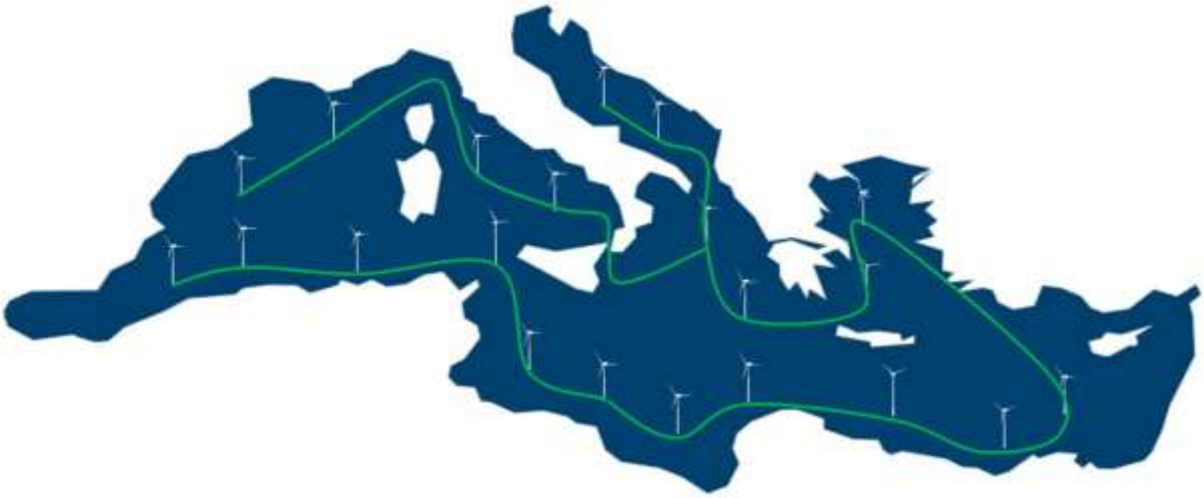

February 2025

1.3 Electricity Transmission Grid Data Collection

https://spowind.interreg-euro-med.eu/

Interreg Euro-MED
Co-funded by the European Union

SPOWIND

Deliverable Euro-MED0200199

Project acronym	SPOWIND
Project title	Spatial Planning for Offshore Wind Industry Development
Project mission	Strengthening an innovative sustainable economy
Project priority	1 - Smarter MED
Specific objective	RSO1.1 - Developing and enhancing research and innovation capacities and the uptake of advanced technologies
Type of project	Thematic
Project duration	01/01/2024 – 31/03/2026 (27 months)

Deliverable title	1.3 Electricity transmission grid data collection
Deliverable number	1
Deliverable type	Report
Work package number	1
Work package title	Data collection, synergy and consolidation
Activity name	Electricity transmission grid data collection
Activity number	3
Partner in charge (author)	ICCS
Partners involved	ICCS

Document history

Versions	Date	Document status	Delivered by
Version 1.0	24/02/25	Final	ICCS

Table of contents

Executive summary

This deliverable, *"1.3 Electricity Transmission Grid Data Collection,"* describes the methodology and results of the SPOWIND project's activities on open-source electricity transmission system modeling to support offshore wind integration in the Mediterranean region.

The work develops a **transparent, reproducible approach** based on **PyPSA-Eur**, enabling the creation of detailed national grid models using publicly available data. This overcomes the limitations of proprietary datasets and facilitates consistent, data-driven assessments of offshore wind expansion and system readiness.

The methodology allows users to:

- Construct country-specific grid models with substations, lines, transformers, and generation units.
- Integrate **offshore wind farms** and evaluate their impact on existing networks.
- Adjust load and generation to simulate **future scenarios** under decarbonization pathways.

Models were developed for **Albania, Croatia, Greece, Italy, Montenegro, and Portugal**, each accompanied by network statistics and visualizations. The results confirm that open-source tools can effectively reproduce the structure and behavior of European transmission systems, offering a practical foundation for planning and analysis.

