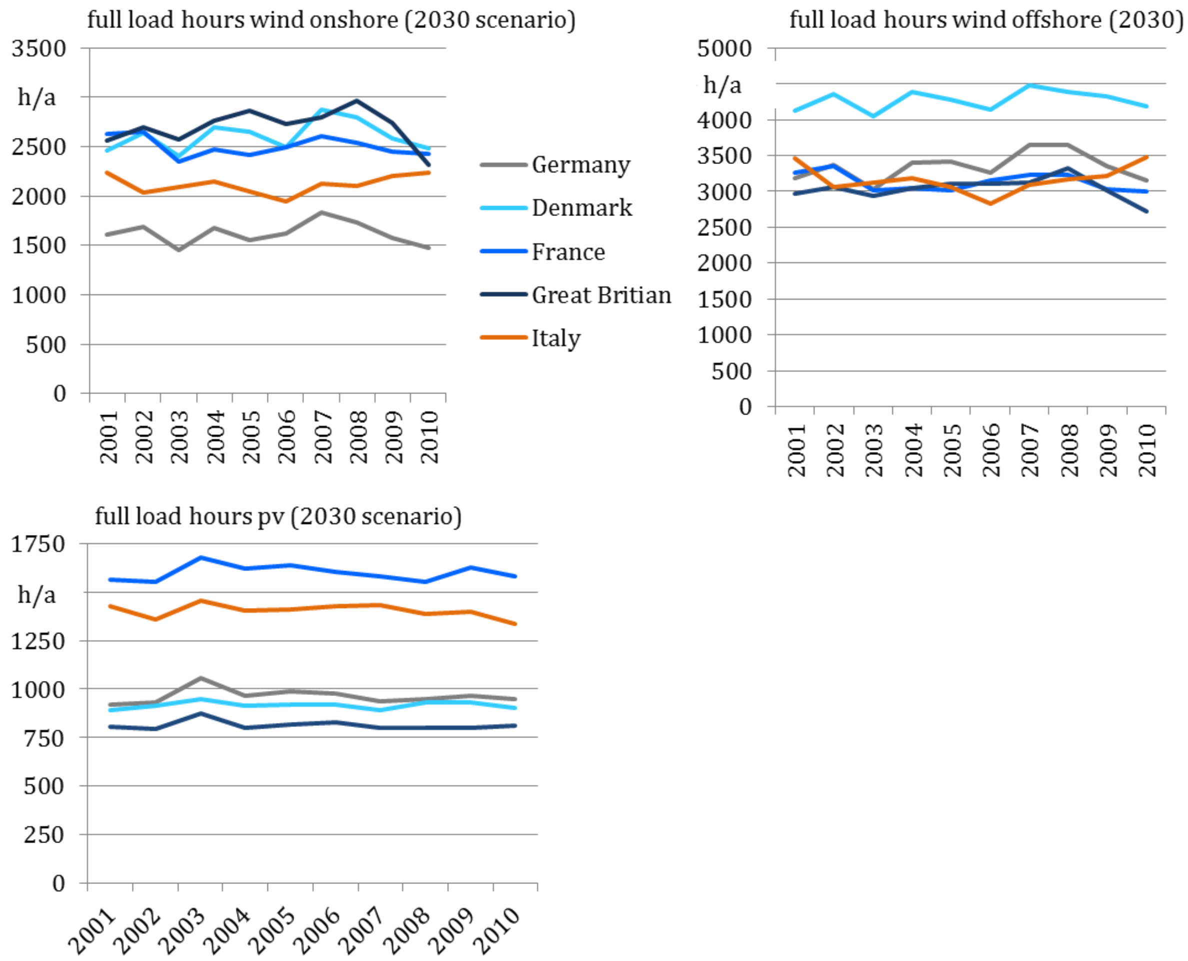

Figure 11 - Wind and PV full load hours per year

Whereas the PV full load hours per year are not changing significantly from one year to the next, the resulting full load hours from wind generation vary considerably.

Appendix D Countries: Table of correspondence

Table 21 –The following Table provides the correspondence between the English name, the Original name, the ENTSO-E code and the PRIMES code of the different countries.

English name	*Original name*	ENTSO-E code	PRIMES code
Austria	*ÖSTERREICH*	AT	AU
Belgium	*BELGIQUE-BELGIË*	BE	BE
Bosnia and Herzegovina	*Bosna i Hercegovina*	BA	BA
United Kingdom	*UNITED KINGDOM*	UK	UK
Bulgaria	*BULGARIA*	BG	BG
Croatia	*Hrvatska*	HR	HR
Cyprus	*ΚΥΠΡΟΣ / KIBRIS*	CY	CP
Czech Republic	*ČESKÁ REPUBLIKA*	CZ	CZ
Denmark	*DANMARK*	DK	DK
Estonia	*EESTI*	EE	ES
Finland	*SUOMI / FINLAND*	FI	FI
France	*FRANCE*	FR	FR
FYR of Macedonia	*Republika Makedonija*	MK	MK
Germany	*DEUTSCHLAND*	DE	GE
Greece	*ELLADA*	GR	EL
Hungary	*Magyarország*	HU	HU
Iceland	*Ísland*	IS	IS
Ireland	*IRELAND*	IE	IR
Italy	*ITALIA*	IT	IT
Latvia	*LATVIJA*	LV	LA
Lithuania	*LIETUVA*	LT	LI
Luxembourg	*LUXEMBOURG (GRAND-DUCHÉ)*	LU	LX
Malta	*MALTA*	MT	MA
Montenegro	*Crna Gora*	ME	ME
Netherlands	*NEDERLAND*	NL	NL
Norway	*Kongeriket Norge*	NO	NO
Poland	*POLSKA*	PL	PD
Portugal	*PORTUGAL*	PT	PL
Romania	*ROMANIA*	RO	RO
Serbia	*Republika Srbija*	RS	RS
Slovakia	*SLOVENSKÁ REPUBLIKA*	SK	SK
Slovenia	*SLOVENIJA*	SI	SN
Spain	*ESPAÑA*	ES	SP
Sweden	*SVERIGE*	SE	SV
Switzerland		CH	CH

Table 21 –Table of correspondence for the country names and abbreviations

Appendix E Table of references

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