Ref. Ares(2025)11423451 - 19/12/2025

TWINVEST

Digital Twin for Forecasting of Power Production to Wind Energy Demand

Project title	Universal, open-source and cybersecure Digital Twin to provide investors in onshore wind farms valuable insights about current operations and future investments		
Project acronym	TWINVEST		
Project number	101146936		
Project start date	1 July 2024	Duration	42 months

D3. 2 – INTERACTIVE WIND ENERGY MAP OF EUROPE FOR INVESTORS

Due date	31/12/2025	Delivery date	19/12/2025
Work package	WP3		
Responsible Author(s)	RINA-C, CERTH		
Contributor(s)	Federico Cerchi (RINA-C) Alessandra Imperadore (RINA-C) Eleonora Desogus (RINA-C) Salvatore Ferraro (RINA-C) Georgios Ntanis (CERTH) Aggelos Aggelakakis (CERTH)		
Reviewer(s)	Matina Karakitsiou (PPC) Zeynep Korkmaz(ZOREN) Ural Halaçoğlu (ZOREN) Nilgün Şide Kurtcu(ZOREN) Feyza Pakelgil(ZOREN)		
Version	V4		
Dissemination level	Public		

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VERSION AND AMENDMENTS HISTORY

Version	Date (MM/DD/YYYY)	Created/Amended by	Changes
V1	31/10/2025	RINA-C, CERTH	Draft
V2	1/12/2025	RINA-C, PPC	Internal review
V3	17/12/2025	ZORLU	External review
V4	19/12/2025	RINA-C	Ready for submission

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LIST OF ABBREVIATIONS

RES	Renewable Energy Sources
VHV	Very High Voltage
ENTSO-E	European Network of Transmission System Operators for Electricity
TSO	Transmission System Operator
THD	Total Harmonic Distortion
EIA	Environmental Impact Assessment
DSO	Distribution System Operator
DT	Digital Twin
RBAC	Role-Based Access Control
TLS/SSL	Encryption protocols
IM	Interactive Map
p.u.	per-unit (system normalised electrical quantity)
RAA(s)	Renewable Energy Acceleration Areas
SEA	Strategic Environmental Assessment
kV	kilovolt

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1. INTRODUCTION

The transformation of the European energy landscape, driven by the accelerated integration of renewable energy sources (RES), has fundamentally reshaped the dynamics of electricity generation, transmission, and distribution. While the transition toward cleaner and more sustainable energy systems is vital for achieving the European Union's climate goals, it also presents significant challenges, particularly in terms of regulatory coherence and technical interoperability across member states. Grid integration of RES projects remains fragmented, with countries applying diverse technical standards and approval procedures for grid connection. This heterogeneity prevents cross-border investments, delays project timelines, and complicates the planning of transnational energy infrastructure.

The lack of harmonized grid connection codes and assessment frameworks creates uncertainty for developers, especially in the case of technologies like wind energy, which often face different technical expectations depending on the national context. In response, ENTSO-E aims to promote greater alignment of technical requirements through the development of pan-European grid codes and standardized connection criteria. These efforts are essential for creating a more integrated and resilient electricity system that can accommodate fluctuating renewable generation while maintaining system stability and operational security.

Task 3.2 of this project addresses these challenges by providing a comprehensive assessment of current grid capability and requirements for project connection across the EU. The task begins with a literature review that maps the current regulatory landscape and extracts the key technical parameters that govern grid connection, particularly for new RES installations, such as wind farms where the information is available. Special emphasis is placed on cataloging those aspects most critical for project developers to consider when designing grid-compliant infrastructure.

Building upon this foundation, Task 3.2.1 will deliver an interactive European map that visualizes the technical and regulatory requirements for grid connection across member states. This tool will support both investors and policymakers by highlighting differences and identifying areas where harmonization efforts are most urgently needed. It will also reflect ongoing ENTSO-E initiatives and propose pathways for aligning national practices with emerging European standards, ultimately contributing to a more coherent, efficient, and investment-friendly regulatory environment for the energy transition.

2. WIND FARM REQUIREMENTS

In this chapter, all the information gathered throughout the course of the task on connection requirements, land use, and the current status and development plans of the grids in the various areas of interest is presented.

2.1. Grid connection requirements

Grid connection requirements, as previously introduced in the report, are one of the central focus of this study. The objective is to compile a clear and accessible dataset that covers key technical parameters across EU member states. The analysis focuses specifically on requirements at the Very

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High Voltage (VHV) level, as this is the typical connection point for large-scale installations, such as wind farms.

By limiting the scope to VHV-level grid codes, we ensure consistency while reducing the complexity of the data collection process. It should be noted, however, that requirements may differ at lower voltage levels. For developers or stakeholders interested in Medium or High Voltage connections, consultation of the respective national grid codes is recommended. To support this, all referenced grid codes are listed in the work, offering direct access to source materials for further inquiry.

2.2. Land use

The interactive map also integrates publicly available data on land use restrictions related to wind energy development. This includes national and regional guidelines that specify where wind farms can or cannot be built, based on zoning laws, environmental constraints, protected areas, and other planning considerations. This layer of information is essential for understanding the regulatory and spatial feasibility of deploying new renewable energy projects in specific areas.

As part of the search for information regarding the applicable regulatory framework for the siting of onshore wind farms in each E.U. member state, relevant literature, articles in scientific journals, and responses from the competent Ministries and related bodies of the member states were utilized. These responses were obtained through direct communication with the authorities or institutions, where this was feasible. The relevant information concerning each E.U. member state is summarized below.

2.3. Grid capability

A further key component of this study concerns grid capabilities, which presented one of the most significant challenges in this research. Beyond mapping regulatory and technical connection requirements, this section seeks to provide practical insight into whether the grid in a specific area can accommodate new generation capacity.

Using publicly available data from Transmission System Operators (TSOs) and existing national grid maps, we compiled all accessible information regarding the current state of the electrical network in each country. This includes indications of available capacity, existing constraints, and relevant grid development plans where available. By combining this layer with the regulatory and land-use data, users can form a more complete picture of the technical feasibility of new energy projects across Europe.

In this chapter the main information available, per each member of EU, that may be useful to compute the grid capabilities of the specific country are outlined. Where available, the grid map and the grid development plan are shown, otherwise the most relevant documentation is given. The scope of this study is to provide a complete overview of the current status of the European grid and give details on its evolution. Looking at the ten-year development plan can give an idea to developers to where the next project should be aimed to match with the TSOs plan and have an increased change to have a successful project.

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2.4. Areas of interest

All European countries and countries relevant within the project are included in the analysis, with a focus on grid connection and land use requirements. Additionally, for countries where data is available, information on grid capability is also provided.

2.4.1. Austria

Grid requirements: The following information were summarized for the purpose of readability; more detailed information can be found in the provided references.

- TSO: Austrian Power Grid (APG)
- Fault-ride through: Must remain connected during dips down to 0.15 p.u. for 150 ms
- Voltage limits: +- 10%
- Frequency limits: +- 2 Hz
- Capability curves:

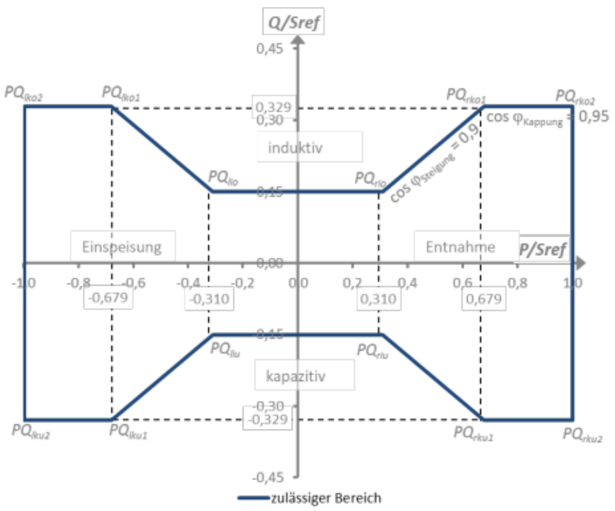

Figure 1. Capability curve required by AGP

- Reference:
    1. *APG, "Balancing",* Balancing - Austrian Power Grid*, Accessed on: June, 2025*

Land use: The federal states (Länder) are designated as the responsible authorities for the siting of onshore wind farms. The policy concerning wind energy utilization is integrated into regional energy and spatial planning, through which priority zones for wind energy development are delineated.

Regarding the minimum distances of wind farms from residential areas, these range between 800 m and 1,500 m. Characteristic examples of statutory minimum distances from residential areas in

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specific provinces are provided here: Burgenland: 1,200 m, Carinthia: 1,500 m, Lower Austria: 1,200 m, Upper Austria: 1,000 m, and Styria: 1,000 m.

Exclusion zones for the installation of onshore wind farms comprise protected landscapes, Natura 2000 sites, national parks, and areas featuring sensitive biodiversity. Priority for the installation of onshore wind farms is given to areas outside ecologically protected regions that exhibit low population density and sufficient wind potential (e.g., the Weinviertel, Waldviertel, and Wiener Becken regions).

- References:

1. Felber, G., & Stoeglehner, G. (2014). *Onshore wind energy use in spatial planning—a proposal for resolving conflicts with a dynamic safety distance approach. Energy, Sustainability and Society, 4, 1-8. (https://link.springer.com/article/10.1186/s13705-014-0022-8)*
2. Government of Lower Austria (2024). (https://www.noe.gv.at)
3. Legal Information System of the Republic of Austria (RIS). (https://www.ris.bka.gv.at/UI/Erv/Info.aspx)
4. State of Upper Austria (2025). (https://www.land-oberoesterreich.gv.at/)5. State of Styria (2025). (https://www.verwaltung.steiermark.at/cms/ziel/74835125/EN)

Grid capability: Renewables' share in total feed-in 93.5 percent. The overall volatility in Austria's electricity system is primarily due to fluctuations in the production of renewable energy. To make the volatile, renewable electricity usable and transport it to where it is needed, a strong electricity grid is necessary. Redispatch measures are used to prevent overloads in the electricity grid and ensure a secure power supply. This refers to the targeted and controlled use of power plants. In practical terms, this means that when there is a risk of line overloads in the electricity grid, targeted interventions in Austria's power plant fleet and those of neighbouring countries, as well as in flexible consumers, must be carried out to counteract the issue in a controlled manner.

Below the maps of the current Austrian grid and the one based on the ten years development plan are presented (Figure 2, Figure 3). Generally, the TSO provides a lot of information and interactive interfaces related to the status of the grid.

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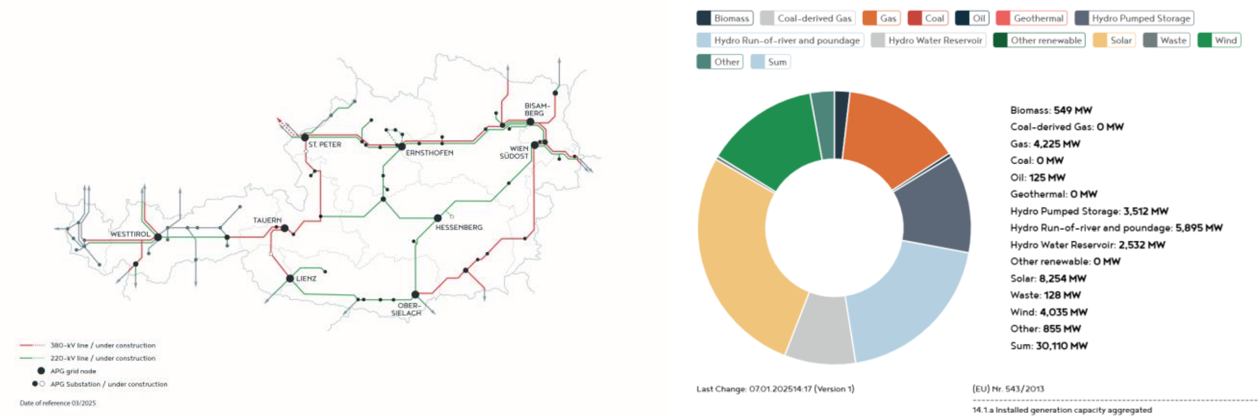

Figure 2. Austrian grid map (on the left) and current installed capacity (on the right)

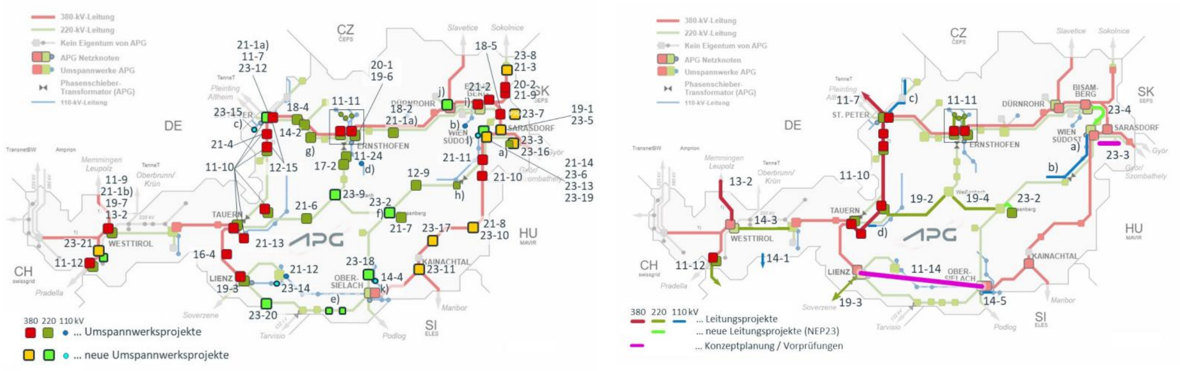

Figure 1: NEP projects 2023: Substations and switchgear

Figure 2: NEP projects 2023: Transmission line projects and major transmission line projects

Figure 3. Austrian grid map based on the ten years development plan

- <u>References</u>:

1. *APG, "Network development plan 2023", September 2023, [Network Development Plan 2023 - Austria needs electricity](#).*
2. *APG, "Power grid Austria", https://www.apg.at/en/power-grid/power-grid-austria/, Accessed on: July, 2025.*
3. *APG, "Redispatch", https://www.apg.at/en/infographics/ , Accessed on July, 2025.*

2.4.2. Belgium

Grid requirements: The following information were summarized for the purpose of readability; more detailed information can be found in the provided references.

- <u>TSO:</u> Elia
- <u>Fault-ride through:</u> Must remain connected during dips down to 0 p.u. for 200 ms
- <u>Voltage limits:</u> -10%, +15%
- <u>Frequency limits:</u> - 2.5 Hz, + 2 Hz

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- Capability curves:

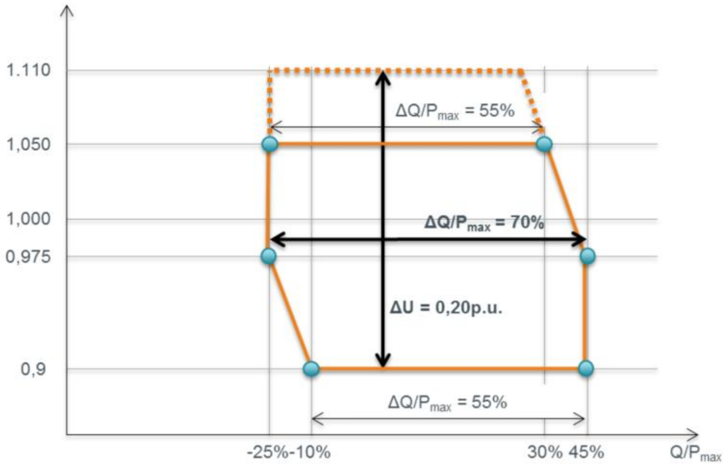

Figure 17: Capability curve for SPGM type C and D.

Figure 4. Capability curve required by Elia

- Reference:
  1. *Elia, "RFG REQUIREMENTS OF GENERAL APPLICATION", 22 Augst 2019.*
  2. *Elia, "PROPOSAL FOR NC DCC REQUIREMENTS OF GENERAL APPLICATION", 17 May 2018.*

Land use: Spatial planning concerning the installation of onshore wind farms is regulated at the regional level. The various development plans that are drafted, which include the utilization of wind energy through the installation of wind farms, must comply with existing urban planning schemes and current land use legislation, as well as the environmental impact assessments required for every such project. The respective municipal and regional authorities participate in decisions primarily concerning the siting of wind farms.

There is no nationally uniform, defined minimum distance for the siting of wind farms and, as such, it is typically determined by regional criteria related to noise generation and shadow flicker, resulting in distances on the order of 300 to 600 m. The installation of onshore wind farms is prohibited within protected areas, including Natura 2000 sites, forests, military zones, and areas within a 2.5 km radius of airports. Belgium has established noise standards (43 dB(A) at night, 45 dB(A) during the day) and shadow flicker limits, while an Environmental Impact Assessment (EIA) is mandatory for wind farms exceeding specified capacity thresholds. Areas with low environmental sensitivity, low population density, and direct access to infrastructure, such as roads and electricity grids, are proposed as suitable locations for the siting of onshore wind farms.

- References:

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2. Dobrowolski, Z., Adamišin, P., Babczuk, A., & Kotylak, S. (2025). Towards a Green Transformation: Legal Barriers to Onshore Wind Farm Construction. Energies, 18(5), 1271. (https://www.mdpi.com/1996-1073/18/5/1271)
3. European Commission (2024). (https://energy.ec.europa.eu/index_en?prefLang=el)
4. Wallon, G. (2013). Cadre de référence pour l'implantation d'éoliennes en Région Wallonne. Approuvé par le Gouvernement wallon le, 21. (http://www.plainedevie.net/wp-content/uploads/2013/02/CADRE_DE_ReFeRENCE_POUR_L_IMPLANTATION-_D_eOLIENNES_EN_ReGION_WALLONNE.pdf)

Grid capability: Only some snippets of the real-time exchanges of the energy observed at the borders were found and they are presented in Figure 5. The physical flows on the Belgian grid indicate how heavily each line is loaded in relation to the maximum possible loading of the line. Looking at the grid infrastructure, there seems to be no criticalities on the internal interconnection lines, and some on the cross-border ones, depending on the hour and on the day.

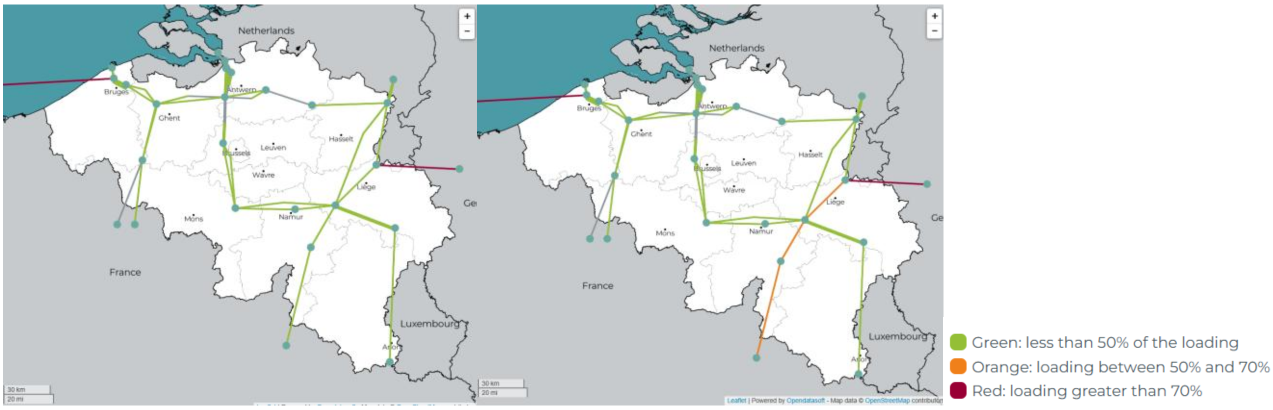

Figure 5. Real-time energy exchange in the Belgian grid: Ref. 02/09/2025 on the left Ref. 17/08/2025 01:00 am on the right

In terms of grid reinforcement,

Figure 6 and Figure 7show the hosting capacity reservation and allocation targeting the year 2034.

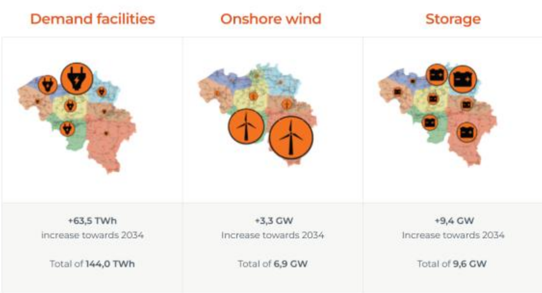

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Figure 6. Hosting capacity reservation and allocation by region by 2034

NATIONAL TOTAL				
	Currently existing volume (normalised)	Additional volume taken into account (up to 2034)	Total volume taken into account (up to 2034)	Reference context for target year 2034 (see FAQ)
Demand Facilities	80,7 TWh**	47,6 TWh + 13,8 TWh (pre-reserved for HP & EV) + 2,1 TWh (pre-reserved for MV & HV demand)	144,0 TWh	126,4 TWh**
Onshore Wind	3,6 GW	2,5 GW + 0,8 GW (pre-reserved)	6,9 GW	6,9 GW
Offshore Wind	2,3 GW	3,5 GW	5,8 GW	5,8 GW
Solar	11,3 GW	1,1 GW + 5,6 GW (pre-reserved)	18,0 GW	18,0 GW
Large-Scale Batteries	0,2 GW	9,4 GW	9,6 GW	3,3 GW

(*) For other types of production units (e.g. gas-fired power plants), the reserved/allocated capacity was also considered. The exact values are not shown for confidentiality reasons.
(**) Not including TSO losses.