By promoting **open data**, **collaboration**, and **regional harmonization**, this deliverable supports SPOWIND's broader objective of advancing offshore wind development and contributing to a sustainable, integrated Mediterranean energy system.

Introduction

The global transition towards renewable energy is accelerating, with offshore wind power emerging as a key component in achieving decarbonization targets and enhancing energy security. In Europe, offshore wind energy plays a pivotal role in the European Commission's strategy for sustainable and secure energy production, as outlined in the Offshore Renewable Energy Strategy. With vast wind resources and technological advancements, offshore wind energy presents a significant opportunity to contribute to the European Union's climate and energy objectives.

However, integrating large-scale offshore wind generation into existing transmission systems poses substantial challenges related to grid reliability, stability, and capacity. The variability and geographic dispersion of offshore wind farms necessitate advanced transmission network planning and robust system integration strategies to ensure efficient and stable electricity supply. Addressing these challenges requires detailed analysis and representative modeling of transmission networks to assess their readiness for accommodating offshore wind penetration.

Accurate and accessible transmission system models are essential for conducting such studies. However, existing models provided by Transmission System Operators (TSOs) remain largely proprietary, limiting their use for broader research, analysis, and collaboration. While some TSOs offer simplified models, these often lack the necessary detail for high-level renewable integration studies. Furthermore, access to the transmission grid dataset provided by the European Network of Transmission System Operators for Electricity (ENTSO-E) for the Ten-Year Network Development Plan (TYNDP) is restricted, making it unsuitable for open academic and research purposes.

To address these limitations, this deliverable presents a methodology designed to build the necessary models which will allow to study the integration of offshore wind energy into existing power systems, using open-source data and tools. By leveraging resources such as PyPSA-Eur for transmission system modeling and simulation, this methodology provides an accessible, flexible, and scalable approach for evaluating steady-state grid performance under various wind integration scenarios. It enables users to modify key network parameters, such as generation dispatch and peak load, while incorporating visualization tools to communicate insights effectively.

The proposed methodology aims to bridge the gap between the need for detailed transmission system analysis and the lack of openly accessible models. It is designed to support researchers, policymakers, municipalities, and small to medium enterprises in addressing the technical and operational challenges of offshore wind integration.

By facilitating open and collaborative analysis, this initiative contributes to the broader European goals of renewable energy adoption, energy system decarbonization, and grid modernization. Ultimately, this deliverable underscores the importance of open-source methodologies in advancing Europe’s transition towards a sustainable and resilient energy future.

Methodology

This section outlines the methodology used for the electricity transmission grid data collection. the integration of offshore wind energy into existing power systems. The proposed methodology leverages open-source tools and datasets, offering a scalable and efficient approach for modeling, analysis, and visualization. The methodology comprises the construction of a detailed transmission network model, the incorporation of new generation assets, and the ability to modify generation and demand to simulate future scenarios.

The methodology is divided into three primary components:

- an overview of its capabilities,
- detailed network modeling using PyPSA-Eur,
- the adjustment of network elements to represent potential future configurations.

Each component is discussed in detail below.

Methodology Overview

The methodology is developed in Python, utilizing the PyPSA-Eur library to model transmission networks, generation, and load. This approach provides a detailed, adaptable, and open-source representation of the power system, making it suitable for a wide range of applications.

One of the key features of the approach is its flexibility, allowing users to customize network conditions by modifying generation profiles and peak load parameters. These adjustments preserve the initial proportional distribution of system generation and loading, ensuring that the system’s original characteristics and balance are maintained. This functionality enables users to conduct scenario-specific analyses with confidence in the integrity of the underlying model.

Additionally, the methodology incorporates the PyPSA-Eur dataset, which includes geospatial data for all network components, such as substations and transmission lines. This will allow users in the future to specify the geographic coordinates and nominal output power of a proposed offshore wind farm, to integrate the new generation asset into the network

The generated networks are stored in .netcdf format. Including all asset coordinates so can be visualized using PyPSA or other external libraries. This flexibility enhances usability, allowing users to tailor the output format to their specific analytical needs and also makes it suitable for webGIS applications.

