iDesignRES

Integrated Design of the Components of the Energy System to Plan the Uptake of Renewable Energy Sources: An Open Source Toolbox

North Sea Power System Data

WP1 -- Multi-Physics component models: Implementation and development

Task 1.1 – Data gathering at NUTS level 2: The North Sea.

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Author(s)	Ehsan Nokandi, Jannis Kerl
Primary Contact and Email	Ehsan Nokandi, ehsan.nokandi@ntnu.no
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1. EXECUTIVE SUMMARY

The data presented is published as part of the iDesignRES project, specifically under WP 1, Task 1.1. This task involved collecting detailed energy system data, here for the North Sea region and focusing on electricity, to serve as test data for the models utilized within the iDesignRES project.

The data presented here covers electricity generation, consumption, and the power grid of the North Sea region and is used as a macro-region validation use case for testing and validating the project's models. It includes detailed information on power generation assets—both offshore and onshore—such as wind farms, thermal plants, and other renewable energy sources. Additionally, it contains the high-voltage transmission grid and interconnections between countries.

Data on load distribution through the grid, as well as load time series data for 2024 with hourly temporal resolution, has been embedded in the dataset. The dataset spans Norway, Germany, the Netherlands, Denmark, the United Kingdom, and Belgium, with France included for completeness.

2. Network Data

The network data for the North Sea power grid is scraped from PyPSA [1], which contains the European High voltage grid (220 kV to 750 kV) and is based on OpenStreetMap Data. This dataset is filtered to the needed countries for the iDesignRES North Sea-case - included are lines, links, buses and data for transformers of the said countries. In addition, connections to buses in neighboring countries are also included. The grid has been depicted in Figure 1.

The network data consists of the following files:

- buses.csv
- neighboring_buses.csv
- lines.csv
- links.csv
- transformers.csv
- converters.csv

2.1 buses.csv and neighboring_buses.csv

While buses.csv contains data on transmission buses located within North Sea countries, neighboring_buses.csv provides information on buses outside these countries that are directly connected to their transmission grid.

Both buses.csv and neighboring_buses.csv have the same structure. An excerpt from the bus_data.csv file is shown as an example in Figure 2. The files contain the following columns.

bus_id: Contains a unique identifier for each bus in the system.

voltage: Represents the voltage level of each bus, expressed in kilovolts (kV). The voltage levels range from 220 kV to 520 kV.

dc: Indicates whether the bus is located in the DC part of the grid or not. The values can be f (False) or t (True)

y and x: Contain latitude and longitude of the buses respectively.

country: Contains country code where the bus is located. The country codes are based on ISO 3166-1 Alpha-2 standard.

An excerpt from the buses.csv and neighboring_buses.csv files can be seen in Figure 2.