Figure 7. Hosting capacity reservation and allocation for the overall country by 2034

- References:
  1. *Elia, "Physical flows on the Belgian high-voltage grid", https://www.elia.be/en/grid-data/transmission/physical-flows-on-the-belgian-grid, Accessed on July, 2025.*
  2. *Elia, "Intraday capacity", https://www.elia.be/en/grid-data/transmission/intraday-capacity, Accessed on July, 2025.*
  3. *Elia, "Grid Hosting Capacity", Grid Hosting Capacity, Accessed on September, 2025.*

2.4.3. Bulgaria

Grid requirements: The following information were summarized for the purpose of readability; more detailed information can be found in the provided references.

- TSO: Electricity System Operator (ESO)
- Fault-ride through: N/A
- Voltage limits: +- 5%
- Frequency limits: - 3.5 Hz, + 2 Hz
- Capability curves:

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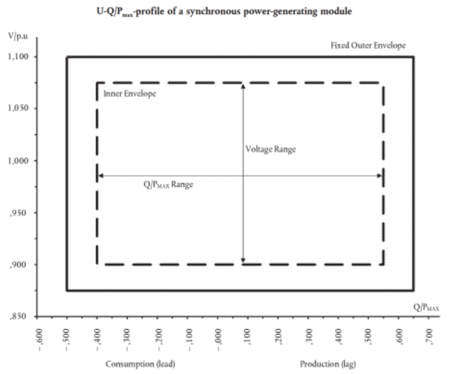

Synchronous area	Maximum range of Q/P_{max}	Maximum range of steady-state voltage level in PU
Continental Europe	0,75	0,225
Nordic	0,95	0,150
Great Britain	0 (*) 0,33 (**)	0,225
Ireland and Northern Ireland	0,66	0,218
Baltic	0,8	0,22

Figure 8. Capability curve required in Continental Europe

- Reference:

1. *ESO, "Bulgarian Grid Code", https://www.eso.bg/fileObj.php?oid=625, Accessed on June, 2025.*
2. *COMMISSION REGULATION (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators, [COMMISSION REGULATION (EU) 2016/ 631 - of 14 April 2016 - establishing a network code on requirements for grid connection of generators](#).*

Land use: The siting of onshore wind farms lies within the responsibilities of the respective government at the national level and is regulated by the relevant laws concerning spatial planning, energy, renewable energy sources, and environmental protection, as well as by municipal and regional spatial plans. Strategies and Environmental Impact Assessments are considered mandatory for such projects.

There is no statutory minimum distance for the siting of onshore wind farms from residential areas; instead, criteria for noise, shadow flicker, and safety are typically applied, resulting in average proposed distances that range between 500 and 700 m.

Exclusion zones for the installation of onshore wind farms include Natura 2000 sites, national parks, military security zones, aviation safety zones, protected cultural heritage sites, coastal wetlands, and areas located on bird migration corridors. Regions in Northeastern Bulgaria that exhibit high wind performance are proposed as suitable areas for the siting of onshore wind farms, such as: Dobrich, Shumen, Varna, Razgrad, Silistra, and Kaliakra.

References

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1. *Byanova, N. (2024, June). From fossil fuels to renewable energy: Tracking Bulgaria's transition. In ENVIRONMENT. TECHNOLOGIES. RESOURCES. Proceedings of the International Scientific and Practical Conference (Vol. 1, pp. 90-94) (https://journals.rta.lv/index.php/ETR/article/view/7958)*
2. *Iliev, T., Fazylova, A., & Stoycheva, B. (2024). Comparative assessment of anticipated wind power capacities in Bulgaria and Kazakhstan. In E3S Web of Conferences (Vol. 551, p. 02008). EDP Sciences. (https://www.e3s-conferences.org/articles/e3sconf/abs/2024/81/e3sconf_eepes2024_02008/e3sconf_eepes2024_02008.html)*
3. *Resch, G., Liebmann, L., Hirner, R., Mezosi, A., Szabo, L., & Varga, K. (2023). Study on the wind power potential in Bulgaria, Hungary and Romania. Technical Report*

Grid capability: Only real-time data of the grid was found (Figure 9). From ESO imbalance grid data, it is possible to look at the historical information on the interconnected system in which it seems that there is a lot of imbalance.

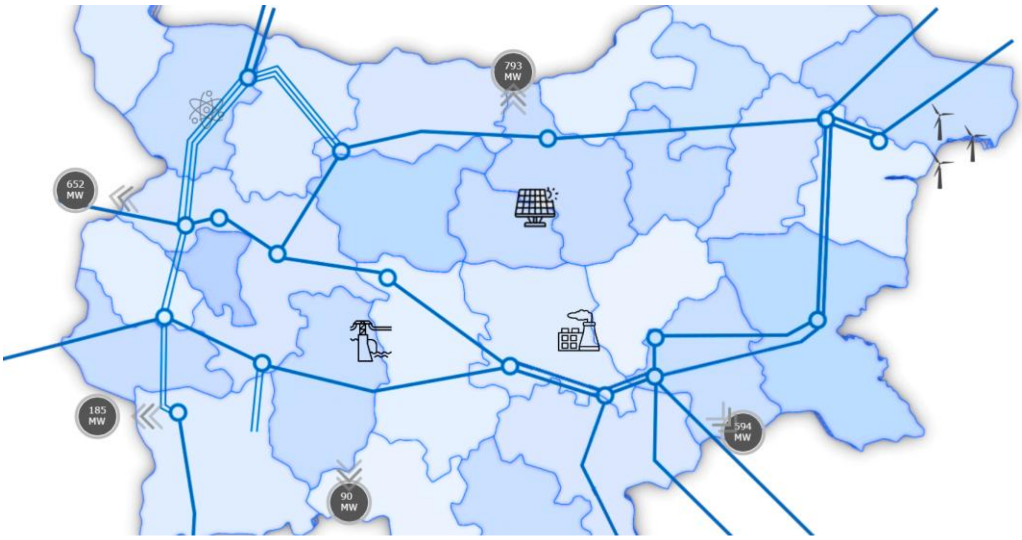

Figure 9. Real-time data of the Bulgarian grid from ESO

Few information was found directly shared from the national TSO, nonetheless by 2030 it is expected a high expansion of the interconnection capacity from 4 GW to 10 GW, prioritizing renewable energy sources.

- References:

    1. *ESO, https://www.eso.bg/#dashboard , Accessed on July, 2025.*
    2. *ESO, "Estimated balancing energy prices", https://www.eso.bg/imb/?imbalance-prices&date=01.09.2025, Accessed on July, 2025.*

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3. *Strategic Energy Europe, "Bulgaria to double interconnection to 10 GW by 2030 to boost renewables", June 2025,* [*Bulgaria to double interconnection to 10 GW by 2030 to boost renewables - Strategic Energy Europe*]().

2.4.4. Croatia

Grid requirements: The following information were summarized for the purpose of readability; more detailed information can be found in the provided references.

- TSO: HROTE
- Fault-ride through: Must remain connected during dips down to 0 p.u. for 200 ms
- Voltage limits: +- 15%
- Frequency limits: - 2.5 Hz, + 2 Hz
- Capability curves:

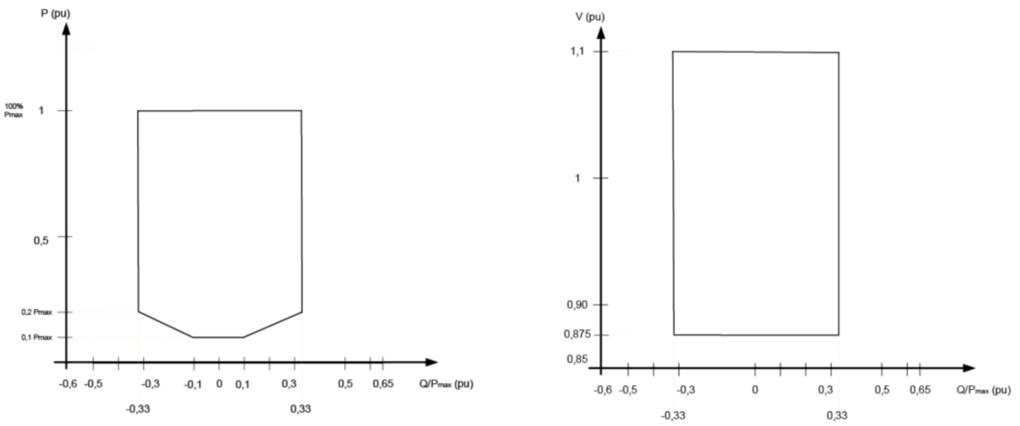

Figure 8. Characteristic P-Q/Pmax for Type D Power Park Module

Figure 9. U-Q/Pmax Characteristic for Type D Power Park Modules

Figure 10. Capability curve required by HROTE

- Reference:
  1. *Narodne Novine,* [*https://narodne-novine.nn.hr/clanci/sluzbeni/2020_11_128_2453.html*](https://narodne-novine.nn.hr/clanci/sluzbeni/2020_11_128_2453.html) *, Accessed on: June, 2025.*

Land use: The siting of onshore wind farms falls under the purview of the respective government and must comply with the national legislation regarding spatial and environmental planning, as well as with regional and municipal spatial plans. A significant portion of the Adriatic coastline and the islands within Croatian territory are under the Natura 2000 protection regime, which, consequently, significantly restricts the land available for the placement of onshore wind farms.

There is no legislated minimum distance between wind farms and residential areas. Instead, distances are examined on a case-by-case basis, using noise and safety models. Areas where the installation of

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onshore wind farms is prohibited include Natura 2000 sites, national parks, military security zones, and aviation safety zones, as well as protected cultural heritage sites. Furthermore, a general exclusion rule of 1 km inland from the coastline is enforced.

A mandatory prerequisite for the approval of both the siting and operation of an onshore wind farm is the preparation of an Environmental Impact Assessment (EIA). The licensing for onshore wind farms can have a duration of up to 10 years. Suitable areas for the placement of terrestrial wind farms are proposed in the southern coastal zones, particularly around Rijeka and Split.

References

1. *Rnjak, D., Janeš, M., Křižan, J., & Antonić, O. (2023). Reducing bat mortality at wind farms using site-specific mitigation measures: A case study in the Mediterranean region, Croatia. Mammalia, 87(3), 259-270. (https://www.degruyterbrill.com/document/doi/10.1515/mammalia-2022-0100/html)*
2. *Holjevac, N., Baškarad, T., Đaković, J., Krpan, M., Zidar, M., & Kuzle, I. (2021). Challenges of high renewable energy sources integration in power systems—the case of Croatia. Energies, 14(4), 1047. (https://www.mdpi.com/1996-1073/14/4/1047),*
3. *Godjevac, I. (2009). Assessment of the regulatory framework for wind power in Croatia (Doctoral dissertation). (https://repositum.tuwien.at/handle/20.500.12708/11711),*
4. *Lučin, I., Čarija, Z., Kandukuri, S. T., & Schlanbusch, R. (2024, November). Transnational experience exchange between countries towards speeding up EU renewable transition: example of Norway-Croatia. In Journal of Physics: Conference Series (Vol. 2875, No. 1, p. 012049). IOP Publishing. (https://iopscience.iop.org/article/10.1088/1742-6596/2875/1/012049/meta)*

Grid capability: Together with the Slovenian power system and the power system of Bosnia and Herzegovina it constitutes the control block SLO – HR – BIH within the ENTSO-E association. For security reasons, quality of supply and exchange of electricity, the Croatian power system is interconnected with the systems of neighbouring countries and together with them it is connected into the synchronous network of continental Europe. By its size, the Croatian power system is one of the smallest power systems in Europe. Due to its geographical position and location of generating plants, electricity is transported for most of the year from the south to the north and vice versa, and from the north toward the east. By putting into operation, the newly constructed 400/220/110 kV Žerjavinec substation and the reconstructed 400/110 kV Ernestinovo substation, transmission capacity, security and reliability of the power system have significantly increased, especially in its northwestern and eastern parts. By reconnecting the UCTE synchronous zones 1 and 2, the Croatian power system has become a transit system again.

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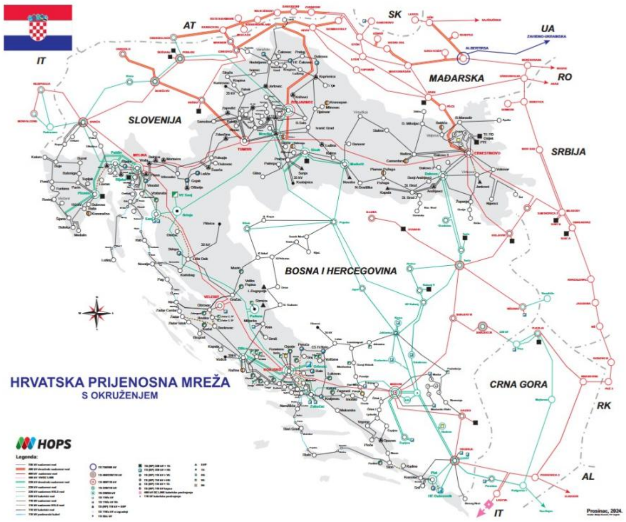

Figure 11. Current map of SLO-HR-BIH

Real-time data are available on the TSO website, though no information was found regarding a planned development for the grid.

- References:
    1. *HOPS, "System scheme", https://www.hops.hr/en/system-scheme , Accessed on July,2025.*
    2. *HOPS, "Network use/Transmission", https://www.hops.hr/en/network-use-transmission , Accessed on July, 2025.*
    3. *HOPS, "Croatian Power System", https://www.hops.hr/en/croatian-power-system, Accessed on July, 2025.*

2.4.5. Cyprus

Grid requirements: The following information were summarized for the purpose of readability; more detailed information can be found in the provided references.

- TSO: Transmission System Operator Cyprus (TSOC)
- Fault-ride through: Must remain connected during dips down to 0.05/0.15 p.u. for 150/200 ms
- Voltage limits: +- 10%
- Frequency limits: - 3 Hz, + 2 Hz
- Capability curves:

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Voltage range	Step Voltage Connection	Limits at Continuous Maximum loading
60 kV to 72 kV	66 kV	Power coefficient from 0.93 capacitive to 0.80 inductive
51 kV to 60 kV		Power coefficient from 1.00 to 0.80 inductive
120 kV to 145 kV	132 kV	Power coefficient from 0.93 capacitive to 0.80 inductive
114 kV to 120 kV		Power coefficient from 1.00 to 0.80 inductive
200 kV to 245 kV	220 kV	Power coefficient from 0.93 capacitive to 0.80 inductive
190 kV to 200 kV		Power coefficient from 1.00 to 0.80 inductive

Figure 12. Capability curve required by TSOC (translated)

- Reference:
    1. *TSOC, "Transmission rules", KM Έκδοση 1.1.0.pdf , Accessed on: June, 2025.*

Land use: The installation of onshore wind farms in Cyprus is determined by the Urban and Regional Planning Law, as well as the legislated licensing framework for Renewable Energy Sources (RES). Each onshore wind farm must conform to existing development plans and must be subject, depending on the case, to either a Strategic Environmental Assessment (SEA) or an Environmental Impact Assessment (EIA).

Spatial restrictions mandate specific distances that onshore wind farms must maintain from particular areas (land uses): 1,000–1,500 m from wetlands and Natura 2000 sites, 500–1,500 m from migratory bird corridors, 500–2,000 m from state forests, as well as up to 100 m from radio broadcast corridors and 600 m from legally existing telecommunication antennae corridors. The installation of two wind farms with a combined total of more than 15 wind turbines is not permitted at a distance of less than 2 km between them. For parks with fewer turbines, the Urban Planning Authority may approve a minimum distance of up to 1.5 km. The distances between wind turbines may be differentiated based on the characteristics of the area (wind potential, topography, etc.), to ensure aesthetic harmony and visual balance in the landscape.

The minimum distance of a wind farm from a residential area is set at up to 850 m from the boundaries of an approved Development Zone and, additionally, up to 350 m from a legally existing, individual dwelling located outside the boundaries of a Development Zone. Areas prohibited for the installation of onshore wind farms include: Natura 2000 sites, national parks, military security zones and aviation safety zones, areas of archaeological, hydrological, and geological protection, migratory bird corridors, and areas with high-voltage lines. Suitable areas are considered to be the mountainous and semi-mountainous uninhabited regions with high wind potential, outside of residential development zones,

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primarily in the areas of western Nicosia, southern Larnaca, and the mountainous regions of Limassol and Paphos.

<u>References</u>

1. *Department of Town Planning and Housing (2024). Licensing framework for renewable energy sources in Republic of Cyprus: Regulatory guidelines and procedures (Report No. ΕΝΤΟΛΗ 1/2024)*

Grid capability: In Cyprus under normal operating conditions, the electrical network (overhead lines and underground cables) operates at a high voltage of 132 kV, with some individual sections operating at a voltage of 66 kV. The 66 kV overhead lines are gradually being replaced by 132 kV lines with the aim of their complete withdrawal.

Real-time information on the transmission system is available online and it is possible to see the grid's congestions, which has led to the need of improving the infrastructure. The following image shows the grid in Cyprus state as of 2021 (Figure 13) and based on the ten years development plan (Figure 14). Generally, the TSO provides many information and interactive interfaces related to the status of the grid.

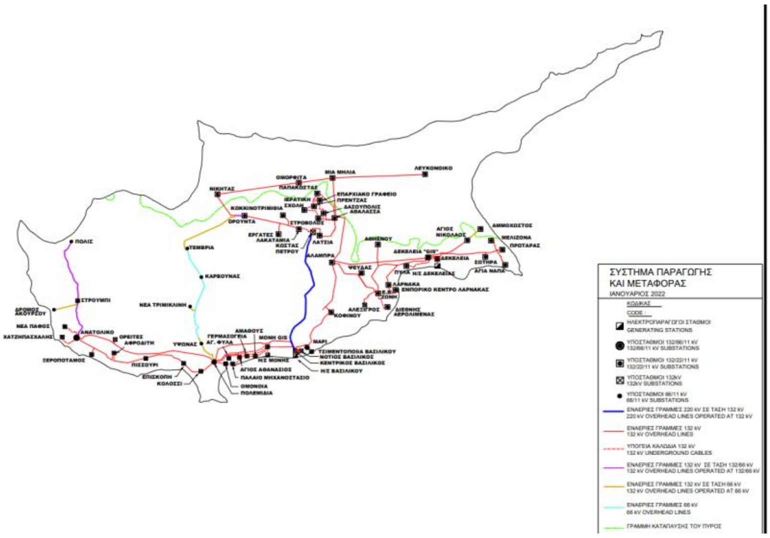

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Figure 13. Cypriot grid map as of 2021

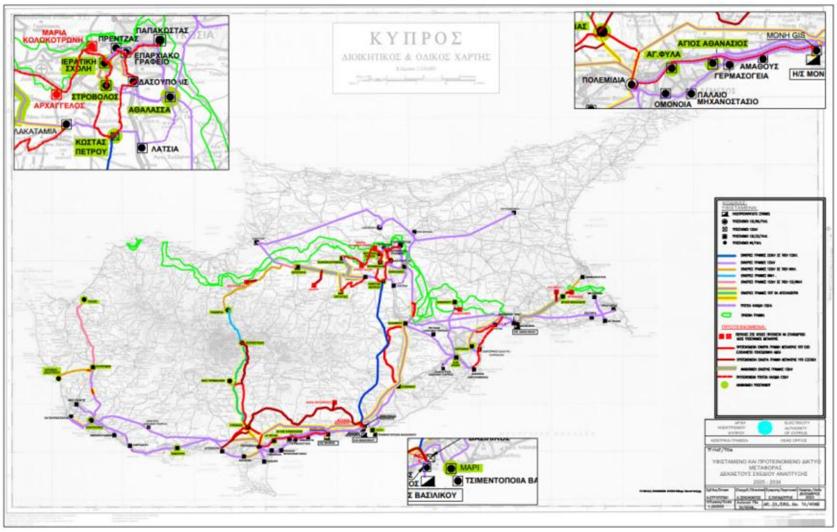

Figure 14. Cypriot grid map based on the ten years development plan

- References:
    1. *Arcgis, https://www.arcgis.com/apps/dashboards/134fdd8988d44ade8dd33b5c1c26ca65, Accessed on July, 2025.*
    2. *TSOC, "Geographical Representation of Production and Transportation Systems", https://tsoc.org.cy/electrical-system/cyprus-transmission-system/geographical-overview-of-generation-and-transmission-systems/, Accessed on July, 2025.*
    3. *TSOC, "Ten years development plan 2025-2034", August 2025.*

2.4.6. Czech Republic

Grid requirements: The TSO is Czech Transmission System Operator (CEPS) but no information was found regarding the connection requirements for wind farms and therefore the European regulation can be considered.

- Reference:
    1. COMMISSION REGULATION (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators, COMMISSION REGULATION (EU) 2016/ 631 - of 14 April 2016 - establishing a network code on requirements for grid connection of generators.

Land use: The siting of onshore wind farms is subject to the provisions of national legislation regarding spatial and environmental planning, as well as to existing municipal and regional spatial planning schemes. There is no uniform national minimum distance between onshore wind farms and inhabited

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areas. These distances are determined through the Environmental Impact Assessment (EIA) process, as well as through acoustic and visual evaluations.

Prohibited areas for the installation of onshore wind farms include Natura 2000 areas, regions with steep slopes (greater than 20°), areas surrounding airports, regions with high forest cover, high-altitude areas, densely populated urban zones, cultural landscapes, and tourist recreation routes. Visual impact is the primary reason for the cancellation of onshore wind farm construction projects (in approximately 85% of cases), and such projects often face delays of up to 10 years due to procedural and social barriers.

Areas deemed suitable for the installation of wind farms are those with strong wind potential, low land-use density, visually degraded or of low aesthetic value, and free from environmental or technical constraints. Approximately 15% of the total land area of the Czech Republic is considered suitable for the development of wind energy projects.

