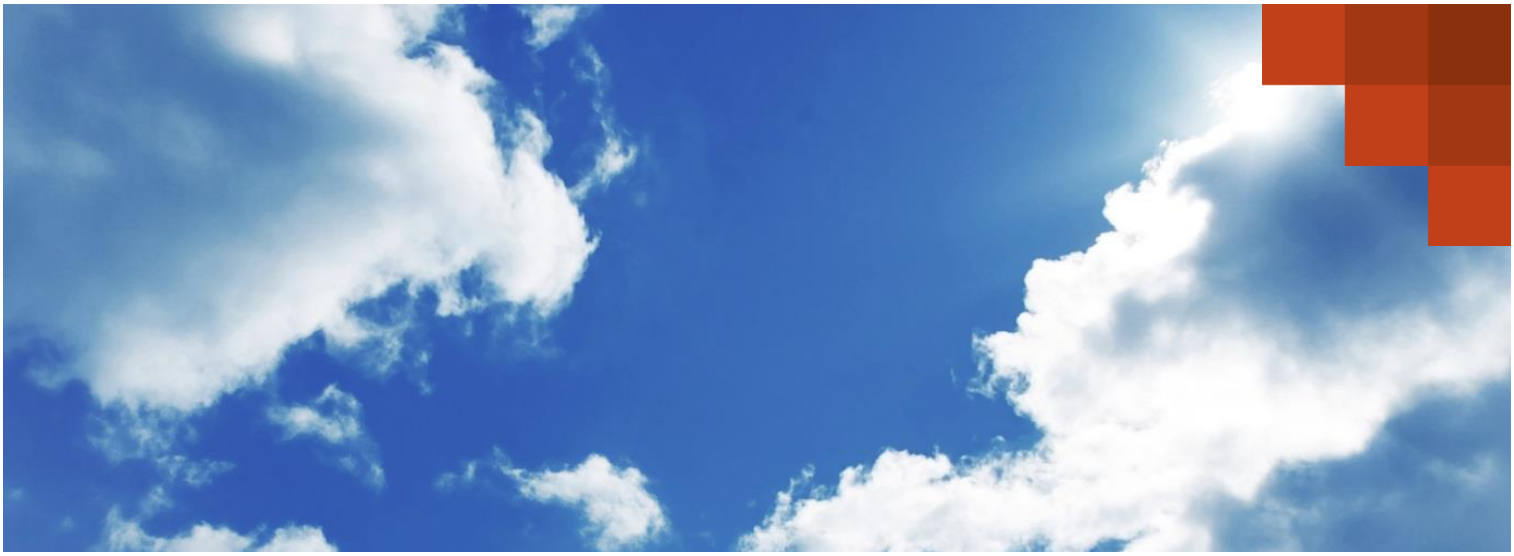

WeatherAggReOpt

Developing Aggregation and Reduction Methods for Implementing Disaggregated Renewable Infeed Profiles in Energy System Models

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Content

1 Introduction

This data documentation describes a data set of the German, France and Polish electricity system compiled within the research project “WeatherAggReOpt” (Developing Aggregation and Reduction Methods for Implementing Disaggregated Renewable Infeed Profiles in Energy System Models). The project is a collaboration between the Chair for Management Science and Energy Economics at the University of Duisburg-Essen and the Fraunhofer Institute for Solar Energy Systems (ISE). With a project period of three years WeatherAggReOpt (03ET4042A) is funded by the Federal Ministry for Economic Affairs and Energy (BMWi).

The background is that the development of a futureproof energy system requires a consistent evaluation of technology options in a system context. Optimizing energy system models play an important role in this process. However, to achieve manageable computation times, an integral optimization will require limited spatial and temporal disaggregation. On the other hand, the infeed characteristics of renewable energy sources as well as the use and dispatch of transmission lines and conventional generators requires a sufficiently high disaggregation.

Main goals of the project are therefore to achieve a better theoretical knowledge of the implications of aggregation and disaggregation on the results of optimizing energy system models and to develop improved, reproducible methods of aggregation and reduction of high-resolution infeed profiles aiming to reduce complexity and improve calculation speed. Hence, a model framework and data set were set up to test and validate developed approaches.