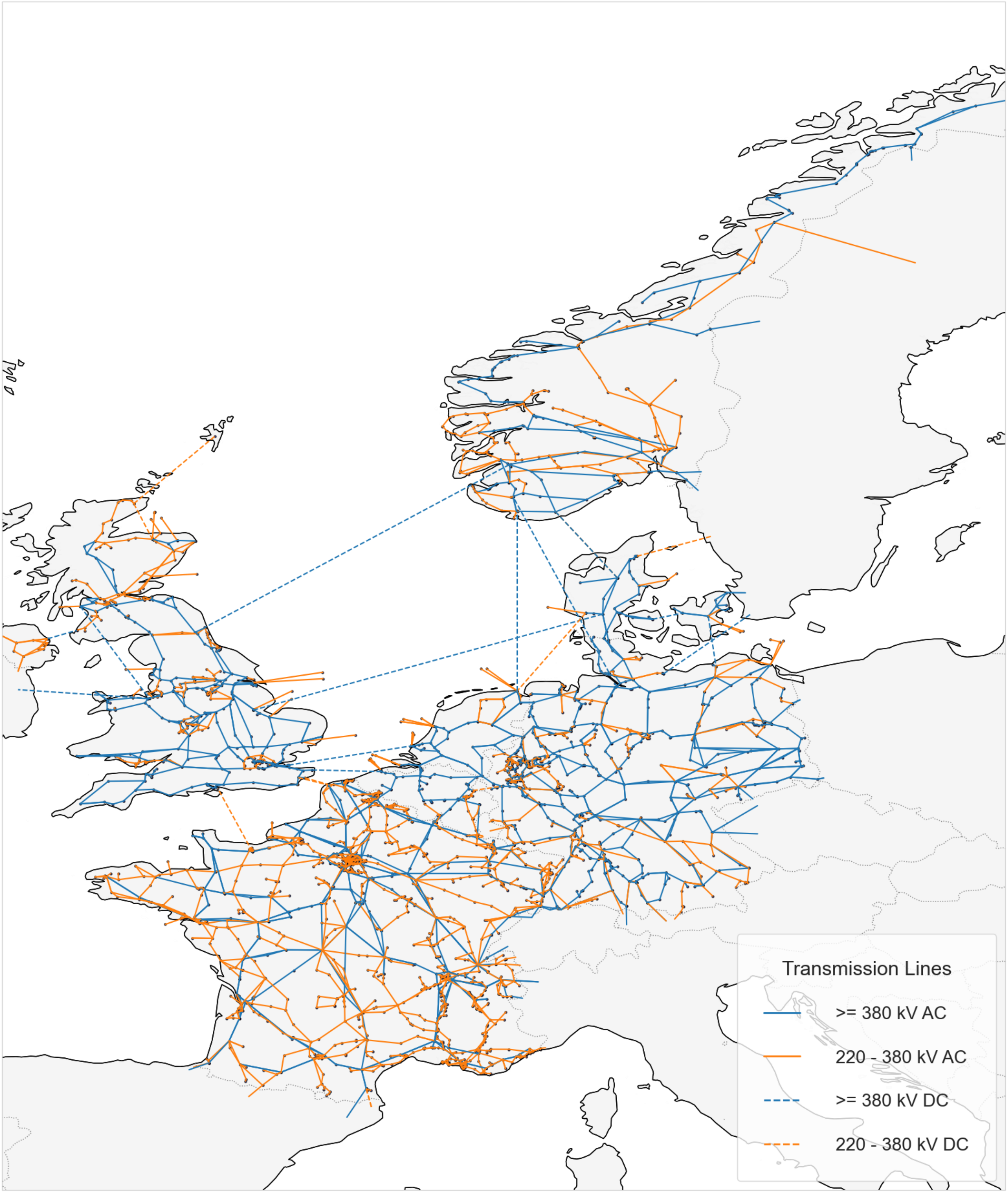

Figure 1: The power transmission grid of the North Sea countries, obtained from PyPSA.

bus_id	voltage	dc	x	y	country
BE1-220	220	f	2.917742	51.6198	BE
DE100-22(	220	f	7.135589	51.41707	DE
DE100-38(	380	f	7.135882	51.41726	DE
FR80-400	400	f	3.489653	48.44471	FR
FR81-225	225	f	-4.18182	48.42753	FR

Figure 2: An excerpt from the buses.csv and neighboring_buses.csv files.

2.2 lines.csv

The lines.csv file contains information regarding the AC transmission lines of the grid. The file includes the following columns.

line_id: A unique identifier for each transmission line in the system.

bus0: Indicates the "from" bus of the transmission line, represented by its unique bus ID.

bus1: Indicates the "to" bus of the transmission line, represented by its unique bus ID.

voltage: Represents the voltage level of the transmission line, expressed in kV. The voltage level of the dataset's lines varies from 220 to 420 kV.

i_nom: Specifies the maximum allowable current for the transmission line circuit, expressed in kiloamperes (kA).

circuits: Specifies the number of circuits that the transmission line includes.

s_nom: Specifies the nominal power transfer capability of the transmission line, expressed in mega voltamperes (MVA).

r: Contains the resistance of the transmission line, measured in ohms (Ω).

x: Contains the reactance of the transmission line, measured in ohms (Ω).

b: Contains the susceptance of the transmission line, measured in siemens (S).

length: Provides the physical length of the transmission line in meters (m).

underground: Indicated whether the line is underground (t) or overhead (f).