Network Model

PyPSA-Eur is an open-source dataset representing the European energy system at the transmission network level, covering the entire ENTSO-E area. This dataset includes demand and supply data for all energy sectors. The PyPSA Python library serves as an open-source toolbox for performing load-flow analysis. PyPSA was selected over alternative tools due to its compatibility with the PyPSA-Eur dataset, eliminating the need for further conversion or modification.

Network Topology

The network topology, including substations and transmission lines, is derived from the geographical vector data of the ENTSO-E Interactive Map using the GridKit toolkit. The dataset incorporates the geographical coordinates of all network elements, making it highly suitable for visualization and interactive tools.

Electrical parameters for transmission lines are based on standard AC line types, with line lengths calculated from the coordinates of their endpoints. Since the ENTSO-E map does not include transformer details, a single standard transformer type is assumed and used to connect buses at different voltage levels. The dataset provides information on buses and transmission lines at 220 kV, 300 kV, and 380 kV voltage levels within European countries and exclusive economic zones.

Table 1: Cable Types

Line Type	Nominal Frequency (HZ)	R per length (pu/km)	X per length (pu/km)	C per length (pu/km)	Nominal Current(kA)	Nominal Voltage (kV)
Al/St 240/40 2-bundle 220.0	50	0.06	0.301	12.5	1.29	220
Al/St 240/30 3-bundle 300.0	50	0.04	0.265	13.2	1.935	300
Al/St 240/40 4-bundle 380.0	50	0.03	0.246	13.8	2.85	380

To minimize computational burden during model generation and in future load flow analysis, the methodology does not construct the model for the entire ENTSO-E area. Instead, it builds the transmission model specifically for each studied country.

Existing Generation

The existing generation capacity is obtained from PyPSA-Eur using the Powerplantmatching Python library.

This package combined multiple power plant databases and provides ready-to-use powerplant data for the European system. This is an open-source library and the dataset is fully compatible with PyPSA.

In cases where multiple generators are connected to a single busbar, they are aggregated into a single equivalent generator with the same total capacity.

This aggregation reduces the number of network elements while maintaining the quality and accuracy of results.

PyPSA-Eur also provides the geographical coordinates and technological classifications of generators, enabling clear distinctions between renewable and conventional energy sources. These attributes are valuable for both network analysis and result visualization.

Existing Load

The electricity demand data for each country is sourced from PyPSA-Eur. PyPSA-Eur derives national electricity demand primarily from **ENTSO-E's Transparency Platform**, which provides real-time and historical data on electricity consumption, generation, and grid operations across European countries.

Since the dataset provides total national load values, an essential step is required to distribute this demand spatially within each country. To achieve this, the distribution of electricity demand among substations is proportional to the population density in the surrounding area. This method assumes that electricity consumption is strongly correlated with population density, which is a reasonable approximation in the absence of more granular consumption data at the substation level.

The process of spatial demand allocation involves:

1. **Identifying Substation Locations** – Using geographical data of substations within the country.
2. **Mapping Population Density** – Leveraging population datasets to determine the distribution of residents near each substation.
3. **Weighting Load Distribution** – Assigning a share of the national electricity demand to each substation based on the proportion of the country's population living within its vicinity.

This approach ensures a realistic and data-driven representation of electricity demand across the power grid. By aligning the demand distribution with population density, the model captures urban centers' higher electricity consumption and accounts for lower consumption in sparsely populated regions.

Load/Generation Modification

To evaluate the impact of a new offshore wind farm on the future power system, it is essential to allow modifications in both generation and demand within the system to simulate potential future scenarios.

Regarding system generation, users can adjust or entirely withdraw generating units from the model. Any withdrawn generation is proportionally redistributed among the remaining generating units while preserving the initial generation proportions.

This redistribution is performed based on the initial dispatch, as described by the following equation:

$$S_{Gnew} = S_{Gpre} + \frac{S_{Gpre}}{S_{system\ total}} S_{modified}$$

where:

- S_{Gnew}: New generation dispatch for a specific generator,
- S_{Gpre}: Initial generation dispatch for the same generator,
- $S_{system\ total}$: Total system generation before modification,
- $S_{modified}$: Total generation capacity modified or withdrawn.