References

2. *Betakova, V., Vojar, J., & Sklenicka, P. (2015). Wind turbines location: How many and how far?. Applied Energy, 151, 23-31. (https://www.sciencedirect.com/science/article/pii/S030626191500522X)*
3. *Sklenicka, P., & Zouhar, J. (2018). Predicting the visual impact of onshore wind farms via landscape indices: A method for objectivizing planning and decision processes. Applied Energy, 209, 445-454. (https://www.sciencedirect.com/science/article/pii/S0306261917315854)*
4. *McKenna, R. V., Hollnaicher, S., vd Leye, P. O., & Fichtner, W. (2015). Cost-potentials for large onshore wind turbines in Europe. Energy, 83, 217-229. (https://www.sciencedirect.com/science/article/pii/S0360544215001681)*
5. *Frantál, B., Frolova, M., & Liñán-Chacón, J. (2023). Conceptualizing the patterns of land use conflicts in wind energy development: Towards a typology and implications for practice. Energy Research & Social Science, 95, 102907. (https://www.sciencedirect.com/science/article/pii/S2214629622004108)*
6. *Frantál, B., & Nováková, E. (2019). On the spatial differentiation of energy transitions: Exploring determinants of uneven wind energy developments in the Czech Republic. Moravian Geographical Reports, 27(2), 79-91. (https://www.proquest.com/docview/2545282782?pq-origsite=gscholar&fromopenview=true&sourcetype=Scholarly%20Journals)*
7. *Tverijonaite, E., & Sæþórsdóttir, A. D. (2023). Tourism and onshore wind turbines: Literature review. (https://www.ramma.is/media/ra5/Wind_tourism_lit_review_2023_final.pdf) 7. Frantál, B., & Kunc, J. (2011). Wind turbines in tourism landscapes: Czech experience. Annals of tourism research, 38(2), 499-519. (https://www.sciencedirect.com/science/article/pii/S0160738310001271)*

Grid capability: The Czech 400kV and 220kV electricity transmission network, often termed the "backbone network", is required for the distribution of the output of large Czech power plants

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throughout the whole of the Czech Republic and, at the same time, forms an important part of the international European network. The Czech transmission network is interconnected, via cross-border lines, with the transmission networks of neighbouring countries thus enabling its synchronous operation with the interconnected power systems of the rest of Continental Europe.

Figure 15 and Figure 16 show the current grid in Czech Republic and the one based on the ten years development plan.

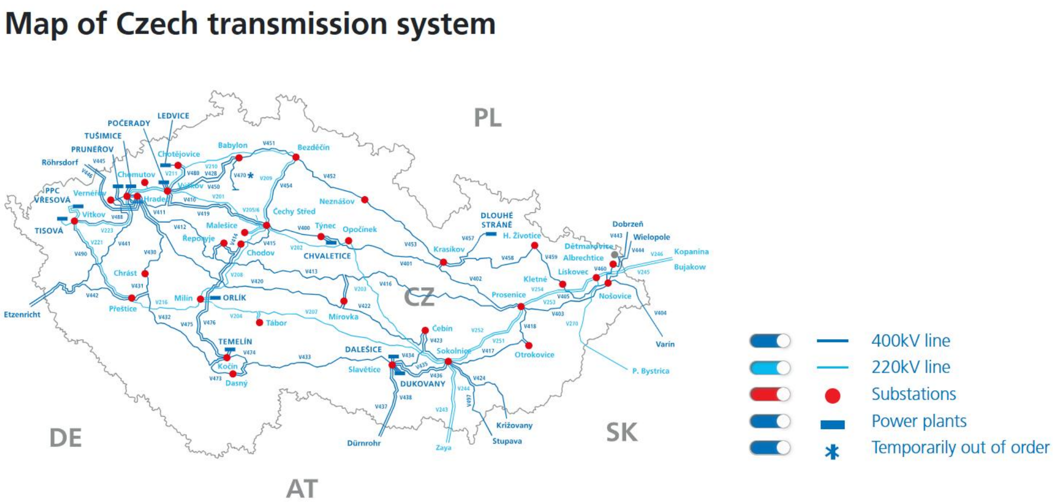

Figure 15. Map of the Czech transmission system from CEPS

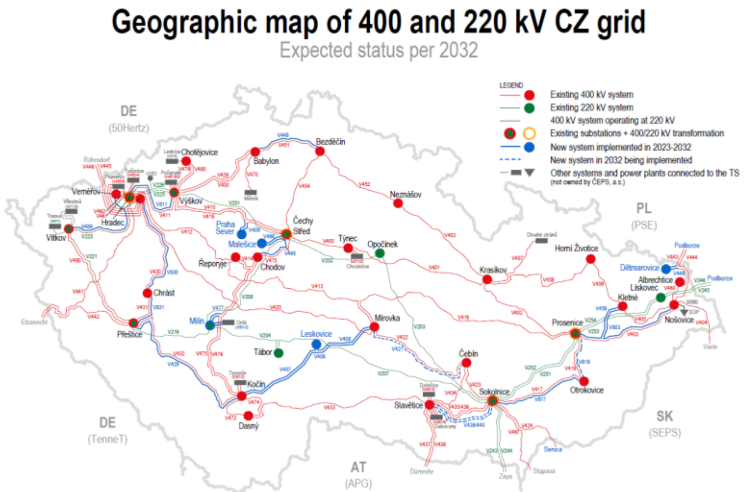

Figure 16. Grid in Czech Republic based on the ten years development plan

Within the ten years development plan six different business scenario targeting the year 2040 were studied, outputting both a forecast of energy mix and energy consumption.

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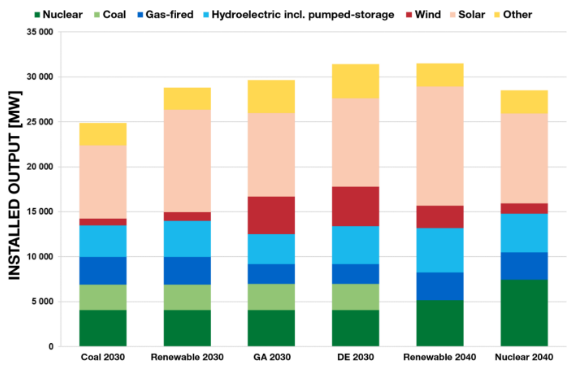

Figure 5.13: Comparison of installed capacities of generating facilities in the Czech Republic (Source: ČEPS)

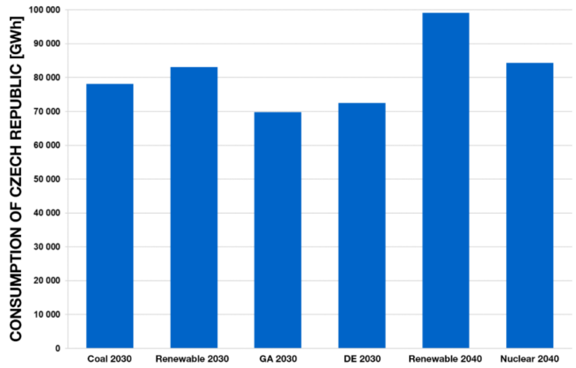

Figure 5.14: Comparison of Czech consumption (Source: ČEPS)

Figure 17. Ten years development plan output scenario targeting 2040 in Czech Republic

- <u>References:</u>

    1. *CEPS, "Transmission System", https://www.ceps.cz/en/transmission-system, Accessed on July, 2025.*
    2. *CEPS, "Transmission system development", https://www.ceps.cz/en/transmission-system-development, Accessed on July, 2025.*

2.4.7. Denmark

Grid requirements: The following information were summarized for the purpose of readability; more detailed information can be found in the provided references.

- <u>TSO:</u> Energinet
- <u>Fault-ride through</u>**:** Must remain connected during dips down to 0.15 p.u. for 250 ms
- <u>Voltage limits:</u> +- 10%
- <u>Frequency limits:</u> N/A
- <u>Capability curves:</u>

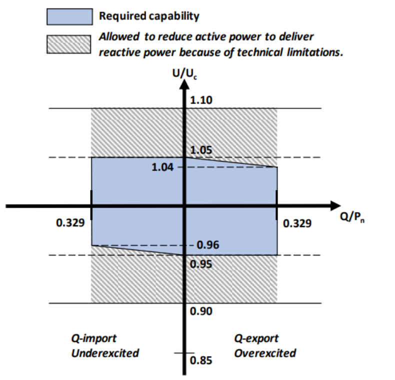

Figure 4.7 – Requirements for supply of reactive power at maximum active power generation.

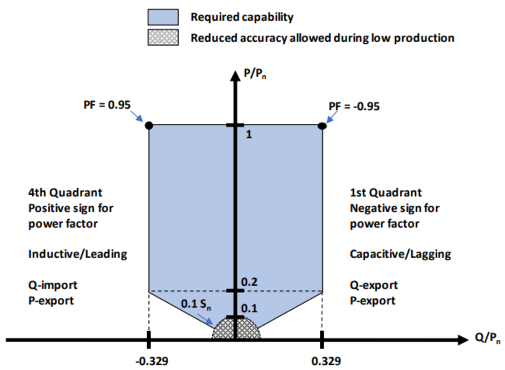

Figure 4.8 – Requirements for supply of reactive power at different active power levels.

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Figure 18. Capability curve required by Energinet

- Reference:
    1. *Energinet, appendix-1-grid-connection-terms-april-2024.pdf, Accessed on: June, 2025*

Land use: Spatial planning for onshore wind farms is the responsibility of municipalities, in accordance with the Danish Planning Act, guided by the National Guidelines for the siting and permitting of wind turbines. The minimum distance from a wind turbine to a residence is set at least four times the total height of the turbine (e.g., 600 m for a 150 m high turbine). In certain cases, greater distances may be imposed due to visual disturbance or local planning considerations.

Exclusion zones for the installation of onshore wind farms include Natura 2000 sites, nature reserves and protected landscapes, cultural monuments and heritage sites, coastal zones, airport and radar safety zones, protection zones for main roads and railway lines, groundwater areas, as well as areas integrated into forestry or mining management plans.

All wind turbines within a wind farm must possess certificates covering safety, structural integrity, and noise emission measurements. Maintenance of the wind turbines must be conducted annually by certified companies, according to strict protocols. Following the expiration of the design lifespan, extensive maintenance checks are required. Suitable areas for the siting of wind farms are considered to be rural areas at distances exceeding 600 m from settlements, with low environmental sensitivity and sufficient wind potential, as well as proximity to electricity transmission networks and road infrastructure.

References

1. *Bessin, A., Serra-Adroer, J., Debonne, N., & van Vliet, J. (2025). Location determinants of industrial solar photovoltaics and onshore wind turbines in the EU. Renewable and Sustainable Energy Reviews, 210, 115257. (https://www.sciencedirect.com/science/article/pii/S1364032124009833)*
2. *Tapoglou, E., Tattini, J., Schmitz, A., Georgakaki, A., Długosz, M., Letout, S., Kuokkanen, A., Mountraki, A., Ince, E., Shtjefni, D., Joanny Ordonez, G., Eulaerts, O.D. and Grabowska, M., Clean Energy Technology Observatory: Wind energy in the European Union- 2023 Status Report on Technology Development, Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/618644, JRC135020. (https://publications.jrc.ec.europa.eu/repository/handle/JRC135020)*
3. *Danish Housing and Planning Authority. (2022). Guidance on planning and permitting for onshore wind turbines (VEJ nr. 9317, 26 January 2022). Copenhagen. (https://www.plst.dk/Media/637909682911065239/vejledning_om_planlaegning_for_og_tilladelse_til_opstilling_af_vindmoeller_jan2022.pdf)*
4. *Danish Environmental Protection Agency. (2022). Environmental report (SEA) for the amendment of the Wind Turbine Noise Order—Change to low-frequency noise calculation for*

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offshore wind . Copenhagen. (https://www.retsinformation.dk/eli/retsinfo/2022/9317), 5. Danish Energy Agency. (2023). Order on technical certification and servicing of wind turbines (Executive Order No. 648 of 30 May 2023). Unofficial English translation. Copenhagen. (https://www.cas.ens.dk/Media/638701195217542698/unofficial-translation-based-on-executive-order-no-648-of-30-may-2023.pdf)

Grid capability: Within the energy mix in Denmark wind power accounts for a substantial part, as shown in Figure 19 which presents the energy mix of the last 30 days.

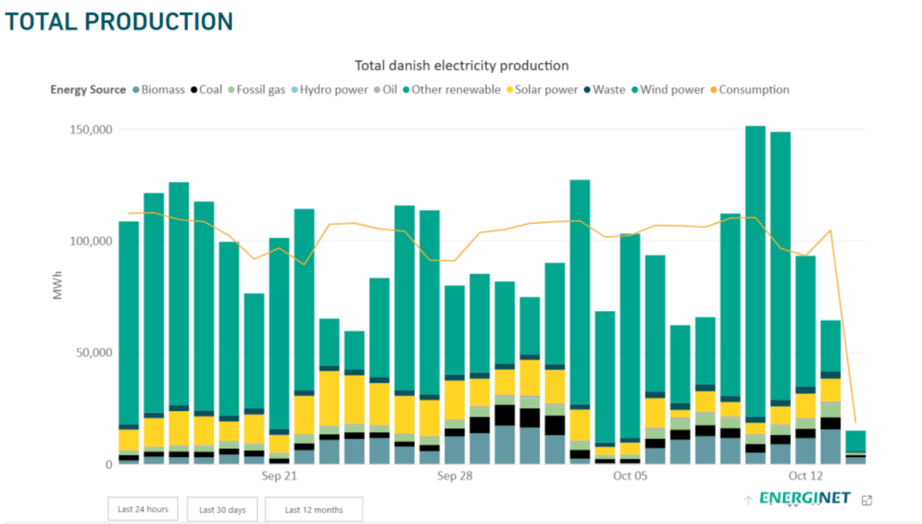

Figure 19. Total production in Denamrk in the last 30 days

Generally, the TSO provides a lot of information and interactive interfaces related to the status of the grid. Based on the share data, Figure 20 show the current status of the grid, while Figure 21 and Figure 22 show respectively the foreseen increase of overload on the grid by 2040 and the consequent investment needed.

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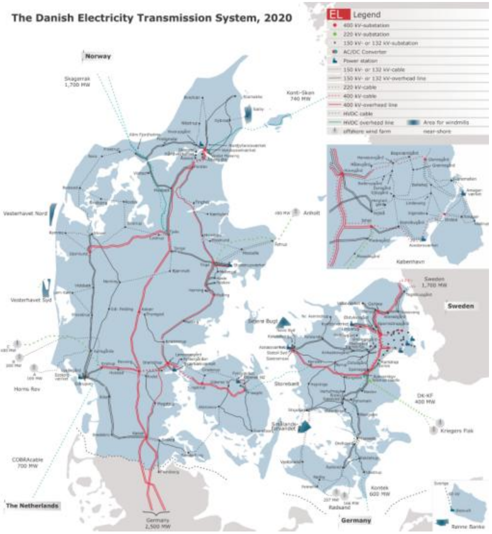

Figure 20. Map of the Danish transmission system from Energinet as of 2020

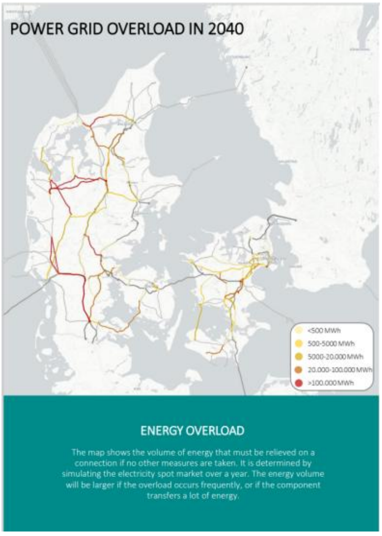

Figure 21. Power grid overload in 2040 in Denmark if no grid reinforcement is applied

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Figure 22. Reinvestment needs by 2040 in Denmark

- References:

    1. *Energinet, "Transmission System data", https://en.energinet.dk/energy-data/system-data/ , Accessed on July, 2025.*
    2. *Energinet, "Energi Data Service", https://www.energidataservice.dk/, Accessed on July, 2025.*
    3. *Energinet, "LONG-TERM DEVELOPMENT NEEDS IN THE POWER GRID", 2022, lup22_behovsanalyse_el_engelsk.pdf.*

2.4.8. Estonia

Grid requirements: The following information were summarized for the purpose of readability; more detailed information can be found in the provided references. No information was found sourced in TSOs documentation, so the following requirements were taken based on the references indicated.

- TSO: Elerig
- Fault-ride through: Must remain connected during dips down to 0.25 p.u. for 250 ms
- Voltage limits: +- 15%
- Frequency limits: - 2.5 Hz, + 1.5 Hz
- Capability curves:

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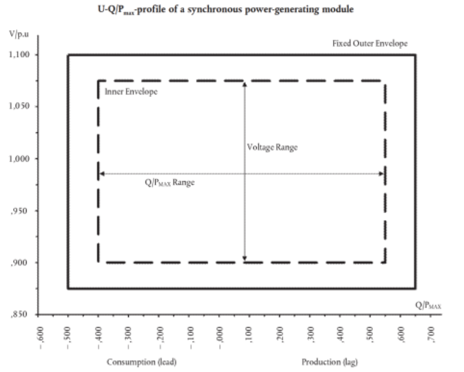

Synchronous area	Maximum range of Q/P$_{max}$	Maximum range of steady-state voltage level in PU
Continental Europe	0,75	0,225
Nordic	0,95	0,150
Great Britain	0 (*) 0,33 (**)	0,225
Ireland and Northern Ireland	0,66	0,218
Baltic	0,8	0,22

Figure 23. Capability curve required in Baltic

- Reference:
    1. *ENTSOE, https://www.entsoe.eu/active-library/codes/cnc/country/ee/, Accessed on: June, 2025.*
    2. *COMMISSION REGULATION (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators, COMMISSION REGULATION (EU) 2016/ 631 - of 14 April 2016 - establishing a network code on requirements for grid connection of generators.*

Land use: Estonia possesses a hierarchical spatial planning system, however, the essential political and legal authority for land use primarily belongs to the municipalities. Onshore wind projects must comply with national spatial planning tools and schemes, as well as municipal spatial plans.

There is no uniform national minimum distance for onshore wind farms from residential areas. However, a noise limit of 45 dB during the night has been applied. In western Estonia, distances on the order of 1,000 meters are commonly applied, which may be increased up to 2,000 meters in certain cases, depending on local conditions and noise levels. Exemptions from wind farm installation include Natura 2000 sites, bird migration corridors, as well as the habitats of protected species, such as the Siberian flying squirrel and sensitive bat populations. Areas deemed suitable for the siting of onshore wind farms are unprotected rural and degraded areas with limited environmental interest.

Reference

1. *Wingenbach, M., Dünzen, K., Krieger, S., & Gibson, J. (2024). Overview of Renewable Energy Spatial Planning and Designation of Acceleration Areas in Selected EU Member States (https://caneurope.org/content/uploads/2024/05/RE-Spatial-Planning-Acceleration-in-EU-MS_13052024.pdf)*

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Grid capability: The national electricity transmission system consists of 5,198 km of electricity overhead lines, 284 km cable lines and 158 substations. The backbone of the transmission system is made up of powerful 330 kV overhead lines designed to transmit large amounts of electricity, but the system is mostly made up of 110 kV overhead lines that ensure electricity reaches the regions. The domestic electricity network is connected to cross-border alternating current connections with Latvia and direct current connections with Finland.

Figure 24 shows the current Estonian grid, as of the beginning of 2025 695 MW of wind farms and 1,210 MW of solar farms had been connected to the transmission system. Generally, the TSO provides a lot of information and interactive interfaces related to the status of the grid, including the grid system based on the ten years development plan shown in Figure 25.

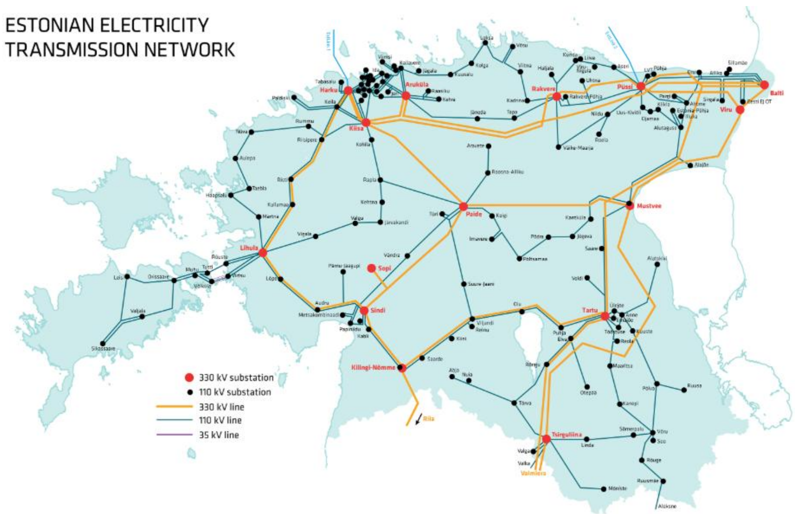

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Figure 24. Map of the Estonian current transmission system from Enerig

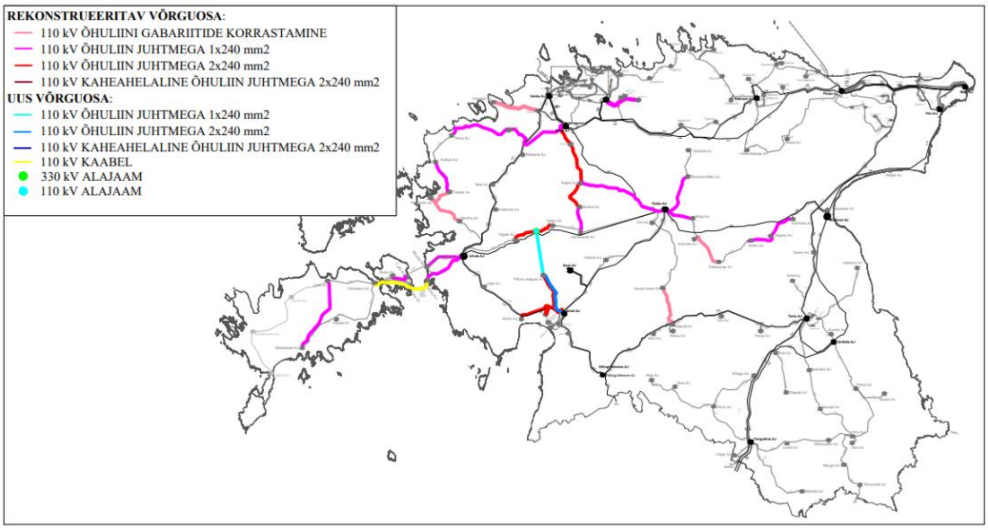

Figure 25. Map of the Estonian grid based on the ten years development plan

- References:

    1. *Elerig, "Electricity transmission system", https://elering.ee/en/electricity-transmission-system, Accessed on July, 2025.*
    2. *Entso-e Transparency Platform, "Forecasted Transfer Capacities – Year Ahead".*
    3. *Elerig, "Development plan of the electricity transmission system", https://elering.ee/en/development-plan-electricity-transmission-system , Accessed on July, 2025.*

2.4.9. Finland

Grid requirements: The following information were summarized for the purpose of readability; more detailed information can be found in the provided references.