Type: Indicates the conductor type of the line.

An excerpt from the lines.csv file can be seen in Figure 3.

line_id	bus0	bus1	voltage	i_nom	circuits	s_nom	r	x	b	length	undergrounc	type
merged_ı	way/88	way/50	220	1.29	1	491.56	0.57	2.87	3.75e-0	9550.2	f	Al/St 240/40 2-bundle 220.
merged_ı	way/66	way/39	220	1.29	1	491.56	4.47	22.4	0.0003	74463	f	Al/St 240/40 2-bundle 220.
merged_ı	way/15	way/66	220	1.29	1	491.56	2.4	12	0.0002	40032	f	Al/St 240/40 2-bundle 220.

Figure 3: An excerpt from lines.csv file.

2.3 links.csv

The links.csv file contains information regarding the DC links of the grid. The file includes the following columns:

link_id: Contains a unique identifier for each link in the dataset.

bus0: Indicates the "from" bus of the link, represented by its unique bus ID.

bus1: Indicates the "to" bus of the link, represented by its unique bus ID.

voltage: Represents the voltage level of the link, expressed in kV.

p_nom: Specifies the nominal active power transfer capability of the link, expressed in megawatts (MW).

length: Provides the physical length of the link, expressed in meters (m).

An excerpt from the links.csv file can be seen in Figure 4.

link_id	bus0	bus1	voltage	p_nom	length
relation/10377412-320-DC	way/753113423	way/636630368	320	1000	230137
relation/13295785-515-DC	relation/12832053	way/642490160	515	1400	723362
relation/14126301-450-DC	way/109189896	way/920127890	450	1000	253393

Figure 4: An excerpt from links.csv file.

2.4 transformers.csv

The transformers.csv file contains information about the transformers in substations of the transmission system. The file includes the following columns:

transformer_id: Contains a unique identifier for each of the transformers in the dataset.

bus0: Indicates the bus on the primary side of the transformers, represented by its unique bus ID.

bus1: Indicates the bus on the secondary side of the transformers, represented by its unique bus ID.

voltage_bus0: Represents the voltage level of the primary side of the transformers, expressed in kV.

voltage_bus1: Represents the voltage level of the secondary side of the transformers, expressed in kV.

s_nom: Specifies the nominal power of the transformers, expressed in mega voltamperes (MVA).

system_base_MVA: Power base (MVA) used for per-unit conversion at system level. It is the denominator reference for values like X_pu_on_system_base.

X_pu_on_system_base: Transformer reactance in per-unit on the chosen system_base_MVA.

X_ohm_HV: Equivalent series reactance in ohms referred to the high-voltage side. It is the physical reactance value at HV base voltage.

X_ohm_LV: Equivalent series reactance in ohms referred to the low-voltage side. It is derived from HV-side reactance by voltage-base transformation.

An excerpt from the transformers.csv file can be seen in Figure 5.

transformer_id	bus0	bus1	voltage_bus0	voltage_bus1	s_nom	base_MVA	X_pu	X_ohm_HV	X_ohm_LV
DE100-220-380	DE100-220	DE100-380	220	380	3397	1000	0.029	4.21166666666	1.41166666666666
DE102-220-380	DE102-220	DE102-380	220	380	3397	1000	0.029	4.21166666666	1.41166666666666
DE107-220-380	DE107-220	DE107-380	220	380	3397	1000	0.029	4.21166666666	1.41166666666666

Figure 5: An excerpt from transformers.csv file

2.5 converters.csv

The converters.csv file contains information about the converters of the system which connects AC and DC parts of the grid. The file includes the following columns.

converter_id: Contains a unique identifier for each of the transformers in the dataset.

bus0: Indicates the bus on the primary side of the transformers, represented by its unique bus ID.

bus1: Indicates the bus on the secondary side of the transformers, represented by its unique bus ID.

voltage: Represents the voltage level of the connected DC link, expressed in kV.

p_nom: Specifies the nominal active power of the converters, expressed in megawatts (MW).