This approach ensures that the initial generation proportions are maintained and that load-generation balance is preserved. Similarly, users can add new generation units (e.g., future planned conventional units) or modify the load at specific busbars. This results in a system with an unchanged topology but with adjusted generation and load dispatch, enabling the simulation of possible future operational scenarios.

Offshore Wind Farm Implementation

Following the described methodology, integrating a new offshore wind generator requires an adjustment in the output power of all existing generators, performed proportionally to accommodate the new generation.

To implement a generator representing an offshore wind farm, the following steps are undertaken:

1. **Bus Creation**: Create a new bus for the offshore wind farm with the appropriate voltage level and specified geographic coordinates.
2. **Generator Creation**: Define a new generator to represent the wind farm, specifying its nominal voltage and power output, and connect it to the created bus.
3. **Substation Identification**: Determine the nearest existing substation to the newly created bus using Euclidean distance.
4. **Transmission Line Construction**: Establish a transmission line using an appropriate line type from PyPSA, ensuring the correct length is specified.
5. **Generation Dispatch Adjustment**: Adjust the power generation dispatch of all existing generators proportionally, as described in the methodology, to reflect the dispatch change caused by the integration of the new offshore wind generation.

This methodology ensures that the offshore wind energy integration is performed systematically and accurately, supporting the objectives of this EU-funded project by facilitating a more resilient and decarbonized power system.

Results

This section presents a detailed overview of the number of components comprising each country's network. Additionally, a comprehensive visualization of the constructed grid is provided to illustrate its structure.

Albania (AL)

Table 2: Albania Network Data

Components	***No. of Components***
Buses	*21*
Generators	*21*
Lines	*23*
Loads	*8*
Transformers	*4*

Updated Total Load (MW)	*1500*

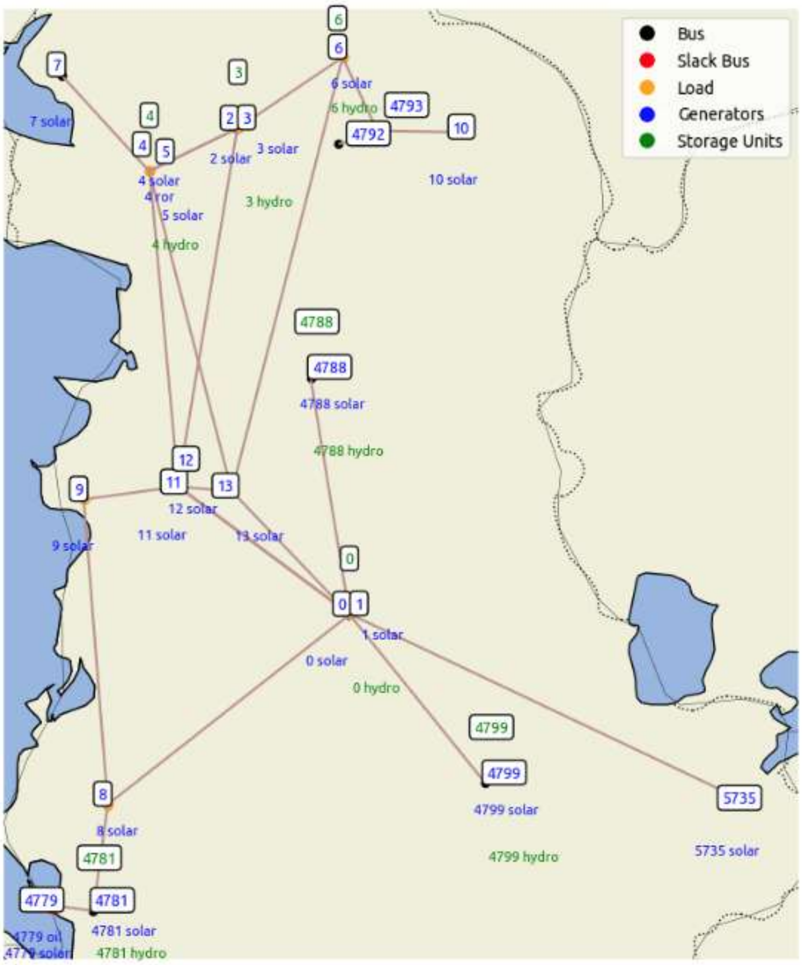

Figure 1: Albanian Network Topology

Croatia (HR)