The data set described in the following sections can be downloaded from the Zenodo repository under the DOI https://doi.org/10.5281/zenodo.3674005.

2 Data

2.1 Geographical coverage and resolution

The geographic scope (cf. Figure 1) is set to the three central European countries France, Germany and Poland, whereby Germany is split into five sub regions represented by the four regions of the German transmission system operators with the TenneT region split into a northern and a southern (Bavarian) region. The red dots within the regions represent the geographical centers calculated as the unweighted centroid of a two-dimensional projection of each region. Only the major area[1] is considered for the centroid calculation and thus crucial for the calculated distances between adjacent regions (cf. Table 1).

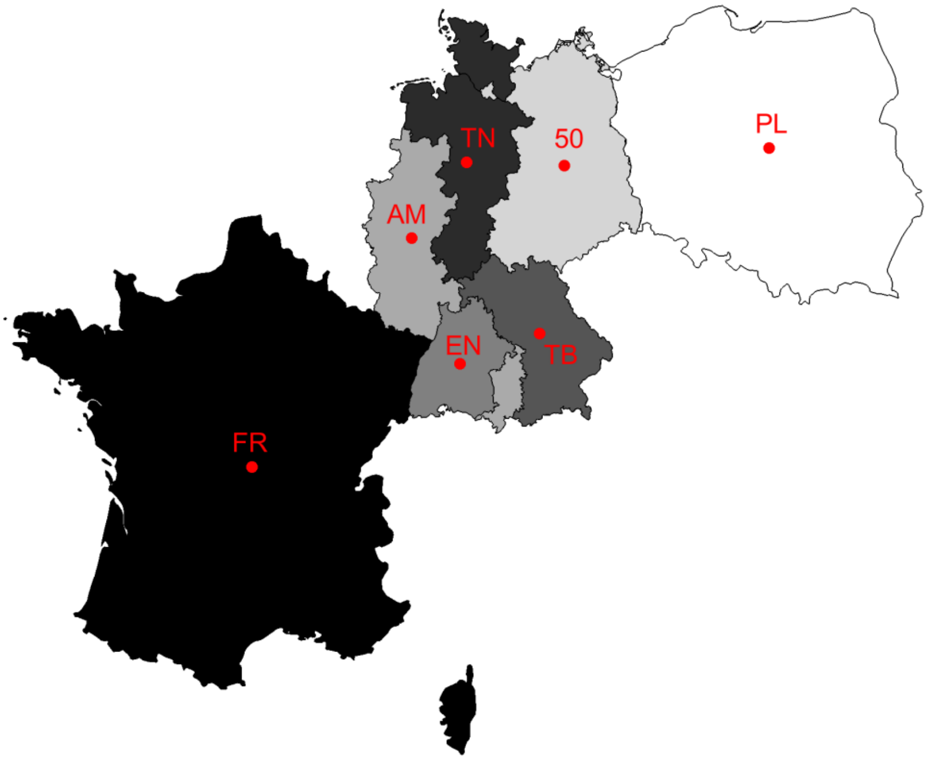

Figure 1: Geographical coverage and resolution

2.2 Transmission grid

For the transmission grid we consider advanced extra high voltage AC transmission lines at the 380 kV level. We derive the parameters for a DC load flow model based on the distances between zone centers as given in Table 1 and a standard reactance parameter per km of 0.04

[1] Namely the islands Neuwerk (Germany) and Corsica (France) as well as the southern part of the Amprion control area and Hamburg (50 Hertz) are not considered.

Ω/km for advanced lines, e.g. based on Aluminium-steel combinations.[2] This yields the total impedances given in Table 1. The operational expenditure are calculated for two and one circuits with costs of 3.000 €/km respectively 2.300 €/km and year.