- TSO: Fingrid
- Fault-ride through: Must remain connected during dips down to 0 p.u. for 200 ms
- Voltage limits: - 10%, + 5%
- Frequency limits: - 2.5 Hz, + 1.5 Hz
- Capability curves:

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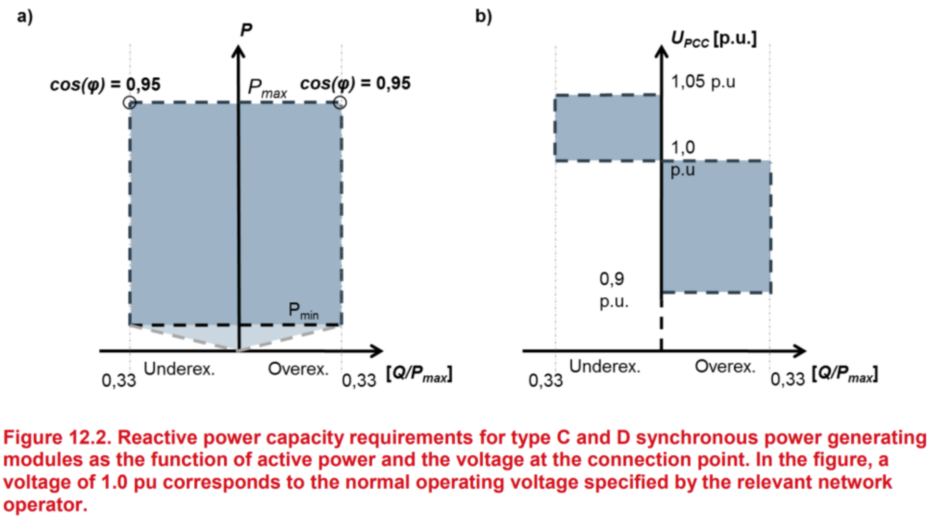

Figure 26. Capability curve required by Fingrid

- Reference:
  1. *FINGRID, "Grid Code Specifications for Power Generating Facilities VHV2018", grid-code-specifications-for-power-generating-facilities-vjv2018-.pdf, Accessed on: June, 2025*

Land use: The siting of onshore wind farms in Finland is regulated by the Land Use and Building Act and is implemented through regional and municipal spatial planning schemes. Municipalities are responsible for determining the areas for wind farm development through detailed planning, while national restrictions regarding nature protection, aviation, defense, radar systems, and cultural heritage must be adhered to. Specific spatial planning restrictions have been established regarding the definition of distances between onshore wind farms and certain types of areas, such as the Natura 2000 network, bird habitats (≥ 500 m), military areas of interest (≥ 500 m), religious sites (≥ 350 m), airports (≥ 10,000 m), meteorological radar stations (≥ 5,000 m), and road networks (≥ 400 m).

Regarding the distance of a wind farm from inhabited areas (settlements), it is temporarily set at 800 m until an official regulation is established. Suitable areas for the installation of wind farms are those that are not protected, have sufficient wind potential, are in close proximity to the electrical grid, and have a low density of settlements. The highest wind potential is found in the region of Ostrobothnia, extending northward to Lapland, while southern Finland presents significant restrictions when mandatory distances of ≥ 1,500 meters are applied.

References

1. *Finnish Consulting Group. (2024). Assessment of the economic impacts of minimum distance rules between wind power and settlements (Raportti; P52842). Helsinki.*

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(https://api.hankeikkuna.fi/asiakirjat/1da1364f-7d29-41ff-89df-2d81853befbf/f16b9176-c60f-44a3-97e2-d65cd977a0a8/KIRJE_20241216082602.PDF)

2. *Ministry of the Environment (Finland). (2015). Government Decree on guide values for the outdoor noise level of wind turbines (1107/2015). (https://www.finlex.fi/api/media/statute-foreign-language-translation/687886/mainPdf/main.pdf?timestamp=2015-08-26T21%3A00%3A00.000Z)*

Grid capability: Fingrid is preparing for a significant increase in electricity production and consumption. By 2030, electricity production and consumption could be 50 percent higher than today, and by 2035, even double compared to current levels. In addition to the electrification of society, the export of power-intensive industrial products from Finland is a significant driver of electricity consumption growth. Thus, Finland's competitiveness as an investment destination for power-intensive industries is crucial. At the moment, investments in electric district heating and data centers are progressing rapidly.

Figure 27 and Figure 28 show the current status of the Finnish transmission systema and the one based on the ten-years development plan.

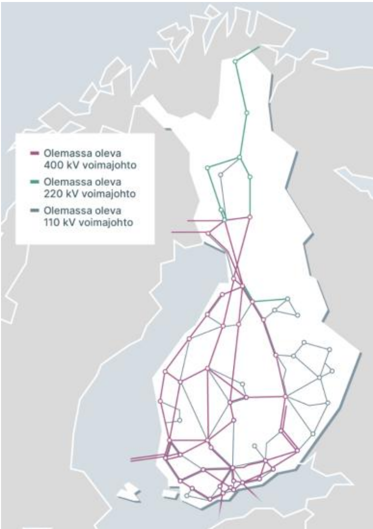

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Figure 27. Map of the Finnish current transmission system from Fingrid

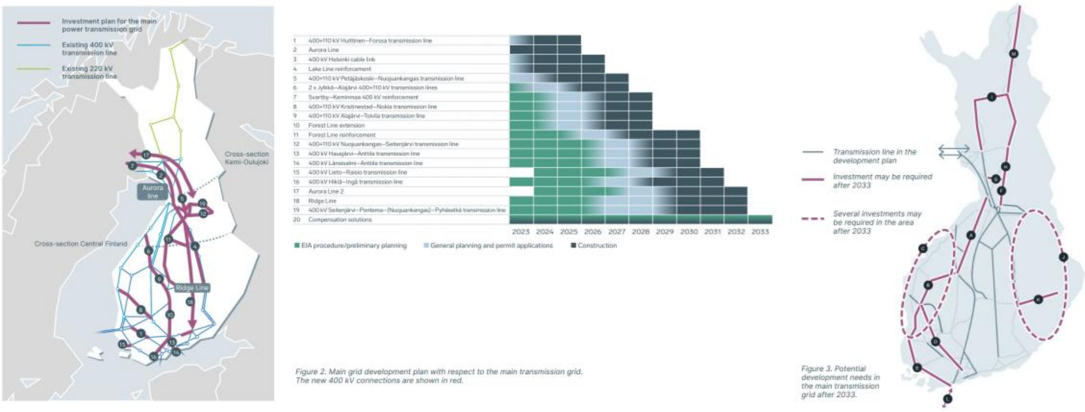

Figure 28. Map of the Finnish transmission system based on the ten-years development plan

- References:

  1. *Fingrid, "Prospects for future electricity production and consumption Q3 2025", https://www.fingrid.fi/en/grid/development/prospects-for-future-electricity-production-and-consumption-q3-2024/ , Accessed on July, 2025.*
  2. *Fingrid, "Fingrid's electricity transmission network", https://www.fingrid.fi/en/grid/development/power-transmission-grid-of-fingrid/, Accessed on July, 2025.*
  3. *Fingrid, "Main grid development plan 2024-2033", https://www.fingrid.fi/globalassets/dokumentit/fi/kantaverkko/kantaverkon-kehittaminen/fingrid_kehittamissuunnitelma_syksy23_en.pdf.*

2.4.10. France

Grid requirements: The TSO is Réseau de Transport d'électricité (RTE) but no information was found regarding the connection requirements for wind farms and therefore the European regulation can be considered.

- Reference:

  1. *COMMISSION REGULATION (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators, COMMISSION REGULATION (EU) 2016/ 631 - of 14 April 2016 - establishing a network code on requirements for grid connection of generators.*

Land use: The approval for the siting of onshore wind farms must comply with national urban planning and environmental legislation, as well as municipal spatial plans. The siting of an onshore wind farm requires the consent of the respective municipal council. There is no legislated national minimum distance for wind farms from settlements. Distances are determined on a case-by-case basis during

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the licensing process, based on noise, safety, and visual impact assessments. An indicative average distance from residential areas is over 500 meters. Exclusion zones for the installation of onshore wind farms include Natura 2000 sites, national and natural parks, aviation safety zones and radar corridors, protected cultural heritage sites, and safety zones around critical infrastructure. The regulatory framework concerning wind farms is quite complex, and the development of such projects can take from 6 to 10 years. Suitable areas for siting onshore wind farms are suggested to be non-protected areas with low visual sensitivity, sufficient wind potential, proximity to the electricity grid, and favorable municipal planning that supports the development of RES projects.

References

1. *Feurtey, É., Ilinca, A., Sakout, A., & Saucier, C. (2016). Institutional factors influencing strategic decision-making in energy policy; a case study of wind energy in France and Quebec (Canada). Renewable and Sustainable Energy Reviews, 59, 1455-1470. (https://www.sciencedirect.com/science/article/pii/S136403211600112X)*
2. *Enevoldsen, P., & Sovacool, B. K. (2016). Examining the social acceptance of wind energy: Practical guidelines for onshore wind project development in France. Renewable and Sustainable Energy Reviews, 53, 178-184. (https://www.sciencedirect.com/science/article/pii/S1364032115009028)*
3. *González, J. S., & Lacal-Arántegui, R. (2016). A review of regulatory framework for wind energy in European Union countries: Current state and expected developments. Renewable and Sustainable Energy Reviews, 56, 588-602. (https://www.sciencedirect.com/science/article/pii/S1364032115013581)*

Grid capability: Few information was found regarding the French transmission system capability. The following map (Figure 29) was made available by the French TSO showing the allocated power for region. This helps understand which area may face more interest of investment in the upcoming future.

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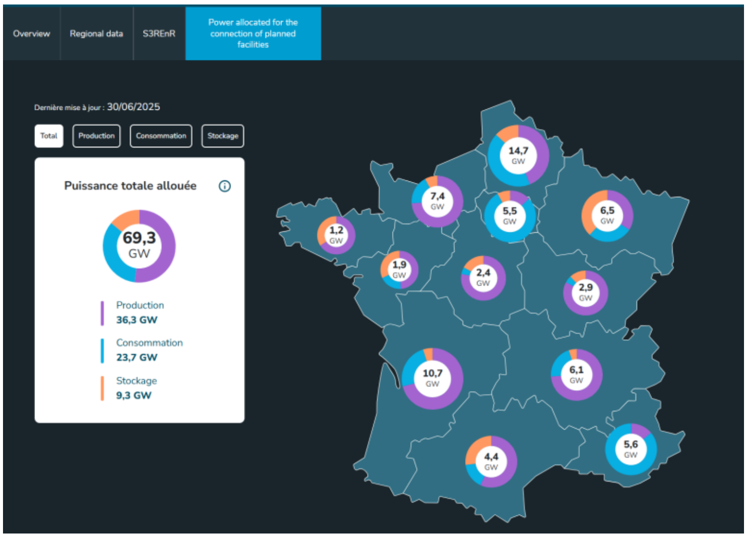

Figure 29. Allocated power per region in France

Furthermore, Figure 30 shows the main new operating assets starting from 2024.

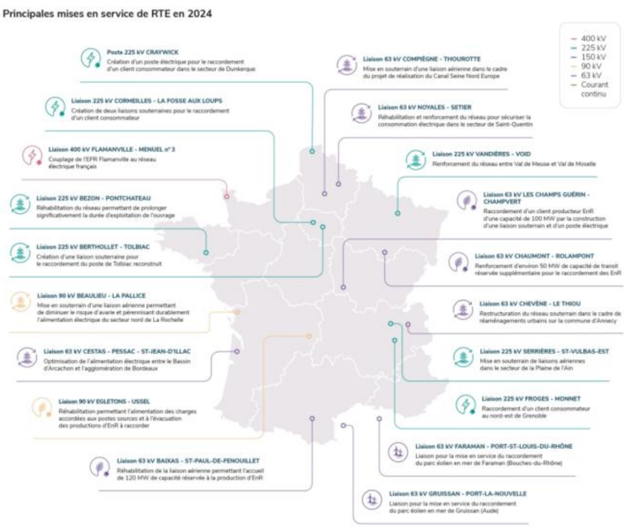

Figure 30. New operating assets in the French transmission system

- References:
    1. *Rte ELECTRICITY ANALYSIS AND DATA, "Regions", [Projets en cours de raccordement [EN] | Analyses et données], Accessed on July, 2025.*
    2. *Rte, "Point d'étape sur la mise en oeuvre du SDDR 2019 Période 2019-2024", https://assets.rte-france.com/prod/public/2025-03/2025-03-point-etape-sddr-2019.pdf.*

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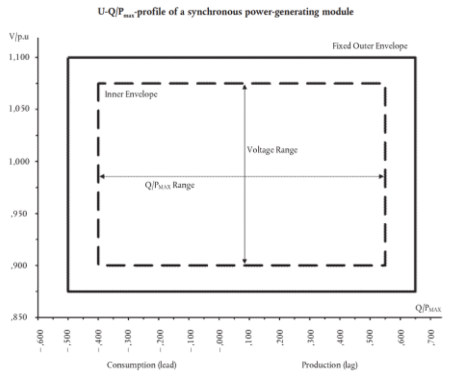
2.4.11. Germany

Grid requirements: The following information were summarized for the purpose of readability; more detailed information can be found in the provided references. No information was found sourced in TSOs documentation, so the following requirements were taken based on the references indicated.TSO: TenneT, 50Hz, Amprion, Transnet BW

- Fault-ride through: Must remain connected during dips down to 0 p.u. for 150 ms
- Voltage limits: **+**- 10%
- Frequency limits: - 2.5 Hz, + 1.5 Hz
- Capability curves:



Synchronous area	Maximum range of Q/P_{max}	Maximum range of steady-state voltage level in PU
Continental Europe	0,75	0,225
Nordic	0,95	0,150
Great Britain	0 (*) 0,33 (**)	0,225
Ireland and Northern Ireland	0,66	0,218
Baltic	0,8	0,22

Figure 31. Capability curve required in Continental Europe

- Reference:

1. *I, Erlich, W. Winter, A. Dittrich, "Advanced Grid Requirements for the Integration of Wind Turbines into the German Transmission System", 2006, IEEE.*

2. *COMMISSION REGULATION (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators, [COMMISSION REGULATION (EU) 2016/ 631 - of 14 April 2016 - establishing a network code on requirements for grid connection of generators](#).*

Land use: The siting of onshore wind farms is characterized by a multi-level planning system, which includes: the binding targets set by the central federal government regarding RES development across the country, the Spatial Development Plans prepared by the federal states (Länder), the definition of concentration zones (Konzentrationszonen) for wind energy carried out at the regional level, and the municipal land use plans that specify and implement these zones. There is no nationally defined minimum distance limit for wind farms from residential areas, as each federal state determines its own

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distances and rules. Distances vary by state and usually range between 500 and 1,000 meters. Specifically, in Bavaria, the defined distance is 10 times the height of the wind turbine; in Brandenburg and Berlin, it is 1,000 m; in Hamburg, it is 500 m; in Hesse and Rhineland, it is 1,000 m; in Saxony, it is 750–1,000 m; and in Schleswig-Holstein, it is 800 m.

Areas prohibited for the installation of onshore wind farms include Natura 2000 sites, national parks, areas with high bird density or bird migration routes, forest areas, and coastal protection zones. Wind energy development is governed by the Wind Energy Area Act (Windenergieflächenbedarfsgesetz – WindBG) and the Renewable Energy Sources Act (EEG 2023). The system uses "hard" and "soft" exclusion zones to delineate wind energy concentration zones. Planning must ensure coherence between environmental protection goals and RES development goals. Suitable areas for siting onshore wind farms are suggested to be lowland regions with high wind potential, far from residential zones, as well as areas of low agricultural productivity, peri-urban degraded areas, and industrial zones. Specifically, the northern and central regions of Germany are considered more suitable for wind farm development. The states exhibiting these characteristics and recommended for wind farm siting are: Rhineland-Palatinate, Hesse, Bavaria, Baden-Württemberg, and Brandenburg.

References

1. *Kiunke, T., Gemignani, N., Malheiro, P., & Brudermann, T. (2022). Key factors influencing onshore wind energy development: A case study from the German North Sea region. Energy Policy, 165, 112962. (https://www.sciencedirect.com/science/article/pii/S0301421522001872)*
2. *Bunzel, K., Bovet, J., Thrän, D., & Eichhorn, M. (2019). Hidden outlaws in the forest? A legal and spatial analysis of onshore wind energy in Germany. Energy Research & Social Science, 55, 14-25. (https://www.sciencedirect.com/science/article/pii/S2214629618312945)*
3. *Pflugfelder, Y., & Weber, C. (2025). The future spatial distribution of onshore wind energy capacity based on a probabilistic investment calculus (No. 01/2025). HEMF Working Paper. (https://www.econstor.eu/handle/10419/315017)*
4. *Wingenbach, M., Dünzen, K., Krieger, S., & Gibson, J. (2024). Overview of Renewable Energy Spatial Planning and Designation of Acceleration Areas in Selected EU Member States (https://caneurope.org/content/uploads/2024/05/RE-Spatial-Planning-Acceleration-in-EU-MS_13052024.pdf) 5. Meier, J. N., Lehmann, P., Süssmuth, B., & Wedekind, S. (2024). Wind power deployment and the impact of spatial planning policies. Environmental and Resource Economics, 87(2), 491-550. (https://link.springer.com/article/10.1007/s10640-023-00820-3)*
5. *Felber, G., & Stoeglehner, G. (2014). Onshore wind energy use in spatial planning—a proposal for resolving conflicts with a dynamic safety distance approach. Energy, Sustainability and Society, 4, 1-8. (https://link.springer.com/article/10.1186/s13705-014-0022-8)*
6. *Geiger, C., Tafarte, P., Wolfram, E., & Lehmann, P. (2025). Wind power deployment in Germany: trade-offs of spatial planning instruments. Journal of Land Use Science, 20(1), 1-20. (https://www.tandfonline.com/doi/full/10.1080/1747423X.2025.2458849)*

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Grid capability: Few information was found regarding the German transmission system capability Only information related to the ten-years development plan was found. In particular, Figure 32 and Figure 33 show respectively the designated projects (either in operation or in an advanced level for targeting the plan) and the expected capacity per regionality.

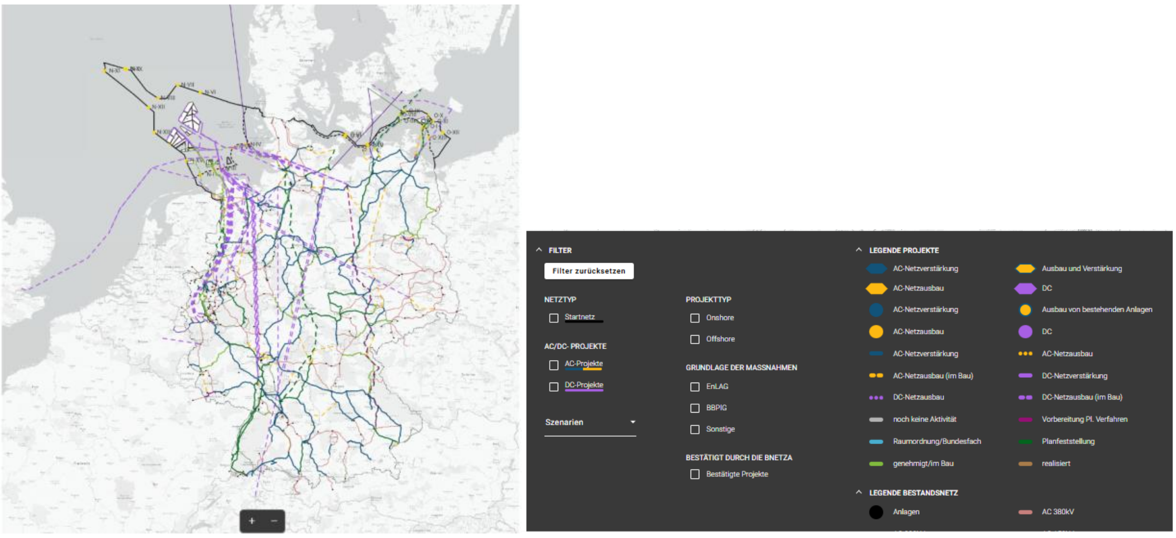
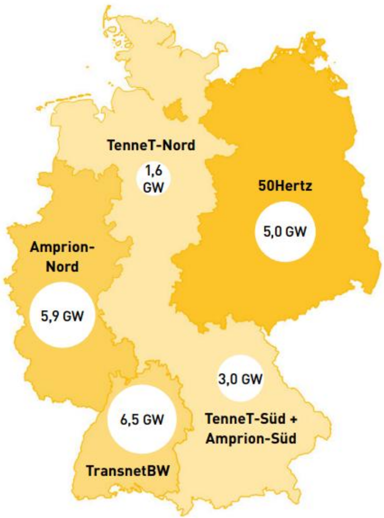


Figure 32. German transmission system based on the development plan



s

Figure 33. Foreseen expansion of the electrical system in Germany

- <u>References:</u>

1. *NETZ ENTWICKLUNGS PLAN STROM, "Projekte im NEP 2037/2045 (2023), https://www.netzentwicklungsplan.de/projekte/projekte-im-nep-20372045-2023, Accessed on July, 2025.*

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2. *NETZ ENTWICKLUNGS PLAN STROM, "Szenariorahmen zum Netzentwicklungsplan Strom 2037/2045, Version 2025", https://www.netzentwicklungsplan.de/sites/default/files/2024-07/Szenariorahmenentwurf_NEP2037_2025_2.pdf.*

2.4.12. Greece

Grid requirements: The following information were summarized for the purpose of readability; more detailed information can be found in the provided references.