An excerpt from the converters.csv file can be seen in Figure 5.

converter_id	bus0	bus1	voltage	p_nom
conv-relation/10695345	relation/10695345	relation/10695345-400	400	1000
conv-relation/11981383	relation/11981383	relation/8894066-420	450	700
conv-relation/12832053	relation/12832053	relation/12832053-420	515	1400

Figure 6: An excerpt from converters.csv file

3. Generation data

The power-generation dataset contains data on active power plants in the considered North Sea region and the included countries, with France added. It contains information on the type of powerplant and its geographical location.

The Energy Types column includes Nuclear, Hard Coal, Hydro, Lignite, Oil, Natural Gas, Solid Biomass, Wind, Solar, Other, Biogas, and Waste, while the Technologies column contains Steam turbine, Steam Turbine, Run-Of-River, Pumped Storage, Reservoir, CCGT, Offshore, Onshore, PV, Marine, Combustion Engine, PV, and CSP.

The generation data is gathered from PyPSA-Europe, specifically the most recent powerplantmatching-publication [2]. It merges powerplant-data from several sources and databases, making it the most comprehensive and high-quality dataset available for European power plants.

The processing is carried out by filtering out powerplants to include only those with no specified decommissioning date or with dates later than 2024, ensuring all active plants up to 2024 are considered.

Due to varying data across countries for solar and wind installations, their values are proportionally scaled using available, aggregated ENTSO-E data. Additionally, for French nuclear power, the more accurate and detailed Global Energy Monitor data [3] is used instead of PyPSA data. A comparison of the total installed capacity per energy source for each country in our dataset and ENTSO-E is illustrated in Figure 7 .

Note that the granularity of technologies varies between the PyPSA-data and the ENTSO-E source. Therefore, differences might occur. Also note that some of the technologies covered by the PyPSA-data are not covered by ENTSO-E, resulting in differences (most notable for Denmark).

From the version 1.2.0, we used Global Energy Monitor data instead of PyPSA-eur, as the main source for wind generation installed capacity in Germany, since PyPSA-Eur did not provide an onshore/offshore classification. The data then scaled based on ENTSO-E Values.

Lastly, powerplants are assigned to their geographically closest buses based on the given coordinates.

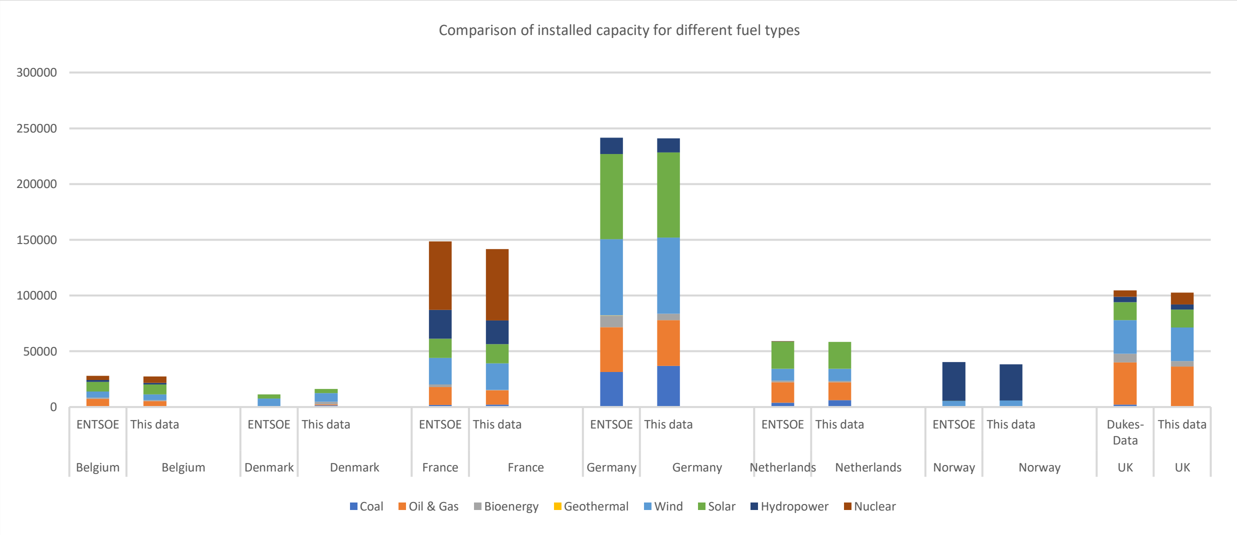

Figure 7: Comparison of installed capacity per fuel type between ENTSO-E and this dataset.