Table 1: Parameters of the transmission grid

Line	Distance [km]	Line Reactance [Ω/km]	OpEx [€/(MW a)]
FREN	520	208	569 - 668
FRAM	593	237	649 - 762
AMEN	280	112	307 - 360
AMTN	199	80	218 - 256
AMTB	351	141	384 - 451
ENTB	191	76	209 - 245
TNTB	388	155	425 - 499
TN50	223	89	244 - 287
TB50	348	139	381 - 447
50PL	468	187	512 - 601

In the load flow equations, the transmission is constrained by the maximum current. This leads for the considered AlSt lines in a double system to a maximum power transfer of 2740 MW. Additionally, voltage stability limits the phase angle difference between two neighbouring nodes. The upper limit is roughly equal to π/6. For the long lines without compensation measures considered here, this is generally the more restrictive limitation.

Losses of approximately 2 % per 100km can be calculated under simplified assumptions for one 380kV transmission line with a current of 1.000 A. The current dependent losses sum up to 88.5 kW/km and the voltage dependent losses amount to 2.5 kW/km (cf. BMWI[3]). The lifetime of transmission lines is assumed as the lifetime of transmission line conductors of 40 years.

[2] Möst (2020) cf. also Crastan (2012)
[3] BMWI (2014)

From the line impedances, PTDF matrices may be derived for a given grid (i.e. disregarding transmission expansion).[4] The PTDF factors in Table 2, are calculated with the assumption of similar transmission capacity between each pair of adjacent nodes.

Note that these parameters as the previous ones have been derived when disregarind

Table 2: PTDF for the transmission grid, reference hub TB

Region--> Line	50	AM	EN	FR	PL	TN
FREN	0,0209	0,0642	-0,0629	0,5291	0,0209	0,0344
FRAM	-0,0209	-0,0642	0,0629	0,4709	-0,0209	-0,0344
AMEN	-0,0832	-0,2549	0,2499	0,0139	-0,0832	-0,1365
AMTN	0,2265	-0,3065	-0,1408	-0,2182	0,2265	0,3715
AMTB	-0,1223	-0,3745	-0,1720	-0,2666	-0,1223	-0,2006
ENTB	-0,1042	-0,3191	-0,6873	-0,5152	-0,1042	-0,1709
TNTB	-0,2281	-0,1824	-0,0838	-0,1299	-0,2281	-0,3742
TN50	-0,4546	0,1240	0,0570	0,0883	-0,4546	0,2544
TB50	-0,5454	-0,1240	-0,0570	-0,0883	-0,5454	-0,2544
50PL	0,0000	0,0000	0,0000	0,0000	1,0000	0,0000

The Investment costs for a standard 380 kV circuit amount to 535 €/(MW km) based on BMWI. Which is the result of averaging the costs of 1-1,4 Mio. €/km for circuits of 1.790 MVA respectively 2.740 MVA.

[4] E.g. Papavasiliou (2016)

2.3 Electricity demand

Table 3: Source and availability of electricity demand

Data source(s)	ENTSO-E[5], IEA[6]
Unit	MW
Temporal resolution	Hourly
Years	2015
Geographical coverage	DE, FR, PL
Spatial resolution	FR and PL country wise, DE on TSO level with a TenneT split into a northern and a southern region
Publicly available	Raw data
Data processing	▪ Hourly load profiles from ENTSO-E[7] for Poland, France and Germany (on TSO level) ▪ Data gaps have been filled by linear interpolation ▪ Profiles have been scaled to meet the annual IEA demand (set to the gross electricity production) ▪ The load split between the TenneT north (TN) and TenneT Bavaria (TB) regions is calculated by dividing all relevant nodes and corresponding load into bavarian and non-bavarian nodes

2.4 Generation technologies

The generation technologies are distinguished as conventional and renewable technologies. The conventional technologies presented in section 2.4.1 are reduced to lignite, hard coal, combined cycle gas turbines (CCGT) and open cycle gas turbines (OCGT). The renewable technologies Wind and solar are presented in section 2.4.2 and 2.4.3.

2.4.1 Conventional generation technologies

Source of all necessary technology information are data sheets of the ESYS[8] (Energy Systems of the Future) initiative of the German Academies of Sciences for a sustainable, secure and affordable energy supply. All accessed data sheets are publicly available on ESYS[9].