- TSO: Independent Power Transmission Operator (IPTO or ADMIE)
- Fault-ride through: Must remain connected during dips down to 0 p.u. for 150 ms
- Voltage limits: +- 5%
- Frequency limits: - 2.5 Hz, + 1.5 Hz
- Capability curves:

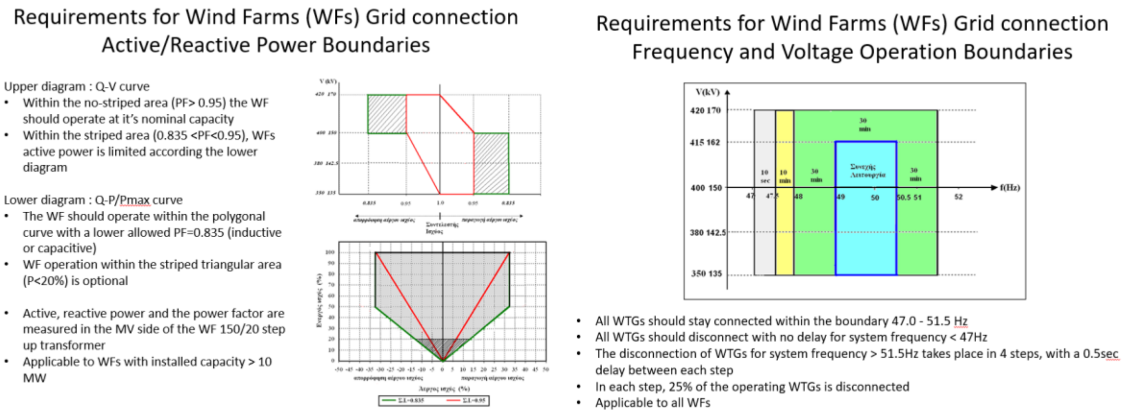

Figure 34. Capability curve required by IPTO

- Reference:
    1. *ADMIE, ΦΕΚ Β' 3757 ΑΠΟΦΑΣΗ ΡΑΕ 1165-2020 - RfG.pdf, Accessed on: June, 2025*

Land use: The installation of onshore wind farms in Greece is governed by a hierarchical spatial planning system. The Special Framework for Spatial Planning for Renewable Energy Sources (SESP-RES) defines the national siting rules, which are specified through regional and municipal spatial plans. Specifically, certain spatial restrictions are defined concerning the delineation of distances around critical land uses, in relation to wind farm installation. Indicative distances are provided below: swimming beaches ≥ 1,000 m, ornithological areas ≥ 200 m, UNESCO / cultural heritage monuments ≥ 3,000 m, tourist zones, ports, and industrial parks ≥ 1,000 m, zones of cultural interest and quarries ≥ 500 m, high-voltage lines, irrigated lands, livestock units, and aquaculture facilities ≥ 120 m, safety zones from roads, railways, and high-voltage lines ≥ 1.5 times the turbine diameter. Restrictions have

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also been set regarding the maximum percentage coverage of municipalities with wind farms. Specifically, in Wind Priority Areas on the mainland, the permissible maximum coverage is up to 8% of the total municipal area, while in areas with a high tourism development index, the maximum coverage is up to 4%. The minimum distance between wind turbines is defined as 2.5 times the turbine diameter, while there is no legislated national minimum distance for wind farms from residential areas. Nevertheless, empirical distances are usually applied: ≥ 1,000 m from cities and settlements with a touristic or cultural character, ≥ 1,500 m from traditional settlements, ≥ 500 m from monasteries, ≥ 2,500 m from existing wind farms, antenna parks, or RADAR installations.

Areas prohibited for the installation of onshore wind farms include Natura 2000 sites, Ramsar wetlands, forests, cultural heritage monuments, archaeological zones, tourist zones, parts of active quarries, mining and quarrying areas, as well as any other area subject to a special land use regime. Law 5037/2023 (Article 154) introduces the concept of Renewable Acceleration Areas (RAA), the implementation of which is still in progress. Suitable areas for siting onshore wind farms are suggested to be rural and semi-mountainous areas with wind speeds ≥ 5 m/s, slope < 20%, and outside protected zones. Degraded agricultural lands, low-vegetation zones, and uncultivated or non-productive lands are also eligible. Gently sloping terrains with access to the grid and road infrastructure are usually preferred.

References

1. *Gemeliari, L. ,E. (2022). Guidance of environmental impact assessment of onshore wind farms. Diploma Thesis, University of West Attica. (https://www.openarchives.gr/aggregator-openarchives/edm/polynoe/000125-11400_3823)*
2. *Mpili, A. (2016). Investigation of criteria and methodologies for the siting of onshore wind farms (Doctoral dissertation, Aristotle University of Thessaloniki). (https://ikee.lib.auth.gr/record/284867/files/MPILH_EE.pdf) 3. Papalazaridou, S. (2009). Wind energy – Siting criteria for wind farms: The case of Florina prefecture (Doctoral dissertation,, Aristotle University of Thessaloniki). (https://ikee.lib.auth.gr/record/124151/files/PAPALAZARIDOU.pdf)*
3. *Wingenbach, M., Dünzen, K., Krieger, S., & Gibson, J. (2024). Overview of Renewable Energy Spatial Planning and Designation of Acceleration Areas in Selected EU Member States. (https://caneurope.org/content/uploads/2024/05/RE-Spatial-Planning-Acceleration-in-EU-MS_13052024.pdf) 5. Triantafyllidis, I. P. (2018). Siting of onshore wind installations (Doctoral dissertation, Aristotle University of Thessaloniki). (https://ikee.lib.auth.gr/record/297076/files/TRIANTAFYLLIDISIOANNIS581_EE.pdf)*
7. *Markou, Z. A. (2021). The use of multicriteria decision-making methods for the selection of the optimal site for wind farm siting (Doctoral dissertation, Aristotle University of Thessaloniki). (https://ikee.lib.auth.gr/record/335851/files/ZWHMARKOY1090_DE.pdf)*
8. *Official Government Gazette 2464/B/2008 (2008). Special Framework for Spatial Planning and Sustainable Development for Renewable Energy Sources (RES) (https://ypen.gov.gr/wp-content/uploads/2020/11/FEK2464B_2008_RES.pdf)*

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Grid capability: The Greek TSO made available both the current status of the grid and the ten-years development plan foreseen for the 2019-2028 period. Based on this information it was possible to retrieve Figure 35 showing the existing grid as well as the planned interconnection projects in Figure 36.

Figure 35. Current grid in Greece (purple lines 400 kV, green lines 150 kV, blue lines submarine cables)

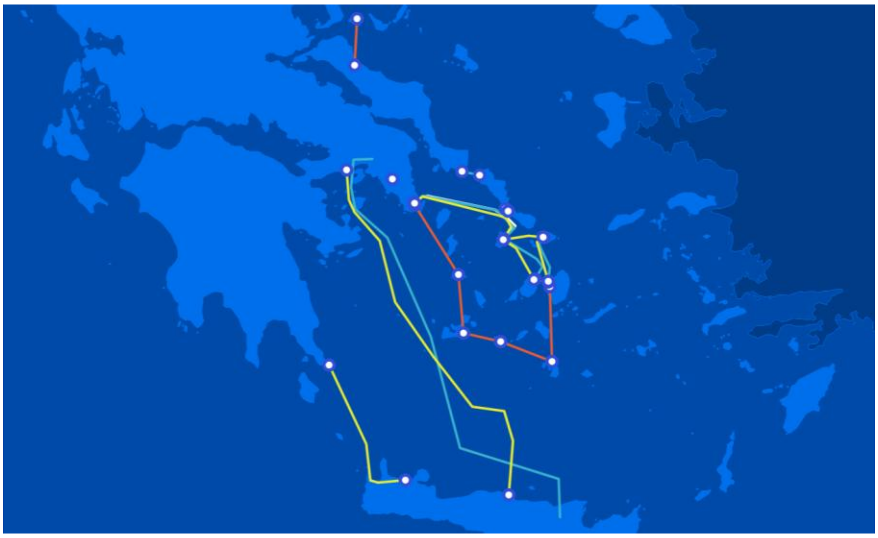

Figure 36. Planned interconnection in the Greek transmission system

- <u>References:</u>
    1. *IPTO, "Grid Map", Grid Map | IPTO, Accessed on July, 2025.*
    2. *IPTO, "Projects", https://www.admie.gr/en/projects/map, Accessed on July, 2025.*

2.4.13. Hungary

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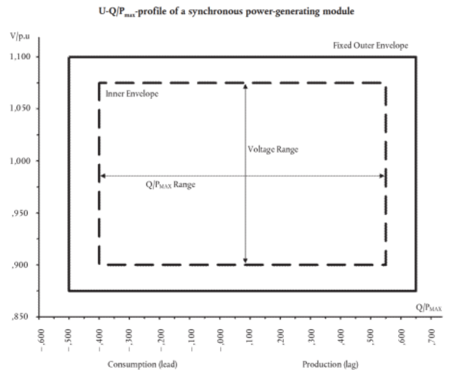
Grid requirements: The following information were summarized for the purpose of readability; more detailed information can be found in the provided references. No information was found sourced in TSOs documentation, so the following requirements were taken based on the references indicated.

- TSO: MAVIR
- Fault-ride through: Must remain connected during dips down to 0 p.u. for 150/250 ms
- Voltage limits: +- 10%
- Frequency limits: - 2.5 Hz, + 1.5 Hz
- Capability curves:



Synchronous area	Maximum range of Q/P_{max}	Maximum range of steady-state voltage level in PU
Continental Europe	0,75	0,225
Nordic	0,95	0,150
Great Britain	0 (*) 0,33 (**)	0,225
Ireland and Northern Ireland	0,66	0,218
Baltic	0,8	0,22

Figure 37. Capability curve required in Continental Europe

- Reference:
    1. *COMMISSION REGULATION (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators, COMMISSION REGULATION (EU) 2016/ 631 - of 14 April 2016 - establishing a network code on requirements for grid connection of generators.*

Land use: A key characteristic of the national spatial planning is the very strict legislation that, especially until the recent past, deterred the installation of wind farms and the exploitation of available wind energy. Specifically, until 31/12/2023, legislation stipulated a minimum distance of 12 km from residential areas. Now, the location of onshore wind farms is determined by a multi-level planning and licensing system, which includes the application of national legislation in conjunction with the provisions of regional and municipal spatial plans. Based on the new legislative regulation, effective from January 1, 2024, the distance of onshore wind farms from residential areas has been set at 700 m. Areas prohibited for the installation of onshore wind farms include Natura 2000 sites, areas of high environmental sensitivity, urban and built-up zones, wetlands, areas of high altitude variation, and

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areas with very low wind potential. The new legislative framework introduces the concept of "favourable areas", where a simplified licensing procedure (with a maximum time of 50 days) applies, provided specific technical criteria are met. Suitable areas for siting onshore wind farms are identified in counties (megyék) with high wind potential, gentle terrain, and more manageable restrictions. The ones considered are: Győr-Moson-Sopron, Veszprém, Vas, Zala, Fejér, Komárom-Esztergom, Csongrád, Szabolcs-Szatmár-Bereg, Somogy, and Hajdú-Bihar.

Reference

1. *Resch, G., Liebmann, L., Hirner, R., Mezosi, A., Szabo, L., & Varga, K. (2023). Study on the wind power potential in Bulgaria, Hungary and Romania. Country Report Hungary.*

Grid capability: The Hungarian electricity system consists of 4,897 km of internation network. The export-import real-time flow is made available by the TSO and a snippet is presented in Figure 38.

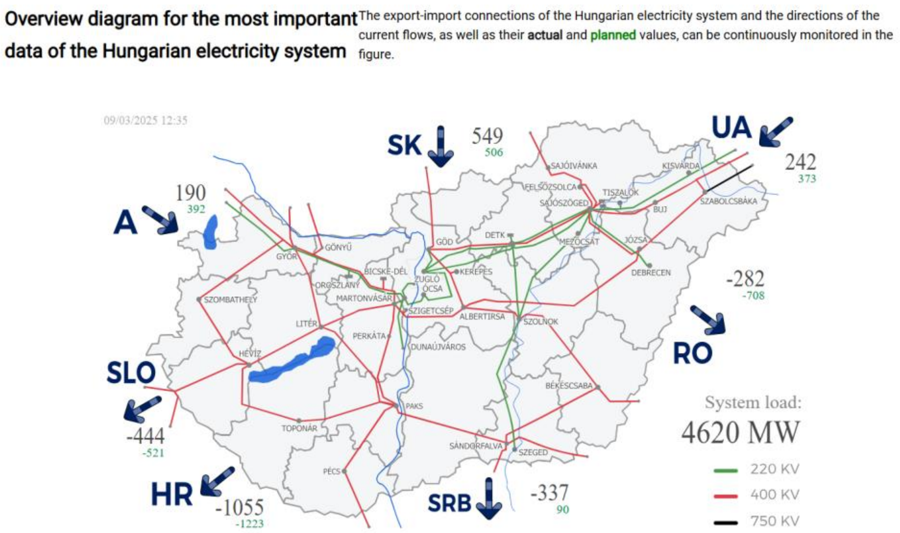

Figure 38. Real-time import/export flow of the Hungarian transmission system

Few information was found directly shared from the national TSO, nonetheless based on online sources in 2024 a Network Development Plan was approved.

- Reference:

1. *MAVIR, [home - MAVIR EN - Magyar Villamosenergia-ipari Átviteli Rendszerirányító Zrt.](), Accessed on September, 2025.*
2. *Nagy Es Trocsanyi, "Hungary: The Network Development Plan for Electricity System 2023 Has Been Approved", CEE LEGAL MATTERS, June 2024.*

2.4.14. Ireland

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Grid requirements: The following information were summarized for the purpose of readability; more detailed information can be found in the provided references.

- TSO: EirGrid
- Fault-ride through: Must remain connected during dips down to 0 p.u. for 140/250 ms
- Voltage limits: +- 10%
- Frequency limits: - 2.5 Hz, + 2 Hz
- Capability curves:

Connection Voltage	Parameter	Parameter in RfG (outer envelope)	Proposal (Inner Envelope)	Article Number	Type Applicability	Justification Code
110 kV	U_{min}	0.875 p.u.	0.9 p.u.	18.2.b (ii)	D SPGMs	1
	U_{max}	1.118 p.u.	1.118 p.u.			1
	Q_{min}/P_{max} (lead)	-0.5 p.u.	-0.5 p.u.			2
	Q_{max}/P_{max} (lag)	0.65 p.u.	0.52 p.u.			2
220 kV	U_{min}	0.875 p.u.	0.9 p.u.			2
	U_{max}	1.118 p.u.	1.118 p.u.			2
	Q_{min}/P_{max} (lead)	-0.5 p.u.	-0.5 p.u.			2
	Q_{max}/P_{max} (lag)	0.65 p.u.	0.52 p.u.			2
400 kV	U_{min}	0.875 p.u.	0.9 p.u.			1
	U_{max}	1.05 p.u.	1.05 p.u.			1
	Q_{min}/P_{max} (lead)	-0.5 p.u.	-0.5 p.u.			2
	Q_{max}/P_{max} (lag)	0.65 p.u.	0.52 p.u.			2

Table 24: Definition of U-Q/Pmax-profile at Maximum Capacity for SPGMs: connection @ ≥110 kV

Figure 39. Capability curve required by EirGrid

- Reference:
  1. *EirGrid, Proposal-for-General-Application-of-RfG-Requirements-for-Ireland-For-Website.pdf, Accessed on: June, 2025.*

Land use: Ireland is among the countries highly suitable for onshore wind farm development, as its geographical location provides high wind potential and favourable topography. The siting of onshore wind farms in Ireland is guided by national policy directives. However, the primary responsibility for approving and managing projects belongs to local authorities at the county level. In practice, approaches vary significantly between counties due to the decentralized nature of the spatial planning system and the differences in local assessment criteria and area classifications. There is no legislated uniform national minimum distance for wind farms from residential areas. Nevertheless, some local authorities apply the 10H rule (ten times the turbine height), corresponding to approximately 1,500 meters, while the 2019 national draft guidelines propose a minimum distance of either 500 m or 4 times the turbine height, whichever is greater (as there are turbines 150 m high, the distance corresponds to 600 m).

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Excluded from wind farm installation are Natura 2000 sites, peatlands, forests and wetlands, areas of high environmental sensitivity, as well as airport zones and large radar installations within a 2.5-kilometer radius. In general, local authorities control planning, while the central government oversees the implementation of national restrictions regarding the siting, installation, and operation of onshore wind farms. Suitable areas for siting onshore wind farms are considered to be the Midlands and Eastern regions of Ireland, which combine low environmental sensitivity, accessibility to the electricity grid and road system, and relatively flat terrains with moderate wind potential.

References

1. *González, A., Daly, G., & Gleeson, J. (2016). Congested spaces, contested scales–A review of spatial planning for wind energy in Ireland. Landscape and Urban Planning, 145, 12-20. (https://www.sciencedirect.com/science/article/pii/S0169204615002066)*
2. *Bessin, A., Serra-Adroer, J., Debonne, N., & van Vliet, J. (2025). Location determinants of industrial solar photovoltaics and onshore wind turbines in the EU. Renewable and Sustainable Energy Reviews, 210, 115257. (https://www.sciencedirect.com/science/article/pii/S1364032124009833)*
3. *Tapoglou, E., Tattini, J., Schmitz, A., Georgakaki, A., Długosz, M., Letout, S., Kuokkanen, A., Mountraki, A., Ince, E., Shtjefni, D., Joanny Ordonez, G., Eulaerts, O.D. and Grabowska, M., Clean Energy Technology Observatory: Wind energy in the European Union- 2023 Status Report on Technology Development, Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/618644, JRC135020. (https://publications.jrc.ec.europa.eu/repository/handle/JRC135020)*

Grid capability: The transmission system in Ireland and Northern Ireland provides the means to transport energy from generators to demand centres across the island. It is operated at 400 kV, 220 kV and 110 kV in Ireland and ~~-~~at 275 kV and 110 kV in Northern Ireland~~.~~ These two systems are then electrically connected by means of a 275 kV double-circuit. From Louth station in Co. Louth (IE) to Tandragee station in Co. Armagh (NI

Given the Government's target of up to 80% of renewable energy (8GW of which is related to onshore wind), the concern is that the existing grid is not adequate. Hence, the implementation of a ten-years development plan to reinforce the grid in specific regions of the country.

Despite not having a map of the future infrastructure, within the ten-years development plan in force during the period 2025-2034 the following information shown in the figures below were gathered.

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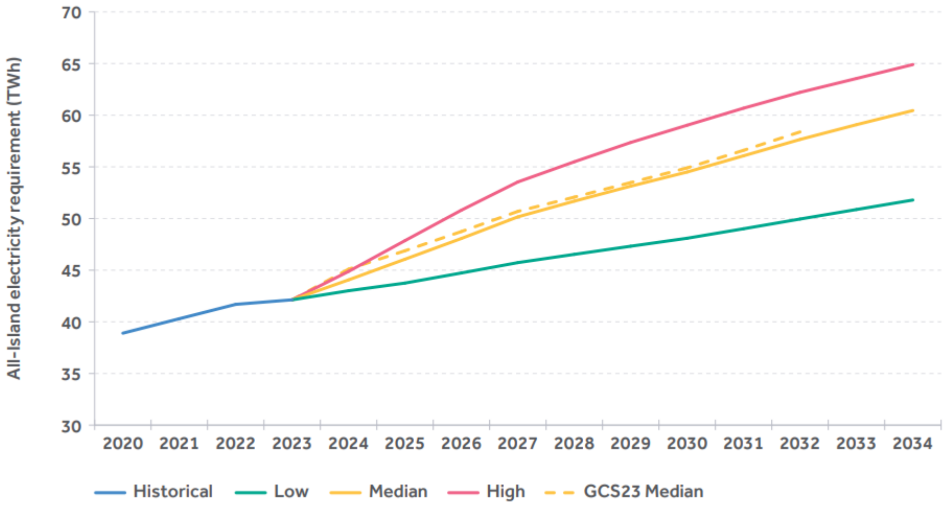

Figure 40. Total Electricity Requirement for all-island system

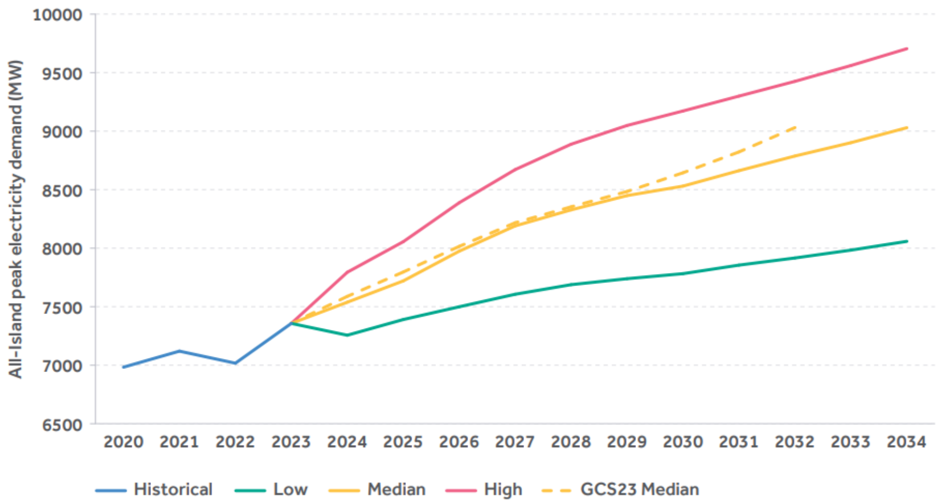

Figure 41. Transmission peak forecast for all-island system

Generally, the TSO provides a lot of information and interactive interfaces related to the status of the grid.