3.1 generation.csv

The file includes the following columns.

unit_id: A unique identifier assigned to each generation unit, following the format "G0001", "G0002", etc.

country: The country where the power plant is located

source: The primary energy source used for power generation, such as "Nuclear" or other fuel types

technology: The specific technology used for power generation, e.g., "Steam turbine"

capacity_mw: The installed capacity of the power plant, measured in megawatts (MW)

y: The geographical latitude coordinate of the power plant

x: The geographical longitude coordinate of the power plant

bus_id: The identifier of the electrical bus to which the power plant is connected, based on the uploaded network-data

An excerpt from the generation.csv file has been depicted in Figure 8.

unit_id	country	source	technolo	capacity_	y	x	bus_id
G0001	FR	Nuclear	Steam tu	1363	47.51	2.87501	way/41829825-400
G0002	FR	Nuclear	Steam tu	1363	47.51	2.87501	way/41829825-400
G0003	FR	Nuclear	Steam tu	951	45.256	-0.6932	way/105515586-225

Figure 8: An excerpt from the generation.csv.

4. Load data

The demand data consists of both a static and a time-dependent component. The static component addresses how load is distributed throughout the grid, while the time-dependent component represents the actual hourly load values over a specific period, in our case, the year 2024.

4.1 load_distribution.csv

This file contains information about the share of each bus in the total electricity consumption of its respective country. Consequently, the sum of the values assigned to the buses in each country equals one.

The primary data source used is the EU Energy Atlas [4]. This dataset consists of a series of maps of the EU in TIFF format, representing the demand for major energy product groups across various economic activities. The data is based on the 2019 energy balances and the 1×1 km reference grid from EUROSTAT and the JRC's Energy and Industry Geography Lab.

The EU Energy Atlas provides an estimate of electricity consumption in EU countries with a spatial resolution of 1 square kilometer. It categorizes consumption by various sectors, such as industry and transportation, while also offering aggregated electricity consumption across all sectors.

Although this data is from 2019, it is assumed that while total electricity consumption may have changed between 2019 and 2024, the spatial distribution of electricity consumption across Europe has remained approximately constant.

To estimate how the load is distributed through the grid, each pixel is assigned to the closest transmission grid of the respective country. Figure 9 illustrates the estimated of electricity demand of EU countries, as provided by EU Energy Atlas. However, the Atlas data does not cover Norway or the United Kingdom.

For the United Kingdom, the current version of our data relies solely on population distribution to estimate the load distribution within the network.

For Norway, a combination of geographical locations and annual electricity consumption of major industrial and oil sites has been used to refine the load distribution estimate, improving upon what would be derived solely from population distribution. Figure 10 illustrates population density alongside the electricity consumption of industrial and oil sites in Norway.

Finally, Figure 11 illustrates the final estimated load distribution through the transmission grid of the North Sea countries.