Table 3: Croatia Network Data

Components	***No. of Components***
Buses	*28*
Generators	*28*
Lines	*29*
Loads	*16*
Transformers	*3*

Updated Total Load (MW)	*3000*

Figure 2: Croatian Network Topology

Greece (GR)

Table 4: Greece Network Data

Components	***No. of Components***
Buses	*34*
Generators	*34*
Lines	*45*
Loads	*18*
Transformers	*0*

Updated Total Load (MW)	*10000*

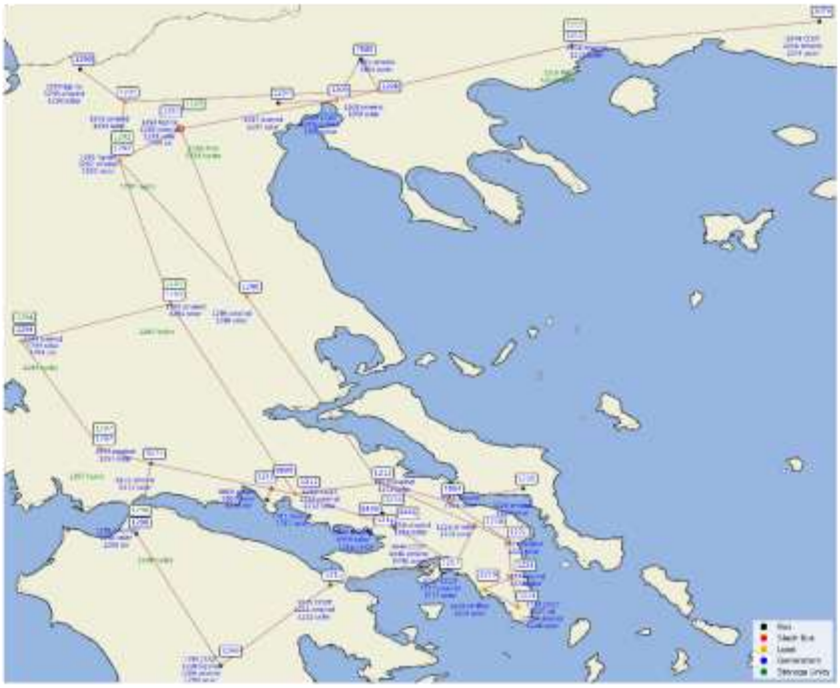

Figure 3: Greek Network Topology

Italy (IT)

Table 5: Italy Network Data

Components	***No. of Components***
Buses	*431*
Generators	*431*
Lines	*561*
Loads	*293*
Transformers	*72*