- References:

1. *EirGrid, SONI, "All-Island Resource Adequacy Assessment 2025-2034", All-Island Resource Adequacy Assessment 2025-2034.*
2. *EirGrid, "Transmission Development Plan 2021 – 2030", June 2022.*
3. *EirGrid, "Interconnection", EirGrid Group plc - Smart Grid Dashboard, Accessed on September, 2025.*

2.4.15. Italy

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Grid requirements: The following information were summarized for the purpose of readability; more detailed information can be found in the provided references.

- TSO: TERNA
- Fault-ride through: Must remain connected during dips down to 0 p.u. for 200 ms
- Voltage limits: +- 15%
- Frequency limits: - 2.5 Hz, + 1.5 Hz
- Capability curves**:**

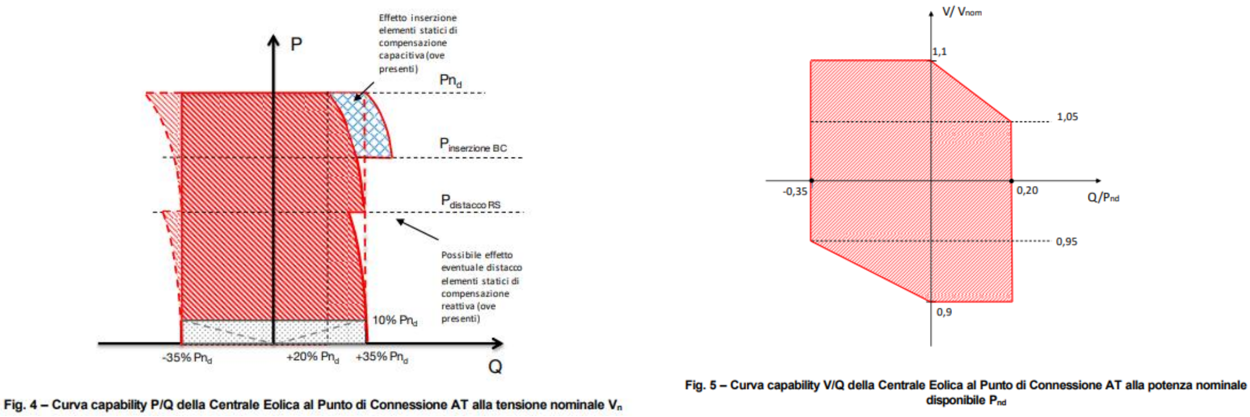

Figure 42. Capability curve required by Terna

- Reference:
    1. *TERNA, Allegato A.17 "CENTRALI EOLICHE Condizioni generali di connessione alle reti AT Sistemi di protezione regolazione e controllo", [Criteri generali di protezione delle reti a tensione uguale o superiore a 120 kV](#).*

Land use: Spatial planning for wind energy is multi-level. Generally, national guidelines (Linee Guida) coexist with regional plans. However, regions follow different approaches: for example, the Region of Tuscany emphasizes landscape protection, while the Region of Apulia promotes wind energy as a lever for local development. The installation of wind farms is permitted in industrial or mixed industrial and commercial zones, provided these areas are outside primary residential zones, and, in addition, a minimum distance of 1 km from developable urban areas is maintained. Prohibition zones for wind farm siting are also defined around specific types of areas, such as: coastal zones (up to 300 m from the coastline), areas around lakes (up to 300 m) and rivers (up to 150 m), forest areas (100 m around them), archaeological sites (100 m around them), and traditional paths ("tratturi") (100 m around them). Regarding minimum distances between wind turbines, these are determined according to the prevailing wind direction, specifically 5–7 times the rotor diameter in the direction of the prevailing wind. There is no legislated uniform national minimum distance for wind farms from residential areas. National guidelines stipulate a distance of at least 200 m from isolated dwellings, while for projects in industrial or mixed industrial and commercial areas, a minimum distance of 1 km from developable urban zones is required.

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Exclusion zones are defined by national guidelines and include national parks and state nature reserves, Natura 2000 sites, Ramsar wetlands, UNESCO cultural heritage sites, areas of particular historical, archaeological, or cultural significance and protected landscapes, forest areas, and areas with hydrological risk or high biodiversity importance. Finally, suggested locations for wind farm installation include areas with suitable wind potential (wind speed >5 m/s), grid access, and low visual impact. These can be either agricultural or industrial areas located outside residential areas and observing the 1 km minimum distance from urban areas. Generally, based on experience and local conditions, the country's southern regions (such as Apulia, Campania, Basilicata, and Sicily) are considered most suitable for onshore wind farm development, due to a combination of high wind potential and adequate infrastructure.

References

1. *Cowell, R., & De Laurentis, C. (2022). Understanding the effects of spatial planning on the deployment of on-shore wind power: Insights from Italy and the UK. Journal of Environmental Planning and Management, 66(2), 241-264. (https://www.tandfonline.com/doi/pdf/10.1080/09640568.2021.1987866)*
2. *Garcia, D. A., & Bruschi, D. (2016). A risk assessment tool for improving safety standards and emergency management in Italian onshore wind farms. Sustainable Energy Technologies and Assessments, 18, 48-58. (https://www.sciencedirect.com/science/article/pii/S2213138816300625)*
3. *Caporale, D., & De Lucia, C. (2015). Social acceptance of on-shore wind energy in Apulia Region (Southern Italy). Renewable and Sustainable Energy Reviews, 52, 1378-1390. (https://www.sciencedirect.com/science/article/pii/S1364032115008308)*
4. *Ministero dello Sviluppo Economico. (2010). Decreto Ministeriale 10 Settembre 2010: Linee guida per l'autorizzazione degli impianti alimentati da fonti rinnovabili. Gazzetta Ufficiale della Repubblica Italiana, n. 219 del 18 settembre 2010. (https://leg16.camera.it/temiap/temi16/DM%2010%20settembre%202010.pdf)*
5. *Regione Puglia. (2010). Regolamento Regionale n. 24 del 30 dicembre 2010 - Regolamento attuativo del D.M. 10 settembre 2010 del Ministero per lo Sviluppo Economico, "Linee guida per l'autorizzazione degli impianti alimentati da fonti rinnovabili", recante la individuazione di aree e siti non idonei alla installazione di specifiche tipologie di impianti alimentati da fonti rinnovabili nel territorio della Regione Puglia. Bollettino Ufficiale della Regione Puglia, n. 195 del 31 dicembre 2010. (https://www.sistema.puglia.it/portal/page/portal/SistemaPuglia/info?id=60A0E262EDC2CB58)*

Grid capability: Based on the information made available by the TSO, Terna is now targeting the year 2030, 2034 and beyond respectively with 7 GW and 8 GW of exchange capacity as shown in

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Figure 43. New infrastructure foreseen by the year 2030 on the left and 2034 in the center and beyond 2034 on the right in Italy

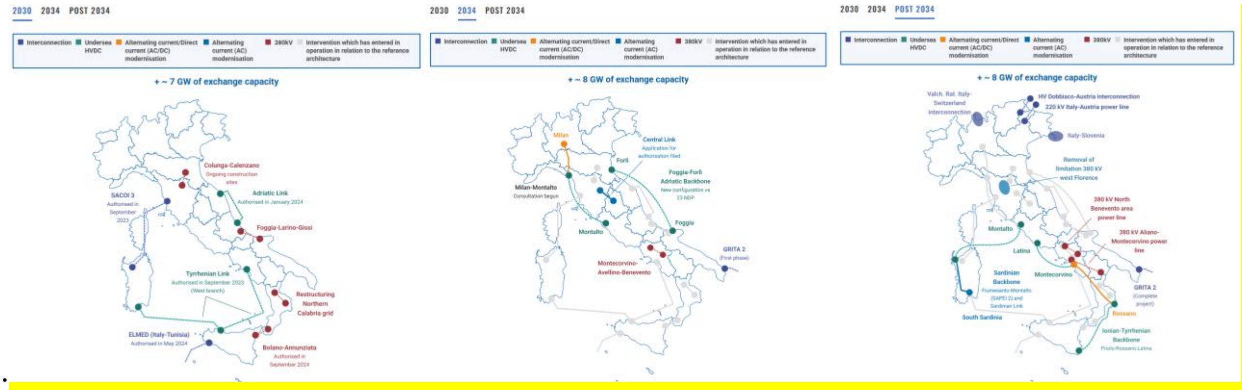

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Figure 43. New infrastructure foreseen by the year 2030 on the left and 2034 in the center and beyond 2034 on the right in Italy

Besides this, TERNA is also planning new interconnections beyond the 30 already in operation as shown in Figure 44.

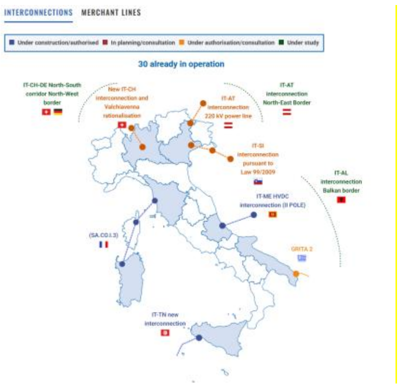

Figure 44. New interconnections planned by TERNA

- References:
    1. *Terna, "Piano di sviluppo della rete", [Piano di sviluppo della rete | Terna Driving Energy - Terna spa](), Accessed on July, 2025.*

2.4.16. Latvia

Grid requirements: The following information were summarized for the purpose of readability; more detailed information can be found in the provided references.

- TSO: AST

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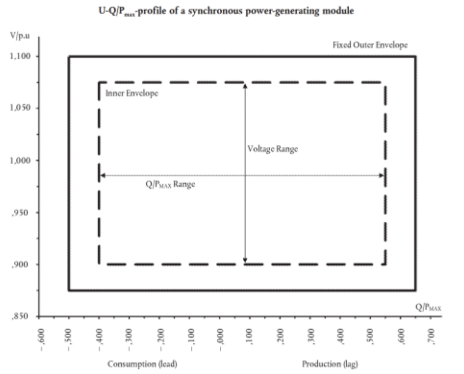
- Fault-ride through: Must remain connected during dips down to 0.15 p.u. for 150 ms
- Voltage limits: +- 10%
- Frequency limits: +- 2 Hz
- Capability curves:



Synchronous area	Maximum range of Q/P_{max}	Maximum range of steady-state voltage level in PU
Continental Europe	0,75	0,225
Nordic	0,95	0,150
Great Britain	0 (*) 0,33 (**)	0,225
Ireland and Northern Ireland	0,66	0,218
Baltic	0,8	0,22

Figure 45. Capability curve required in Baltic

- Reference:
    1. *Likumi, Tīkla kodekss elektroenerģijas nozarē, Accessed on: June, 2025.*
    2. *COMMISSION REGULATION (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators, COMMISSION REGULATION (EU) 2016/ 631 - of 14 April 2016 - establishing a network code on requirements for grid connection of generators.*

Land use: The siting of onshore wind farms in Latvia is plan-led and must comply with national environmental legislation, as well as the provisions of municipal and regional spatial plans. To utilize wind energy, improvements in the existing regulatory framework for RES are necessary, along with enhanced cooperation with municipalities across the country. Available land for onshore wind farm installation is limited, as large areas are covered by Natura 2000 sites, micro-reserves, and high-value agricultural land. There is no legislated minimum distance for wind farms from residential areas. However, an indicative average distance of 800 m from residences is set for the installation and operation of a wind farm, while strict criteria for acoustic and visual disturbance are also applied.

Areas prohibited for the installation of onshore wind farms include Natura 2000 sites, military installations and radar zones, rural settlements, micro-reserves, and areas of high biodiversity. In recent years, a new zoning plan has been underway to align the country with the EU's RED III Directive. Suitable areas for siting onshore wind farms are considered to be industrial and port zones, such as the Ventspils area, which has been identified as a potential area for RES infrastructure development. Additionally, private coastal lands with high wind potential and proximity to transport and logistics

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infrastructure can be utilized, provided they align with local spatial plans and do not fall within environmental protection areas.

References

1. *Laktuka, K., Pakere, I., Kalnbalkite, A., Zlaugotne, B., & Blumberga, D. (2023). Renewable energy project implementation: Will the Baltic States catch up with the Nordic countries?. Utilities Policy, 82, 101577. (https://www.sciencedirect.com/science/article/pii/S0957178723000899)*
2. *González, J. S., & Lacal-Arántegui, R. (2016). A review of regulatory framework for wind energy in European Union countries: Current state and expected developments. Renewable and Sustainable Energy Reviews, 56, 588-602. (https://www.sciencedirect.com/science/article/pii/S1364032115013581)*
3. *Kacare, M., Pakere, I., Gravelsins, A., & Blumberga, A. (2022). Impact assessment of the renewable energy policy scenarios–A case study of Latvia. Rigas Tehniskas Universitates Zinatniskie Raksti, 26(1), 998-1019. (https://reference-global.com/article/10.2478/rtuect-2022-0075)*
4. *Lankovska, A., Brence, K., Jaunzems, D., & Blumberga, D. (2024). Wind Energy in Latvia–Mismatch between the Potential and Reality. Rigas Tehniskas Universitates Zinatniskie Raksti, 28(1), 379-393. (https://reference-global.com/article/10.2478/rtuect-2024-0030)*
5. *Antans, A. (2017). Multi-Criteria Decision Analysis in Wind power Project Development: Case study in Latvia. (https://www.diva-portal.org/smash/record.jsf?pid=diva2%3A1121452&dswid=-2069)*
6. *Khorishko, L., & Rudnieva, A. (2023). Latvian Renewable Energy Policy in the Context of EU Initiatives. Baltic Journal of Economic Studies, 9(2), 211-215. (https://cyberleninka.ru/article/n/latvian-renewable-energy-policy-in-the-context-of-eu-initiatives)*

Grid capability: The transmission system consists of the 330 kV and 110 kV electricity transmission lines as shown in Figure 46

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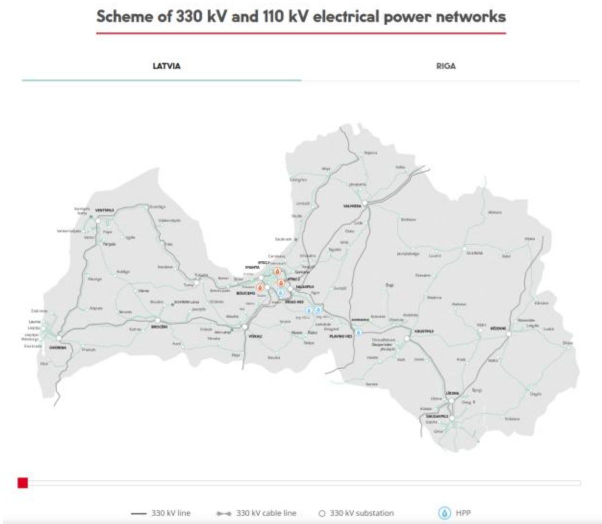

Figure 46. Existing grid in Latvia

The Power Transmission System Development Plan 2025-2034 has been approved in 2024. Connection requests are high, and they were already high at the time of preparing the development plan with an overall capacity of 551 MW, 60 MW of which in wind power plants. Figure 47 shows the expected grid based on the development plan.

Figure 47. Grid in Latvia based on the Transmission Development Plan

- References:

1. *AST, "Transmission Network and Substations", https://www.ast.lv/en/transmission-network-info/transmission-network-and-substations, Accessed on July, 2025.*
2. *AST, "Power Transmission System Development Plan", https://www.ast.lv/en/content/power-transmission-system-development-plan, Accessed on July, 2025.*

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2.4.17. Lithuania

Grid requirements: The following information were summarized for the purpose of readability; more detailed information can be found in the provided references. No information was found sourced in TSOs documentation, so the following requirements were taken based on the references indicated.

- TSO: Litgrid
- Fault-ride through**:** Must remain connected during dips down to 0.05 p.u. for 250 ms
- Voltage limits: +- 10%
- Frequency limits: **-** 2 Hz, + 0.2 Hz
- Capability curves:

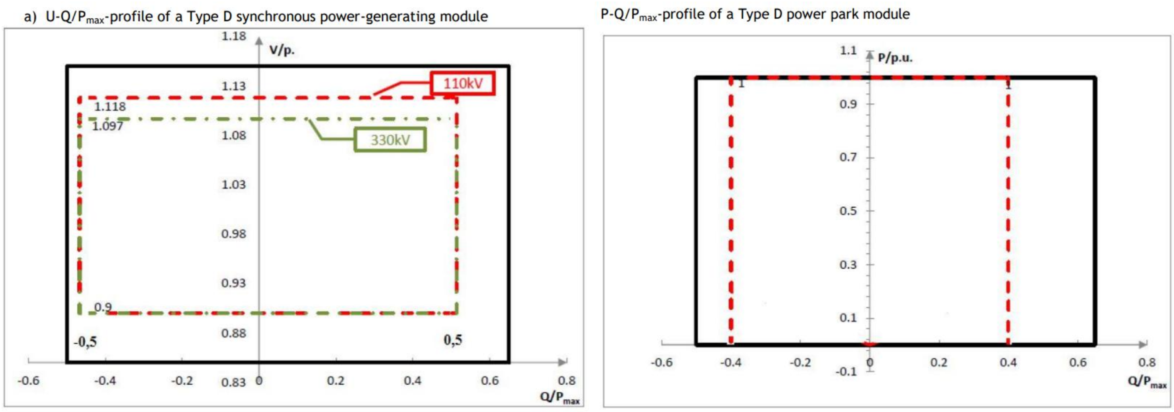

Figure 48. Capability curve required by Litgrid

- Reference:
    1. *RfG_requirements (ENG).pdf, Accessed on: June, 2025*

Land use: The installation of onshore wind farms in Lithuania is regulated by the Law on Renewable Energy (No. XI-1375), the Territorial Planning Act, and the Law on Special Land Use Conditions (No. XIII-2166). These laws determine where and under what conditions wind energy projects can be developed in the country. Projects must also comply with municipal spatial plans. There is no minimum nationally defined safety distance for a wind farm from a residential area; distances are determined on a case-by-case basis during the licensing process, based on the results of acoustic and visual assessments. In practice, local authorities usually apply distances ranging between 500 and 1,000 m to ensure compliance with noise limits and visual impact criteria.

The installation of wind farms is prohibited or strictly restricted in various categories of areas defined by the Law on Special Land Use Conditions, such as: protected natural areas (Natura 2000 sites, nature reserves, national and regional parks), forests with special protection status, water protection zones

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along rivers, lakes, and coastal areas, aviation safety zones, including areas near civil and military airports, cultural heritage monuments and archaeological sites, and infrastructure safety zones, such as high-voltage lines, natural gas and oil pipelines, and technical protection areas for critical infrastructure and facilities. Suggested areas for the installation of onshore wind farms are considered to be rural or non-sensitive areas, outside ecological reserves or natural environment protection zones. Lands already designated as suitable for RES projects, with low land-use conflicts and clear compatibility with municipal spatial plans and sustainable development frameworks, are preferred.

References

1. *Seimas of the Republic of Lithuania. (2019). Dokumento Nr.: XIII-2166 (https://e-seimas.lrs.lt/portal/legalAct/lt/TAD/46c841f290cf11e98a8298567570d639/asr)*
   2. Seimas of the Republic of Lithuania. (2011). Dokumento Nr.: XI-1375 (https://e-seimas.lrs.lt/portal/legalAct/lt/TAD/TAIS.398874/asr)
2. *Paužaitė-Kulvinskienė, J., Žvaigždinienė, I., & Žilinskienė, L. (2025). Lithuania. In Energy solidarity and energy security–from green transition to the EU's crisis management: XXXI FIDE Congress, Katowice 2025: congress publications. Vol. 3 (pp. 443-479). Wydawnictwo Uniwersytetu Śląskiego. (https://epublications.vu.lt/object/elaba:238839027/index.html)*

Grid capability: The Lithuanian electricity transmission grid consists of 400-110 kV transformer substations, which are connected to high voltage electricity transmission lines. There are 6,727 km of 110 – 330 kV power transmission lines of high voltage including 64,5 km of underground cable lines. The TSO provides a quite detailed map of both the existing grid (Figure 49) and the one based on the ten-years development plan for the period 2024-2033.