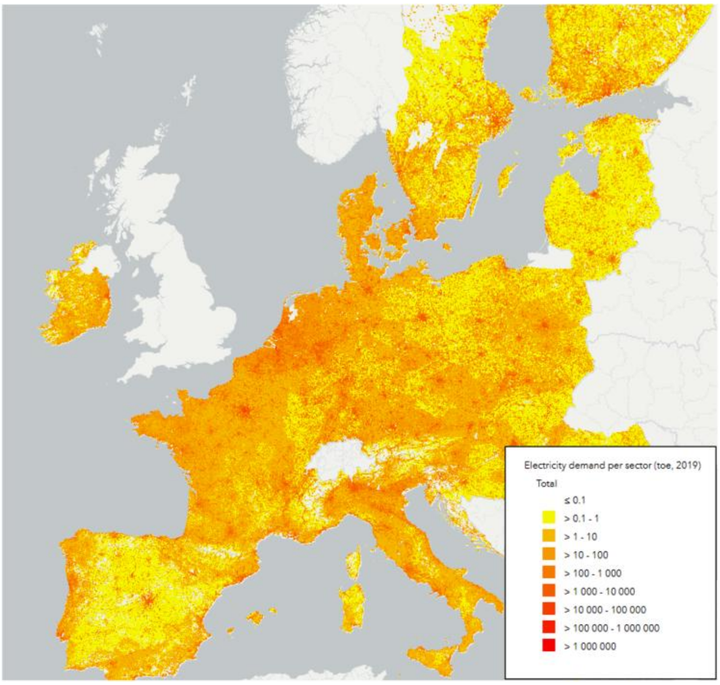

Figure 9: The estimation of electricity demand of Europe in 2019 by EU Energy Atlas (figure from Energy and Industry Geography Lab [5]).

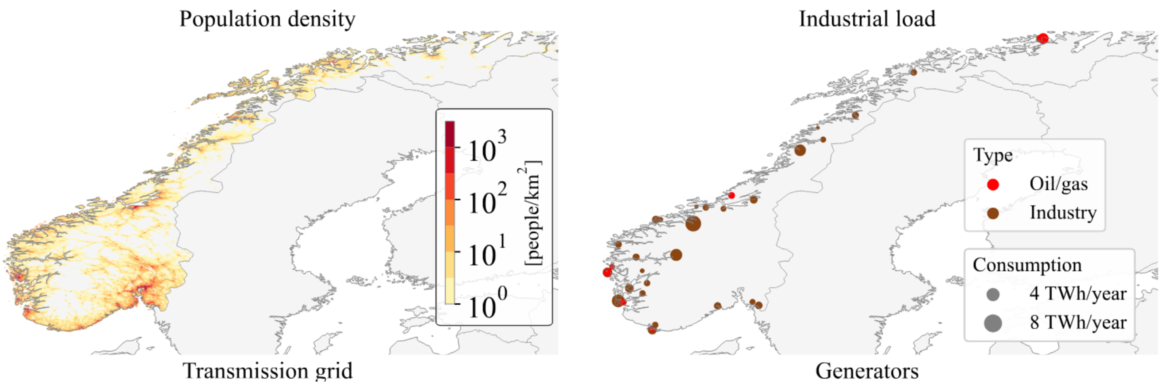

Figure 10: The data of the population density and consumption of the industrial and oil sites of Norway