Updated Total Load (MW)	*50000*

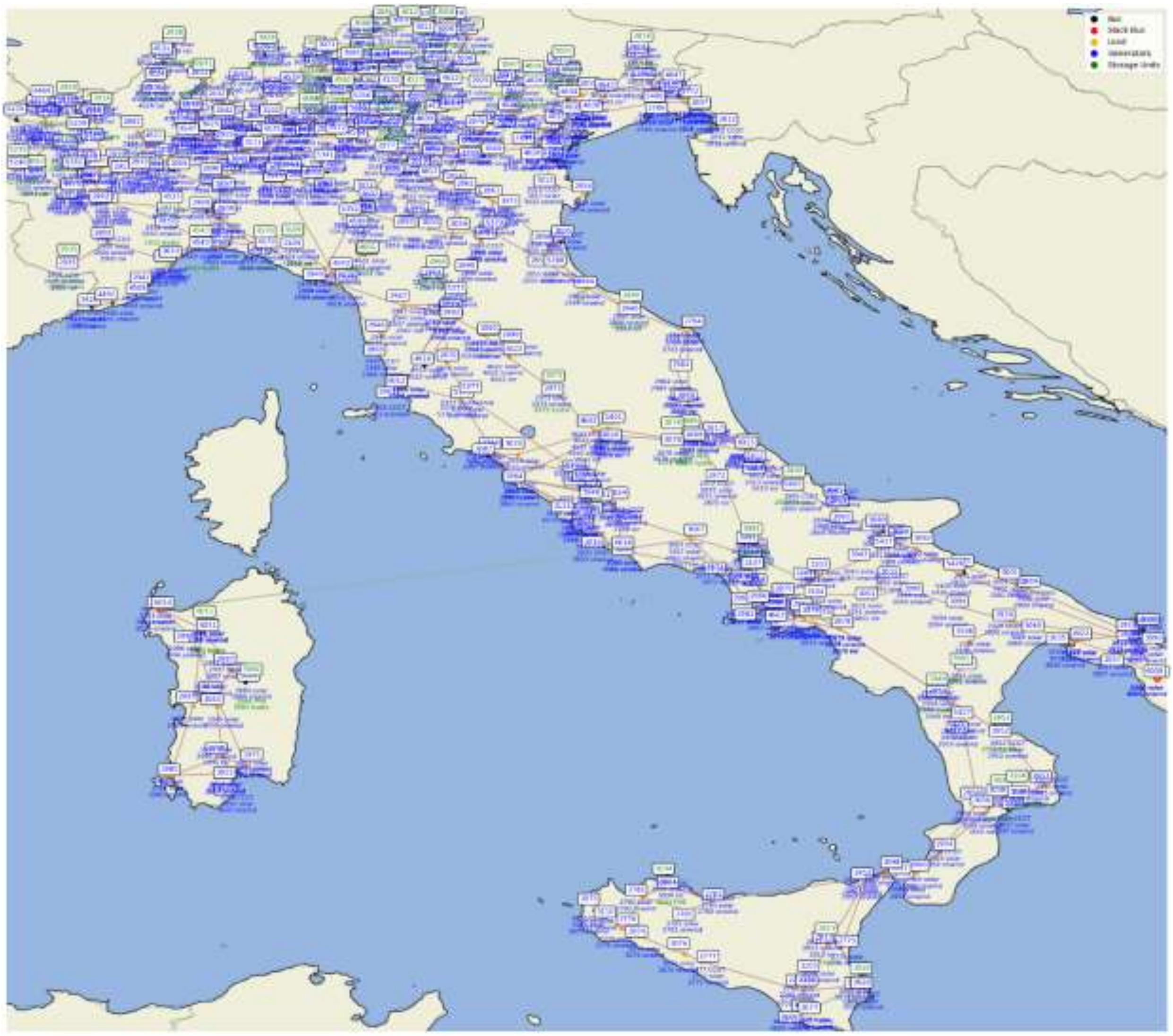

Figure 4: Italian Network Topology

Montenegro (ME)

Table 6: Montenegro Network Data

Components	***No. of Components***
Buses	*13*
Generators	*13*
Lines	*13*
Loads	*3*
Transformers	*2*