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Figure 49. Lithuanian grid map

Development plan at 2033:

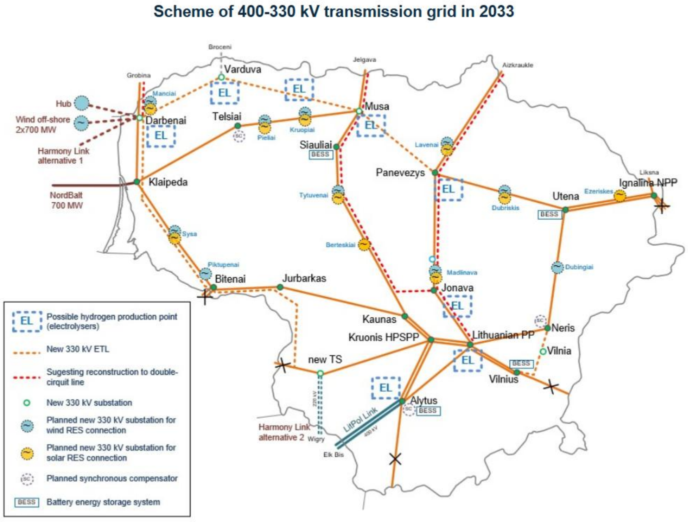

Figure 50. Lithuanian grid map based on the ten year development plan

- *References:*
  1. *Litgrid, "Grid scheme and data", https://www.litgrid.eu/index.php/power-system/power-system-information/grid-scheme-and-data/545, Accessed on September, 2025.*
  2. *Litgrid, "Transmission grid", https://www.litgrid.eu/index.php/power-system/power-system-information/transmission-grid-/544, Accessed on September, 2025.*
  3. *Litgrid, "Electricity Transmission Grid Ten-Year Development Plan", https://www.litgrid.eu/index.php/grid-development-/-electricity-transmission-grid-ten-year-development-plan/3851, Accessed on September, 2025.*

2.4.18. Luxembourg

Grid requirements: The TSO is Creos but no information was found regarding the connection requirements for wind farms and therefore the European regulation can be considered.

- Reference:
  1. *COMMISSION REGULATION (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators, COMMISSION REGULATION (EU) 2016/ 631 - of 14 April 2016 - establishing a network code on requirements for grid connection of generators.*

Land use: The siting of onshore wind farms follows a plan-led approach. National rules are implemented through regional and municipal spatial plans, and there is a series of spatial restrictions concerning wind farm installation, applying specific safety zones around transport infrastructure (roads, airports, railway lines), around settlements/cities, and around protected areas. The defined general minimum distance for wind farms from residential buildings is set at 1,000 m. Areas prohibited for the installation of onshore wind farms include Natura 2000 sites, FFH (Fauna-Flora-Habitat) zones, special protection areas, mountainous areas with high development costs, and safety zones around transport infrastructure and settlements. Regarding suggested areas for wind farm installation, and due to the country's small size, priority is given to non-protected areas with low environmental sensitivity, access to the electricity grid, and low population density.

References

1. *Dale, P., Hochkirch, A., Pauly, M., Penny, C., & Thakur, G. (2025). Impact of agriculture on the environment and biodiversity in Luxembourg–A multidisciplinary approach to sustainability. (https://www.chd.lu/sites/default/files/2025-04/20250417_cellulescientifique_notederecherche_pairing-scheme_agri-env.pdf)*
2. *Kitzing, L., Nysten, J., Gephart, M., Klessmann, C., & Katz, J. (2014). Cooperation under the RES Directive-Case study on a joint project: An offshore wind park in the North Sea (cooperation between the Netherlands, Belgium, UK, and Luxembourg): Task 4 report; A report compiled within the European project "Cooperation between EU MS under the RenewableEnergy Directive and interaction with support schemes". (https://orbit.dtu.dk/en/publications/cooperation-under-the-res-directive-case-study-on-a-joint-project)*
3. *Enevoldsen, P., Permien, F. H., Bakhtaoui, I., von Krauland, A. K., Jacobson, M. Z., Xydis, G., Sovacool, B.K., Valentine, S.V., Luecht, D. & Oxley, G. (2019). How much wind power potential does europe have? Examining european wind power potential with an enhanced socio-technical atlas. Energy Policy, 132, 1092-1100. (https://www.sciencedirect.com/science/article/pii/S0301421519304343)*
4. *González, J. S., & Lacal-Arántegui, R. (2016). A review of regulatory framework for wind energy in European Union countries: Current state and expected developments. Renewable and Sustainable Energy Reviews, 56, 588-602. (https://www.sciencedirect.com/science/article/pii/S1364032115013581)*

Grid capability: The nation transmission system is composed of 64 kV and 220kV lines and it is now aiming at the extra-high voltage level 380 kV for the connection with Germany. The existing grid can be seen in Figure 51, alongside with the evolution of the peak and network demand, showing an increasing trend. Based on this, currently the is in force the ten year development plan referred to the 2024-2034 period, whose content is shown in Figure 52.

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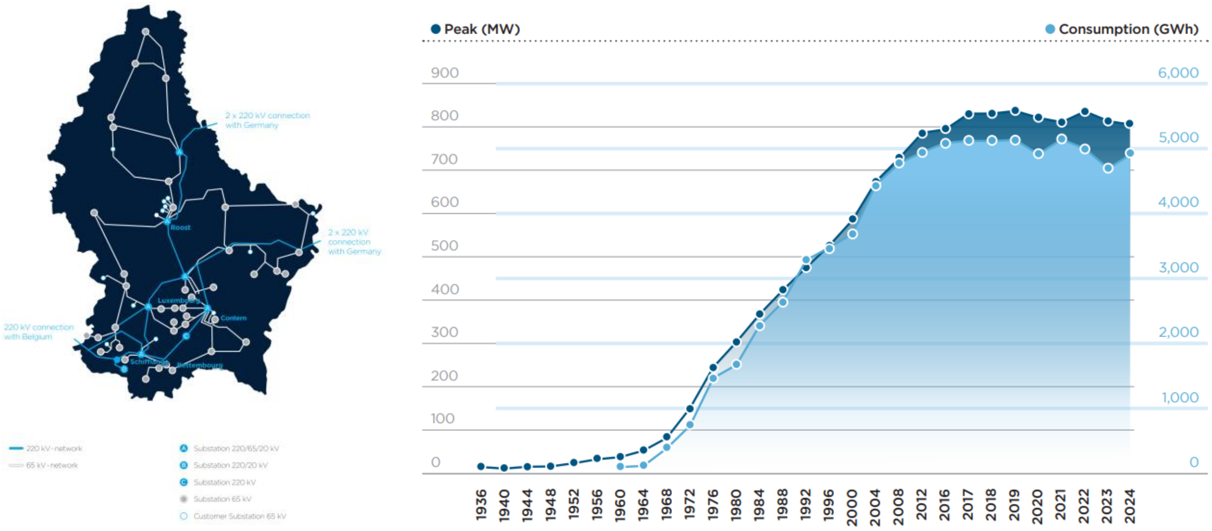

Figure 51. Luxembourg grid map as of 2024 on the left and evolution of the peak and network demand on the right

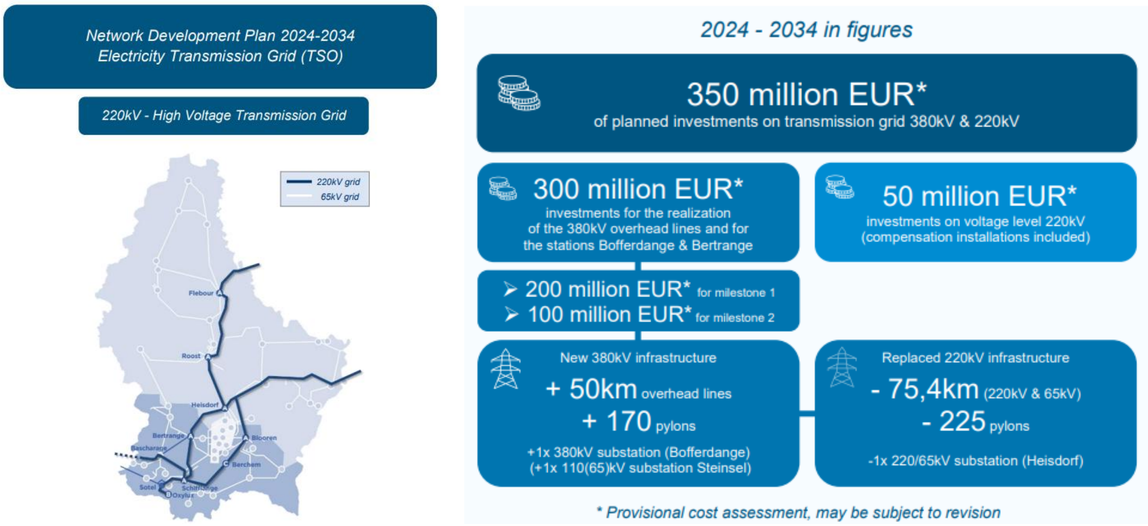

Figure 52. Luxembourg grid based on the ten year development plan map on the left and figures on the right

- <u>References:</u>

1. *Creos, "ANNUAL REPORT 2024", https://www.creos-net.lu/fileadmin/dokumente/downloads/ANNUAL_REPORT2024-WEB_DEF.pdf?t=1756904826096.*
2. *Creos, "NETOWORK DEVELOPMENT PLAN 2024-2034", https://www.creos-net.lu/fileadmin/dokumente/downloads/20240315_Network_Development_Plan_2024-2034_-_Electricity_Transmission_Grid.pdf?t=1739806160386.*

2.4.19. Malta

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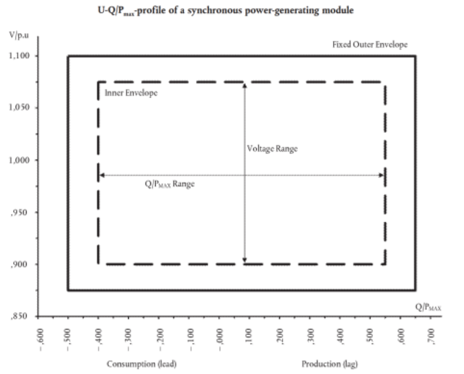
Grid requirements: The following information were summarized for the purpose of readability; more detailed information can be found in the provided references.

- <u>TSO:</u> EneMalta
- <u>Fault-ride through:</u> N/A
- <u>Voltage limits:</u> +- 6%
- <u>Frequency limits:</u> - 2.5 Hz, + 2 Hz
- <u>Capability curves:</u>



Synchronous area	Maximum range of Q/P_{max}	Maximum range of steady-state voltage level in PU
Continental Europe	0,75	0,225
Nordic	0,95	0,150
Great Britain	0 (*) 0,33 (**)	0,225
Ireland and Northern Ireland	0,66	0,218
Baltic	0,8	0,22

Figure 53. Capability curve required in Continental Europe

- <u>Reference:</u>
  1. *EneMalta, "The Network Code", 2013, [Network Code EMC Approved October 2013](). *
  2. *COMMISSION REGULATION (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators, COMMISSION REGULATION (EU) 2016/ 631 - of 14 April 2016 - establishing a network code on requirements for grid connection of generators.*

Land use: The development of onshore wind farms faces significant constraints related to visual and environmental impacts, inadequate road infrastructure, and interference with aviation zones. Due to the country's small size and high population density, available land for onshore wind projects is extremely limited. Strict land-use zoning has been in effect since 1992, defining development zones and special protection areas. Large-scale RES installations (such as onshore wind farms) are permitted in specific areas and under very strict licensing criteria, as defined by MEPA (Malta Environment and Planning Authority). There is no legislated uniform national minimum distance for onshore wind farms from residential areas; each case is examined individually during the licensing process, taking into account noise, shadow flicker, safety, and visual impacts.

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Areas prohibited for the installation of onshore wind farms include Natura 2000 sites and other protected natural areas, coastal habitat protection zones, aviation, radar, and telecommunications protection zones, as well as critical infrastructure areas, around which buffer zones are applied. Regarding suggested areas for wind farm installation, these are non-protected, low-environmental-sensitivity areas with access to electricity grids and road infrastructure, where visual impacts can be mitigated. Such areas that also have the necessary wind potential include l-Aħrax tal-Mellieħa, Wied Rini, Tal-Merhla, and Baħrija.

References

1. *Kotzebue, J. R., Bressers, H. T. A., & Yousif, C. (2010). Spatial misfits in a multi-level renewable energy policy implementation process on the Small Island State of Malta. Energy policy, 38(10), 5967-5976. (https://www.sciencedirect.com/science/article/pii/S0301421510004234)*
2. *Azzopardi, R. M. (2023). Malta: energy policy. In Encyclopedia of Mineral and Energy Policy (pp. 430-439). Berlin, Heidelberg: Springer Berlin Heidelberg. (https://link.springer.com/content/pdf/10.1007/978-3-662-47493-8_300008.pdf)*
3. *Grima, G. (2024). Investigating wind variations within the atmospheric boundary layer: a Maltese case study using LiDAR (Master's thesis, University of Malta). (https://www.um.edu.mt/library/oar/handle/123456789/130603)*
4. *Restall, B. (2010). Assessment of stakeholder perceptions towards Malta's land-based wind energy plans (Doctoral dissertation, Institute of Earth Systems (IES), University of Malta). (https://www.um.edu.mt/library/oar/handle/123456789/7011)*
5. *Farrugia, R. N., Deidun, A., Debono, G., Mallia, E. A., & Sant, T. (2010). The potential and constraints of wind farm development at nearshore sites in the Maltese islands. Wind Engineering, 34(1), 51-63. (https://journals.sagepub.com/doi/abs/10.1260/0309-524X.34.1.51)*
6. *González, J. S., & Lacal-Arántegui, R. (2016). A review of regulatory framework for wind energy in European Union countries: Current state and expected developments. Renewable and Sustainable Energy Reviews, 56, 588-602. (https://www.sciencedirect.com/science/article/pii/S1364032115013581)*

Grid capability: Malta does not have a dedicated electricity transmission system but it is based on the local distribution grid network composed of three voltages, 132 kV, 33 kV and 11 kV. According to Malta's 2030 National Energy and Climate Plan, the country's potential for renewable energy development is limited by environmental constraints and resource availability. For this onshore wind projects are generally quite unfeasible. Nonetheless, EneMalta is assessing an upgrade to the 132 kV network to meet the rising demand.

- Reference:

  1. *"Malta's 2030 National Energy and Climate Plan", December 2019, mt_final_necp_main_en_0.pdf.*

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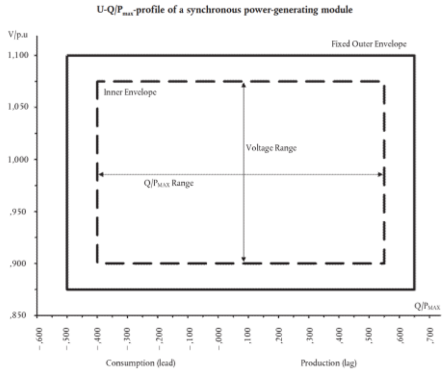
2.4.20. Netherlands

Grid requirements: The following information were summarized for the purpose of readability; more detailed information can be found in the provided references. No information was found sourced in TSOs documentation, so the following requirements were taken based on the references indicated.

- TSO: TenneT
- Fault-ride through: Must remain connected during dips down to 0.05/0.03 p.u. for 150 ms
- Voltage limits: +- 15%
- Frequency limits: - 2.5/3 Hz, + 2 Hz
- Capability curves:



Synchronous area	Maximum range of Q/P_{max}	Maximum range of steady-state voltage level in PU
Continental Europe	0,75	0,225
Nordic	0,95	0,150
Great Britain	0 (*) 0,33 (**)	0,225
Ireland and Northern Ireland	0,66	0,218
Baltic	0,8	0,22

Figure 54. Capability curve required in Continental Europe

- Reference:
    1. *COMMISSION REGULATION (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators, [COMMISSION REGULATION (EU) 2016/ 631 - of 14 April 2016 - establishing a network code on requirements for grid connection of generators]*.

Land use: The approval of onshore wind farm projects in the Netherlands is determined by Municipal Land Use Plans. Municipalities retain veto power over the installation of wind turbines within their territory, as there is no legal obligation to incorporate wind energy projects into local plans. Since 2000, the country's policy has encouraged the spatial clustering of wind turbines to reduce environmental and visual impacts. High population density, extensive agricultural land, and the presence of numerous protected landscapes create significant spatial and aesthetic constraints. Existing legislation does not provide a uniform national minimum distance for wind farms from residential areas. Distances are

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usually determined by local licensing authorities based on noise emission limits and shadow flicker criteria. In practice, the recommended distance ranges between 350 and 400 m.

Areas prohibited for the installation of onshore wind farms include Natura 2000 sites, ecological corridors, water-defence structures, aviation safety zones, and radar or military-significance areas. The licensing process for the installation and operation of a wind farm involves multiple approval stages covering spatial planning, environmental assessment, grid connection, and building permit approval. The total projected minimum duration averages 2 years but often extends up to 5 years. Regarding suggested areas for wind farm installation, these are agricultural and industrial areas with good access to the electricity grid and low residential density. Such areas are found in the provinces of Flevoland, Groningen, Zeeland, and North Holland, which combine high wind potential and availability of suitable land.

References

1. *Agterbosch, S., Vermeulen, W., & Glasbergen, P. (2004). Implementation of wind energy in the Netherlands: the importance of the social–institutional setting. Energy Policy, 32(18), 2049-2066. (https://www.sciencedirect.com/science/article/pii/S0301421503001800)*
2. *Agterbosch, S., Glasbergen, P., & Vermeulen, W. J. (2007). Social barriers in wind power implementation in The Netherlands: Perceptions of wind power entrepreneurs and local civil servants of institutional and social conditions in realizing wind power projects. Renewable and Sustainable Energy Reviews, 11(6), 1025-1055. (https://www.sciencedirect.com/science/article/pii/S1364032105001085)*
3. *González, J. S., & Lacal-Arántegui, R. (2016). A review of regulatory framework for wind energy in European Union countries: Current state and expected developments. Renewable and Sustainable Energy Reviews, 56, 588-602. (https://www.sciencedirect.com/science/article/pii/S1364032115013581)*

Grid capability: Generally, the TSO provides a lot of information and interactive interfaces related to the status of the grid. In particular, the grid capacity map available on the TSO website indicates that there is available space at the 110 kV and 150 kV substations for feeding in renewable electricity, already incorporating the capacity forecast up to the year 2030. Figure 55 shows the existing infrastructure comprising both onshore and offshore connections.

Currently, the TSO is forecasting the grid development up to year 2045 presented in Figure 56.

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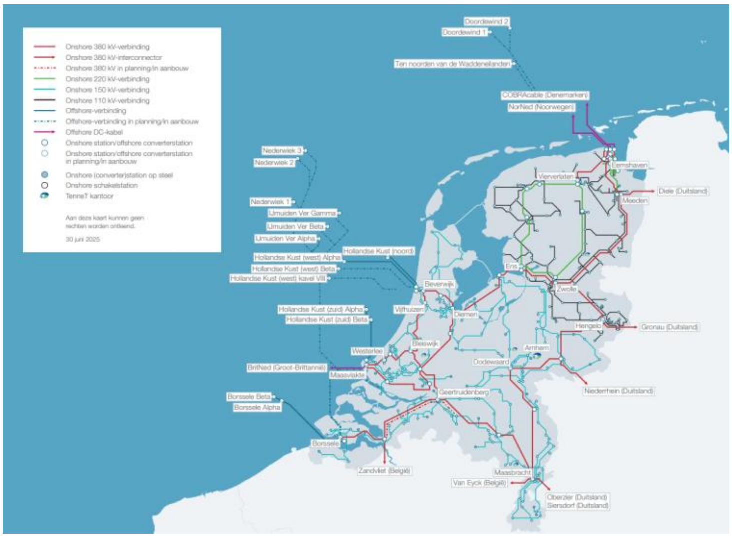

Figure 55. Dutch grid map

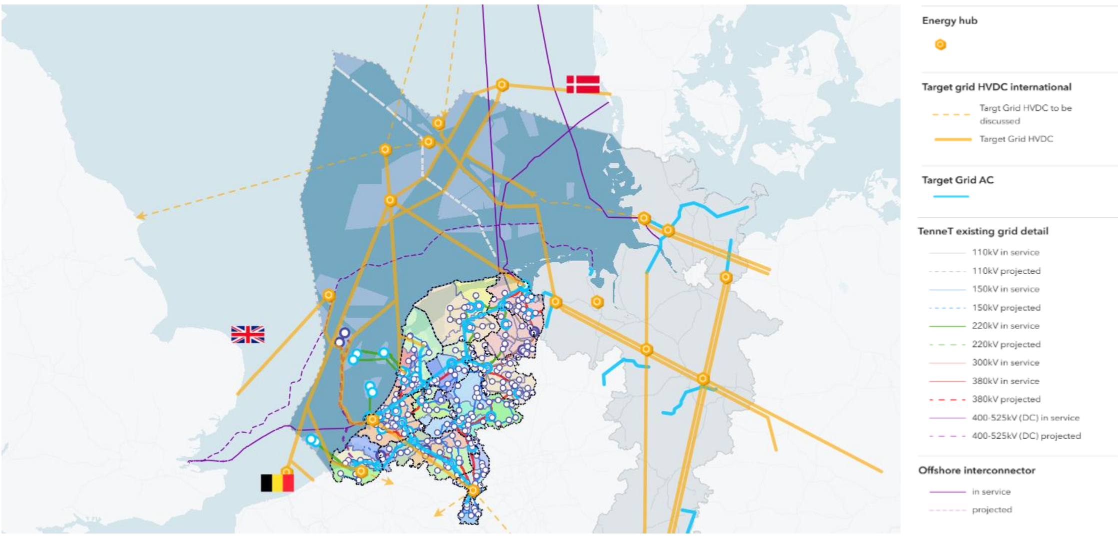

Figure 56. Dutch grid map based on the development plan

- Reference:
    1. *TenneT, "Grid capacity map", Grid capacity map. Accessed on September, 2025.*
    2. *TenneT, "Netkaarten", **NL_JUN2025_Onshore_Netherlands**, Accessed on September, 2025.*
    3. *TenneT, "Target Grid", Target Grid, Accessed on September, 2025.*

2.4.21. Norway

Grid requirements: The following information were summarized for the purpose of readability; more detailed information can be found in the provided references.