[5] ENTSO-E (2017)
[6] IEA (2018)
[7] ENTSO-E (2017)
[8] https://energiesysteme-zukunft.de/en/project/the-project-esys/
[9] ESYS (2016)

The efficiencies, CO_2-emission rates, fixed costs of operation (Fix O) and maintenance (Fix M), capital expenditure as well as the lifetime displayed in Table 4 are averaged values. If available, parameters for 2023 and 2050 and for different plant sizes between 100 and 600 MW were summarized.

Table 4: Parameters of conventional generation technologies

Technology	Efficiency[10]	CO_2 emission rate [tCO_2/MWh_{th}]	Fix O [%]	Fix M [%]	CapEx [€/kW]	OpEx [€/MWh]	Lifetime [a]
Lignite	0.475	0.4104	1.5	1.8	1950	16.12	50
Hard coal	0.4725	0.342	1	1.6	1525	32.02	50
CCGT	0.635	0.2016	1.5	1.5	700	56.89	32.5
OCGT	0.46	0.2016	3.5	0	375	78.53	50[11]

The calculation of the operational expenditure is shown in Eq. (1), with no transport cost considered.

$$OpEx = \frac{c_{Fuel} + e_{CO2} \cdot c_{CO2}}{\eta} + c_{Transport} \tag{1}$$

[10] The efficiencies are assumed constant and represent the optimal point of generation.
[11] Hence the source did not provide information on OCGT lifetimes for 2023 and 2050, the lifetime is set to value given for 2013 technologies.

2.4.2 Wind technologies, time series and capacity potential

Table 5: Source and availability of wind data

Data source(s)	The Crown Estate[12] Climate Data Store[13]
Unit	$MW_{produced}$/ $MW_{installed}$
Temporal resolution	1h
Year	2015
Publicly available	Raw data on the Open Power System Data platform
Data processing	▪ The wind speed at 100m height and the forecast surface roughness from the ERA5 weather reanalysis model are downloaded from the Copernicus climate data store ▪ From the calculated wind speed on hub height and the power curve for each wind turbine the produced power is calculated ▪ The generation time series for each region are clustered with the Ward cluster algorithm to find the five most representative time series for each region.

[12] The Crown Estate (2019)
[13] Climate Data Store (2019)

Table 6: Technology data of wind

Turbine	Hub h. [m]	Rotor d [m]	Power [kW]	Type[14]	Lifetime	Capex [€/kW]
WEAON01	72	53	800	HiSp	22.50	1047.03
WEAON02	139	121	2530	LoSp	22.50	1571.55
WEAON03	109	92	2350	HiSp	22.50	1155.25
WEAON04	142	114	3170	LoSp	22.50	1290.11
WEAON05	110	109	3000	LoSp	22.50	1169.85
WEAON06	150	140	4000	LoSp	22.50	1573.20
WEAON07	120	124	4500	HiSp	22.50	1363.20
WEAON08	120	140	6000	HiSp	22.50	1483.20
WEAOF01	110	185	10.000	HiSp	22.50	3212.00[15]

The Lifetime of both, onshore and offshore wind turbines lies between 20 and 25 years (cf. ESYS, 2016b) and is chosen to be the average of 22.5.

The costs for one single offshore turbine (WEAOF01) are calculated scaled costs for a single turbine within a 1GW project of 100 10MW turbines located 60km from shore in 30m water depth (cf. The Crown Estate[16]).

Potential

The potential for wind and PV are used from (Ruiz, P. et al. (2019)). The national potential is shown in the table below.

[14] We differentiate low (LoSp) and high speed (HiSp) wind turbines by their specific power (power per swept area) where turbines with more than 0.35 kW/m² are defined as high speed turbines.
[15] Exchange rate of 1.17 €/ £
[16] The Crown Estate (2019)

Table 7: Wind potential for Germany, France and Poland[17]

Country	Wind[GW]
Germany	107
France	813
Poland	102

Each region in the model has five Wind- and five PV-sites. Since there are differences in the sites in terms of capacity factor and power production, the potential is split up between the sites to allow a better distribution for the expansion of wind power. The profiles are selected with a cluster algorithm using the Ward D. cluster method. The algorithm calculates the distance between all time-series and combines the two time series with the smallest distance from each other to a new cluster. The new cluster is represented by the mean values of all time-series that are inside the cluster. One of the advantages of such a method is the possibility, to see how many sites are represented by each cluster. Each of the five clusters is represented by the site that has the smallest distance to the mean time series of that cluster. The total potential of each country is then divided by the total area of the country and multiplied by the area that is represented by the sites in each cluster.