Updated Total Load (MW)	*750*

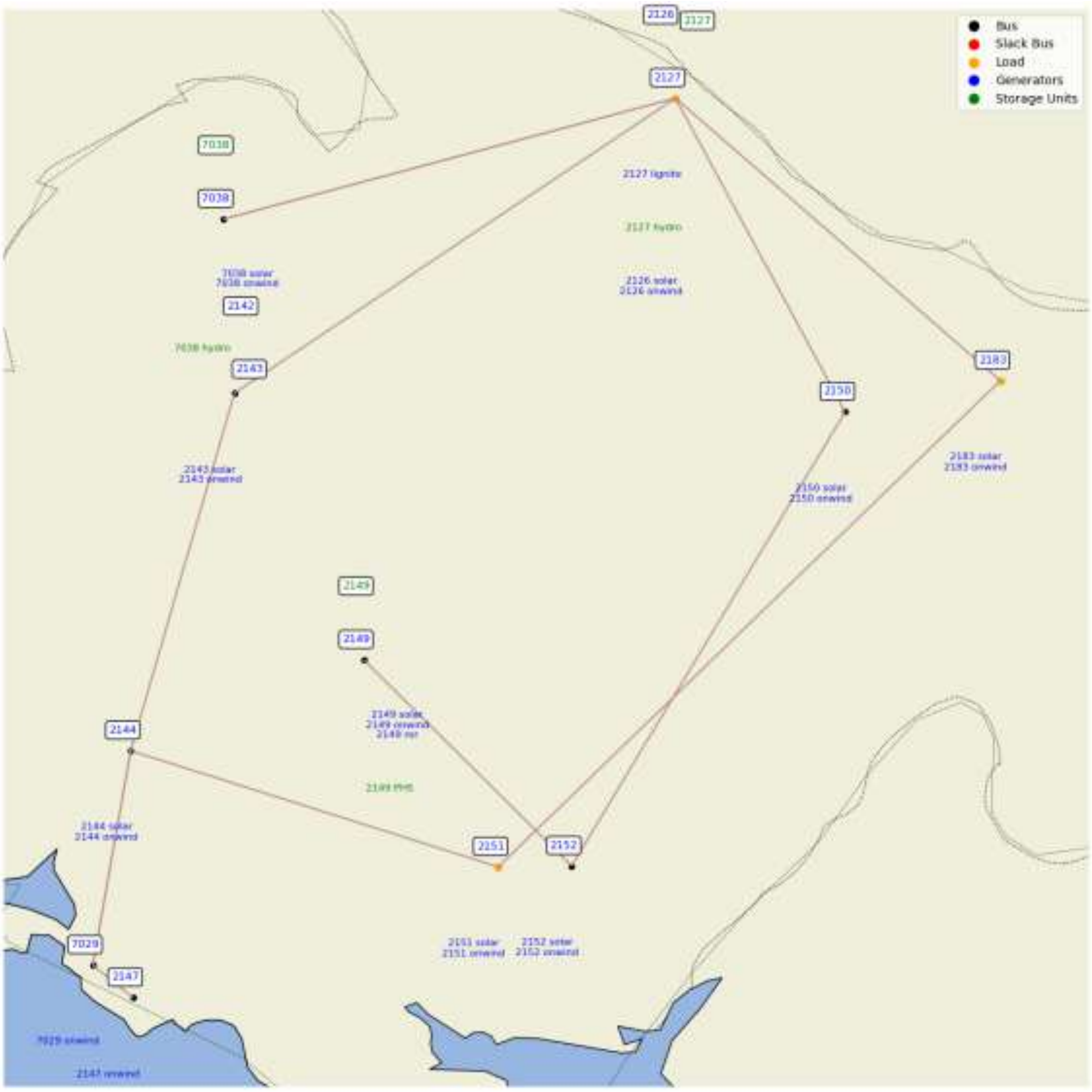

Figure 5: Montenegrin Network Topology

Portugal (PT)

Table 7: Portugal Network Data

Components	***No. of Components***
Buses	*106*
Aggregated Generators	*106*
Lines	*165*
Loads	*59*
Transformers	*20*

Updated Total Load (MW)	*9500*

Figure 6: Portuguese Network Topology

Tables and figures

List of sources

Hirth, L., Mühlenpfordt, J., & Bulkeley, M. (2018). The ENTSO-E Transparency Platform – A review of Europe's most ambitious electricity data platform. *Applied Energy*, *225*, 1054-1067. https://ideas.repec.org/a/eee/appene/v225y2018icp1054-1067.html

List of tables

List of figures

SPOWIND

Interreg
Euro-MED

Co-funded by
the European Union

Politecnico
di Torino

SAPIENZA
UNIVERSITÀ DI ROMA

University
of Cyprus

EIHP

ΕΠΙΣΕΥ
ICCS

edp

ENVPRO

AK3N