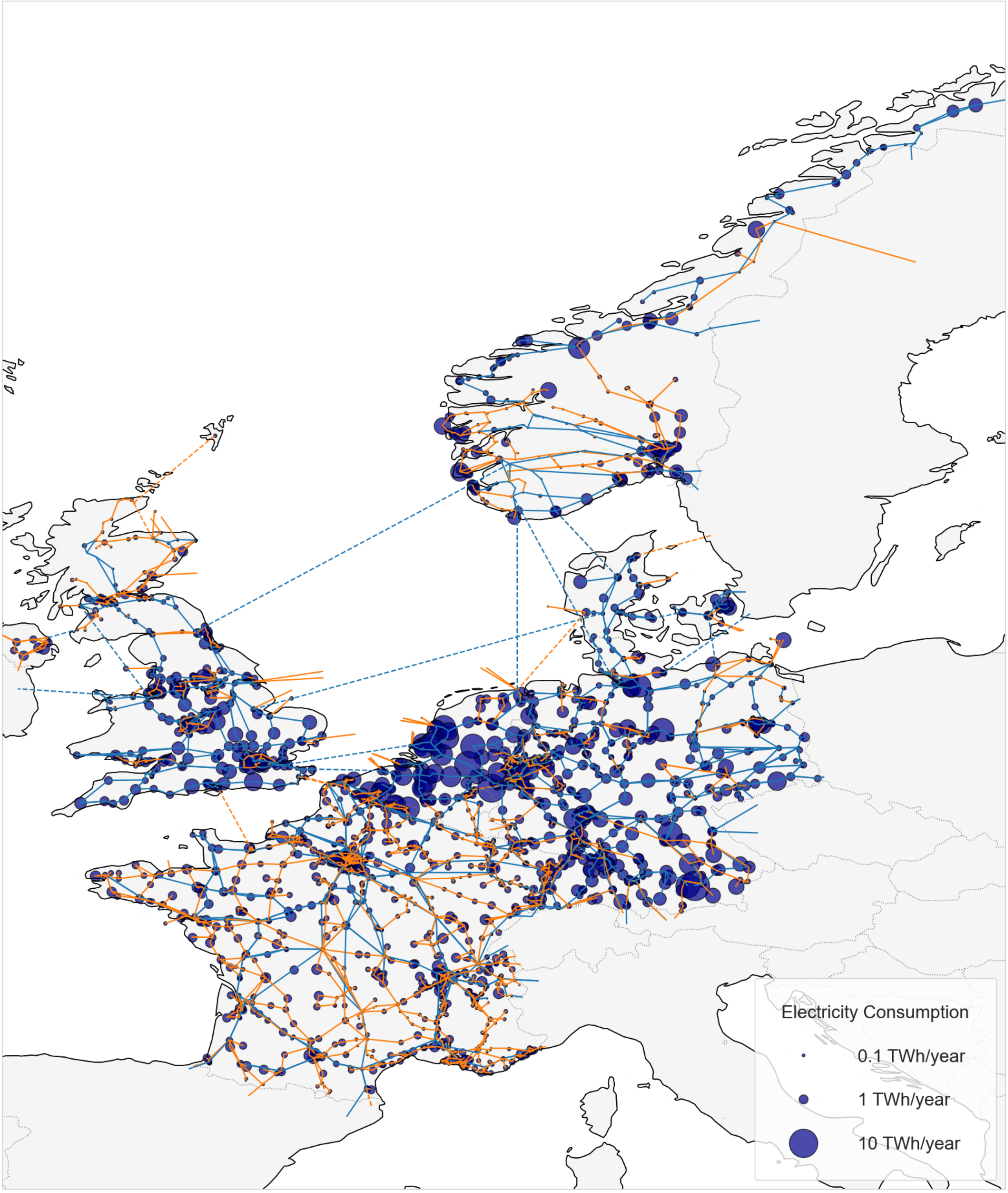

Figure 11: The estimated load distribution through the transmission grid of the North Sea countries.

4.2 load_time_series.csv

The file contains electricity consumption data for the North Sea countries and France in hourly intervals throughout the year 2024. The data was obtained from the ENTSO-E Transparency Platform [6] and from the National Energy System Operator (NESO) of the United Kingdom.

The dataset contains the following columns:

timestamp: This column specifies the timestamp for each recorded data point, indicating the exact date and time at 1-hour intervals throughout the year 2024. The timestamps are in ISO 8601 format, including the time zone offset.

{Country}: This column represents the electricity consumption in the respective country at the corresponding time slot. The values are expressed in megawatts (MW), indicating the total power demand during the 1-hour interval.

An excerpt from the file is shown in Figure 10.

timestamp	Belgium	Denmark	France	Germany	Netherla	Norway	United Kingdom
1/1/2024 0:00	7335	3704	52846	39337	11312	18364	21783
1/1/2024 1:00	7143	3638	51599	38408	11127	18224	22194
1/1/2024 2:00	6878	3660	50992	37308	10848	18030	20619

Figure 10: An excerpt from the load_time_series_data.csv file.

The load data was gathered through the ENTSO-E transparency platform, which contains time series on loads for different European countries. Since there is no data for the UK from 2020 onwards, datasets provided in [7] by the national system operator (NESO) of the UK are used. There, the entries of ND (National Demand) are used to create the load time series. It is defined as:

"*National Demand is the sum of metered generation, but excludes generation required to meet station load, pump storage pumping and interconnector exports.*" [8] This is used since it is the closest load definition compared to the ENTSO-E load data.

5. References

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More information on iDesignRES project:

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