Table 8: Wind potential for each of the selected sites in MW

Wind	a	b	c	d	e
50	456	1.083	1.061	1.072	1.224
AM	11.675	5.017	5.623	4.744	4.510
EN	3.265	2.975	3.323	2.280	3.671
FR	167.254	21.1296	200.241	92.007	142.201
PL	22.909	24.056	17.944	17.217	19.874
TB	5.882	4.581	4.941	4.501	4.301
TN	5.414	6.975	7.745	5.301	5.377

[17] Ruiz, P. et al. (2019)

2.4.3 Photovoltaic technologies, time series and capacity potential

Table 9: Source and availability of photovoltaic data

Data source(s)	ISE[18], Climate Data Store [19]
Unit	$MW_{produced}$/ $MW_{installed}$
Temporal resolution	1h
Year	2015
Publicly available	Raw data on the Open Power System Data platform
Data processing	▪ The Surface solar radiation downwards, the total sky direct solar radiation at surface and the 2 meter temperature are downloaded from the Copernicus climate data store ▪ The power output of the PV module is calculated after Killinger et al. [20] for each of the inclinations and azimuth that are listed in Table 7: Technology data of photovoltaic

Table 10: Technology data of photovoltaic

PV Module	Inclination [°]	Azimuth [°]	Performance Ratio	Type	Capex [€/MW]
PV01	35	90	0.85	Polykristallin	700
PV02	35	135	0.85	Polykristallin	700
PV03	35	180	0.85	Polykristallin	700
PV04	35	225	0.85	Polykristallin	700
PV05	35	270	0.85	Polykristallin	700
PV06	20	0	0.85	Polykristallin	700
PV07	0	180	0.85	Polykristallin	700

[18] ISE (2019),
[19] Climate Data Store (2019)
[20] Killinger et al. (2017)

Potential

The potentials for wind and PV are used from (Ruiz, P. et al. (2019)). The national potential is shown in the table below.

Table 11: Solar potential for Germany, France and Poland[21]

Country	PV [GW]
Germany	988
France	1.644
Poland	893

The procedure to determine the 5 PV time series and their potential is similar to the procedure for wind.

Table 12: PV potential for each of the selected sites in MW

Site	a	b	c	d	e
50	10.166	8.763	7.730	10.221	8.321
AM	69.603	78.129	62.860	42.237	38.668
EN	33.361	26.296	22.371	38.070	23.156
FR	382.146	368.859	291.517	341.889	259.589
PL	188.163	169.576	171.057	176.310	187.894
TB	49.173	46.938	47.954	26.415	53.034
TN	59.962	49.841	47.358	76.193	51.177

2.5 Storage

In order to consider short- and long-term storage, Table 13 covers parameters for battery and pumped hydro storage (PHS). As the main application of the data set provided is in energy system modeling and electricity market optimization, only mass storages are considered (i.e. for the volume costs of battery storages). Furthermore, only Li-Ion-batteries are considered to avoid averaging of different technologies.

[21] Ruiz, P. et al. (2019)

As for the conventional technologies, the storage parameters are averaged over the given values for 2023 and 2050.

Table 13: Technology data of storage (cf. ESYS[22])

Storage technology	Component	Efficiency	Lifetime[23] [a]	Self discharge rate[24] [-]	CapEx [€/kW]
Battery	Charge	0.885	28.5	5.137E-06	58.75
	Discharge	0.885	28.5		55.00
	Volume[25]	---	19.5		139.50
PHS	Charge	0.880	40	5.48E-05	422.50
	Discharge	0.890	40		450.00
	Volume	---	80		50.00

[22] ESYS (2015)
[23] If no lifetime was given the depreciation period was considered as lifetime
[24] Hourly loss as fraction of effective storage content
[25] Energy content

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