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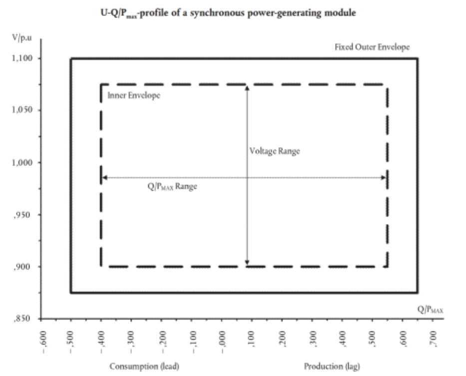
- TSO: Statnett
- Fault-ride through: Must remain connected during dips down to 0 p.u. for 150 ms
- Voltage limits: - 10%, + 5%
- Frequency limits: - 2.5 Hz, + 2 Hz
- Capability curves:



Synchronous area	Maximum range of Q/P_{max}	Maximum range of steady-state voltage level in PU
Continental Europe	0,75	0,225
Nordic	0,95	0,150
Great Britain	0 (*) 0,33 (**)	0,225
Ireland and Northern Ireland	0,66	0,218
Baltic	0,8	0,22

Figure 57. Capability curve required in Nordic

- Reference:
    1. *Statnett, Funksjonskrav i kraftsystemet (FIKS 2012) publisert | Statnett, Accessed on: June, 2025.*
    2. *COMMISSION REGULATION (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators, COMMISSION REGULATION (EU) 2016/ 631 - of 14 April 2016 - establishing a network code on requirements for grid connection of generators.*

Land use: The siting of onshore wind farms in Norway is regulated by the Energy Act and the Planning and Building Act. Although municipalities manage general spatial planning, energy production facilities are approved at the national level. Onshore wind farms occupy an average of 9.7 km^2 per project; however, only 2.3% of the total area is directly used for infrastructure (roads, turbine foundations). The remaining land remains undeveloped due to noise and safety constraints. There is no legislated fixed national minimum distance between wind turbines and residences. Their proximity is determined based on noise and shadow flicker criteria according to the Pollution Control Act and project environmental impact assessments. In practice, a noise limit of 40 dB(A) at night is applied, which corresponds to a distance of approximately 500–700 m for modern wind turbines, depending on the terrain and park layout.

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Excluded from potential onshore wind farm installation areas are national parks and nature reserves, protected areas (Natura 2000), traditional reindeer herding lands, aviation and radar safety zones, as well as areas of high biodiversity and bird migration corridors. From 2019 to 2022, the licensing of new onshore wind projects was suspended; since then, new licenses are permitted only with municipal consent and have a duration of 25 years. Suitable areas for siting onshore wind farms are suggested to be mountainous regions with bare rocky ground, where there is no agricultural or other productive activity. Forest areas dominated by coniferous species such as *Picea abies* (Norway spruce) and *Pinus sylvestris* (Scots pine) are also proposed, as well as areas with low population density to limit social opposition.

References

1. *Mósesdóttir, L. (2024). Energy (in) justice in the green energy transition. The case of Fosen wind farms in Norway. Technology in society, 77, 102563. (https://www.sciencedirect.com/science/article/pii/S0160791X24001118)*
2. *Jikiun, S. P., Tatham, M., & Oltedal, V. M. (2023). Saved by hydrogen? The public acceptance of onshore wind in Norway. Journal of cleaner production, 408, 136956. (https://www.sciencedirect.com/science/article/pii/S0959652623011149)*
3. *Kenawi, M. S., Hedger, R. D., Alfredsen, K. T., Sandercock, B. K., Korpås, M., & Bakken, T. H. (2025). Land efficiency of renewable energy in Norway: A synthesis of footprint and production density. Renewable Energy, 123514. (https://www.sciencedirect.com/science/article/pii/S0960148125011760)*
4. *Enevoldsen, P. (2016). Onshore wind energy in Northern European forests: Reviewing the risks. Renewable and Sustainable Energy Reviews, 60, 1251-1262. (https://www.sciencedirect.com/science/article/pii/S1364032116002355)*
5. *Linnerud, K., Dugstad, A., & Rygg, B. J. (2022). Do people prefer offshore to onshore wind energy? The role of ownership and intended use. Renewable and Sustainable Energy Reviews, 168, 112732. (https://www.sciencedirect.com/science/article/pii/S1364032122006219)*
6. *Dahl, I. R., Tveiten, B. W., & Cowan, E. (2022). The case for policy in developing offshore wind: Lessons from norway. Energies, 15(4), 1569. (https://www.mdpi.com/1996-1073/15/4/1569)*
7. *Kraft, P., & Kraft, B. (2025). Public attitudes and the socio-political divide surrounding onshore wind power in Norway. Frontiers in Sustainable Energy Policy, 4, 1538828. (https://www.frontiersin.org/journals/sustainable-energy-policy/articles/10.3389/fsuep.2025.1538828/full)*
8. *Kenawi, M. S. R., Hedger, R., Alfredsen, K., Korpås, M., Sandercock, B. K., & Bakken, T. H. (2024). Synthesis of Footprint and Production Density for Solar, Hydro, and Onshore Wind in Norway. Hydro, and Onshore Wind in Norway (June 28, 2024).(https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5020007)*

Grid capability: Generally, the TSO provides a lot of information and interactive interfaces related to the status of the grid. The transmission system's total length is 12,000 km and it mostly carries a high voltage of 300 up to 420 kV, but in certain parts also the 132 kV lines are present. Figure 58 presents a

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snippet of the real time power situation, highlighting the risk of rationing the electricity supplied by hydropower, representing nearly all electricity generate in Norway.

In 2023 the TSO has published the ten-years development plan to reinforce the grid. As of 2023, the reserved capacity amounted to 6800 MW for new consumption and 3900 MW for new generation, nonetheless the TSO is planning upgrades at the system focusing mostly in the areas shown in Figure 59.

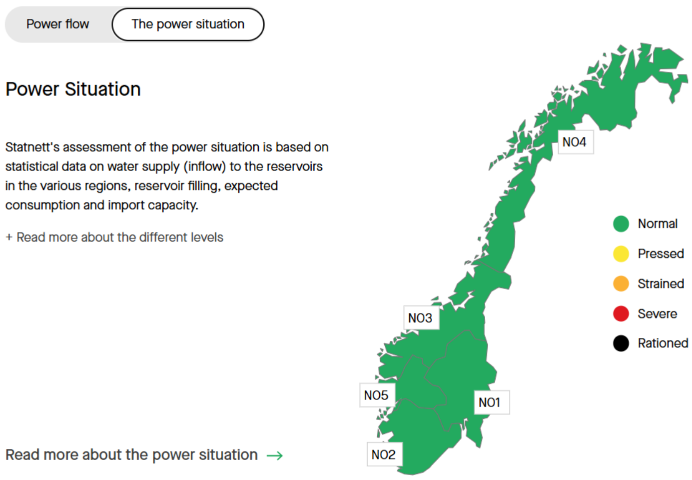

Figure 58. Snippet of real-time power situation in Norway (October 20th 2025)

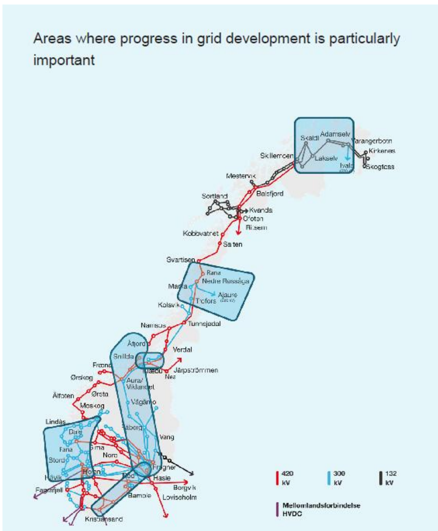

Figure 59. Areas where grid upgrades are mostly needed in Norway

- <u>Reference:</u>
  1. *Statnett, "Data from the power system", [Data from the power system | Statnett](), Accessed on October, 2025.*

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2. *Statnett, "System Development Plan 2023".*

2.4.22. Poland

Grid requirements: The TSO is Polskie Sieci Elektroenergetyczne (PSE) but no information was found regarding the connection requirements for wind farms and therefore the European regulation can be considered.

- Reference:
    1. *COMMISSION REGULATION (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators, COMMISSION REGULATION (EU) 2016/ 631 - of 14 April 2016 - establishing a network code on requirements for grid connection of generators.*

Land use: The spatial planning system is decentralized, as the municipalities (gminas) define the wind development zones, which, however, must align with national energy and environmental frameworks. Each municipality has the right to decide independently on the acceptance of wind farms within its area of responsibility. The development of onshore wind farms in Poland is governed by strict spatial planning rules, based on the Act on Wind Farm Investments, the Local Spatial Development Plans (LSDPs), and the Environmental Impact Assessment (EIA) regime. The national minimum distance between wind turbines and residences has been set at ≥ 700 m, following the 2023 legislative revision, provided that noise and safety limits are met, and that the project is included in an approved Local Spatial Development Plan (LSDP).

Excluded from potential installation sites for onshore wind farms are protected bird habitats, areas at high risk of flooding or landslides, high-fertility soils, airports and radar installations, high-voltage lines, wetlands and forests, Natura 2000 areas and national parks, military zones, and areas with low wind potential. To date, Renewable Acceleration Areas (RAAs) have not yet been delimited, but the roadmap provides for their establishment by February 2026, in accordance with the RED III Directive. Areas with wind speeds >5.5 m/s, proximity to grids, which can be either industrial or agricultural areas with degraded lands, can be considered as suggested areas for the installation of onshore wind farms. Such areas are mainly found in Central and Northern Poland, such as Koszalin, Toruń, and Bydgoszcz.

References

1. *Kazak, J., Van Hoof, J., & Szewranski, S. (2017). Challenges in the wind turbines location process in Central Europe–The use of spatial decision support systems. Renewable and Sustainable Energy Reviews, 76, 425-433. (https://www.sciencedirect.com/science/article/pii/S136403211730357X)*
2. *Sliz-Szkliniarz, B., Eberbach, J., Hoffmann, B., & Fortin, M. (2019). Assessing the cost of onshore wind development scenarios: Modelling of spatial and temporal distribution of wind power for*

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the case of Poland. Renewable and Sustainable Energy Reviews, 109, 514-531.(https://www.sciencedirect.com/science/article/pii/S1364032119302515)

3. *Zarębski, P., Katarzyński, D., Godlewska-Majkowska, H., Komor, A., & Gawryluk, A. (2024). Wind Farms' Location and Geographical Proximity as a Key Factor in Sustainable City Development: Evidence from Poland. Energies (19961073), 17(14). (https://www.mdpi.com/1996-1073/17/14/3447)*
4. *Wingenbach, M., Dünzen, K., Krieger, S., & Gibson, J. (2024). Overview of Renewable Energy Spatial Planning and Designation of Acceleration Areas in Selected EU Member States. (https://caneurope.org/content/uploads/2024/05/RE-Spatial-Planning-Acceleration-in-EU-MS_13052024.pdf) 5. Dobrowolski, Z., Adamišin, P., Babczuk, A., & Kotylak, S. (2025). Towards a Green Transformation: Legal Barriers to Onshore Wind Farm Construction. Energies, 18(5), 1271. (https://www.mdpi.com/1996-1073/18/5/1271)*
5. *D'Angelo, M. (2020). Onshore Wind Energy Market Analysis of Sweden, Poland and Romania (Master's thesis), KTH School of Industrial Engineering and Management, Stockholm (https://www.diva-portal.org/smash/get/diva2:1472686/FULLTEXT01.pdf)*

Grid capability: The transmission system is composed of 311 lines with a total length of 16,601 km, including the 110 kV high voltage level and the 200-400 kV extra-high voltage level (see Figure 60).

The TSO had published the ten-years development for the 2023-2032 period and the following one for 2025-2034 is currently in its draft version. Both plans are focused on renewable energies integration with particular attention to onshore and offshore wind. For a total of 389 projects, the overall investment is estimated to amount to 15 billion euros.

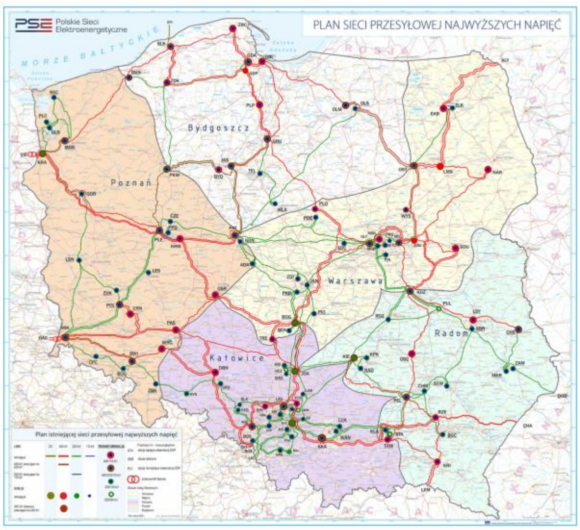

Figure 60. Polish grid map

- <u>Reference:</u>

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1. *PSE, "Scheme of extra high voltage power grid", Scheme of the extra high voltage power grid - PSE eng, Accessed on September, 2025.*
2. *PSE, "Development of the transmission system", Development of the transmission system - PSE Raport, Accessed on September, 2025.*

2.4.23. Portugal

Grid requirements: The following information were summarized for the purpose of readability; more detailed information can be found in the provided references.

- TSO: REN
- Fault-ride through: Must remain connected during dips down to 0 p.u. for 250 ms
- Voltage limits: +- 5%
- Frequency limits: - 2.5 Hz, + 1.5 Hz
- Capability curves:

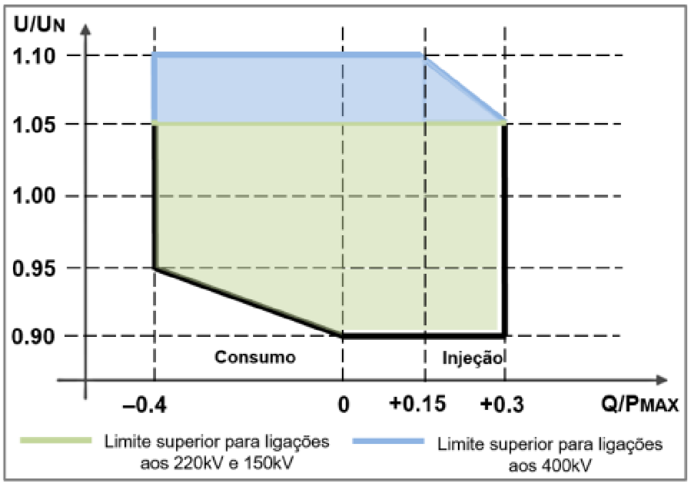

Figure 61. Capability curve required in Portugal

- Reference:
    1. *REN, ENERGY MARKET INFORMATION SYSTEM, Accessed on: June 2025.*

Land use: The development of onshore wind farms in Portugal follows multi-level planning: national, regional, and municipal, covering 308 municipalities. Specifically, their siting is determined by the National Spatial Planning Policy Programme and the National Renewable Energy Action Plan, which are implemented through municipal land use plans. According to the SIMPLEX Urbanism law, a project covering less than 2% of municipality area cannot be rejected. The main existing spatial restrictions primarily concern protected landscapes, cultural heritage areas, and high-risk forest fire zones.

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Regarding the minimum distance of wind farms from residential areas, this is defined based on Decree-Law 9/2007 and noise levels and is set at 500 m for wind turbines producing noise <105 dB and at 700 m for larger wind turbines producing noise > 105 dB.

Exclusion zones for onshore wind farms include Natura 2000 areas, RAMSAR wetlands, UNESCO protected areas, semi-mountainous areas with a slope >14°, and safety zones around critical infrastructure. Recent legislative reforms (Decree-Laws 15/2022 and 30-A/2022) define Renewable Energy Acceleration Areas (RAAs), which provide for faster approval and preventive environmental assessment for areas of low environmental sensitivity. Regarding the suggested types of areas for wind farm installation, these can be agricultural and mountainous areas in non-protected zones in the northern and central parts of the country, with strong wind potential and easy access to the electricity grid. Such areas may include: Minho, Trás-os-Montes, Beira Alta, and Serra da Estrela.

References

1. *Wingenbach, M., Dünzen, K., Krieger, S., & Gibson, J. (2024). Overview of Renewable Energy Spatial Planning and Designation of Acceleration Areas in Selected EU Member States (https://caneurope.org/content/uploads/2024/05/RE-Spatial-Planning-Acceleration-in-EU-MS_13052024.pdf)*
2. *Government of Portugal (2022). Decree-Law No. 15/2022 of 14 January – Organisation of the National Electricity System. Diário da República, 1st Series, No. 10. (https://diariodarepublica.pt/dr/en/detail/decree-law/15-2022-177634016)*
3. *Government of Portugal (2022). Decree-Law No. 30-A/2022 of 18 April – Simplification of Renewable Energy Licensing Procedures. Diário da República, 1st Series, No. 75. (https://diariodarepublica.pt/dr/detalhe/decreto-lei/30-a-2022-182213906)*

Grid capability: The TSO operates the 400 kV, 220 kV and 150 kV extra-high voltage grid, lines and respective substations. In 2024 the overall length of the transmission system amounted to 9,661 km and an overall installed power of 22,813 MW, shown in Figure 62.

The latest development plan published was the PDIRT 2022-2031. Within the plan two types of investment are foreseen: base projects referring to all interventions that aim at maintaining the system in operation and safety, and complementary projects referring to infrastructure related to the promotion of the energy transition and sustainability. Considering two phases for the development plan, in the period between 2022 and 2026 the expected investment was of 71,1 M€, with a higher priority to base projects amounting for 57.9 M€, and in the period between 2027 and 2031 the expected investment amounts to 79,6 M€ prioritizing complementary project with 47.7 M€ dedicated.

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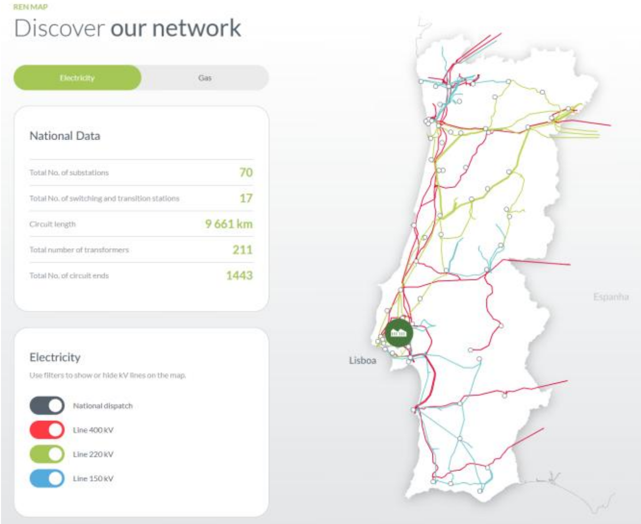

Figure 62. Portuguese grid map

- References:
    1. *REN, "Electricity", [REN | Electricity](), Accessed on September, 2025.*
    2. *REN, "PDIRT Plano de desenvolvimento e investimento da rede nacional de transporte 2022-31", November 2021.*

2.4.24. Romania

Grid requirements: The following information were summarized for the purpose of readability; more detailed information can be found in the provided references.

- TSO: Transelectrica
- Fault-ride through: N/A
- Voltage limits: +- 2%
- Frequency limits: - 3 Hz, + 2 Hz
- Capability curves:

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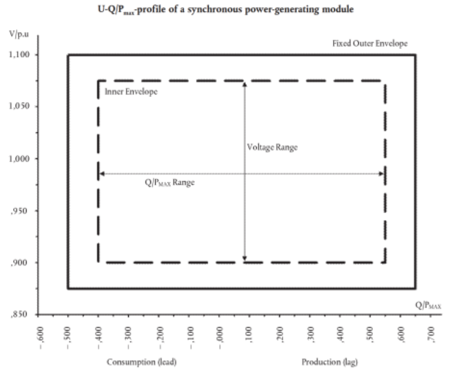

Synchronous area	Maximum range of Q/P_{max}	Maximum range of steady-state voltage level in PU
Continental Europe	0,75	0,225
Nordic	0,95	0,150
Great Britain	0 (*) 0,33 (**)	0,225
Ireland and Northern Ireland	0,66	0,218
Baltic	0,8	0,22

Figure 63. Capability curve required in Continental Europe

- Reference:
    1. Transelectrica, "Technical Transmission Grid Code of the Romanian Power System", 2004, Microsoft Word - cod_ret_eng.doc.
    2. COMMISSION REGULATION (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators, COMMISSION REGULATION (EU) 2016/ 631 - of 14 April 2016 - establishing a network code on requirements for grid connection of generators.

Land use: Spatial planning for onshore wind farms in Romania is regulated by the Law on Spatial and Urban Planning (No. 350/2001), the Law on Environmental Protection (No. 137/1995), and the Law on Renewable Energy Sources (No. 220/2008). In relation to existing spatial restrictions, minimum distances are applied from critical infrastructure and facilities, such as motorways and national roads, electrified railway lines, overhead power transmission networks, surface pipelines for flammable and non-flammable fluids, oil and natural gas extraction facilities, dams, bridges, flammable materials storage facilities, and telecommunication stations. For all the facilities and critical infrastructure mentioned above, the minimum distance is defined as ≥ 200m. Regarding the minimum distances between wind turbines, these are determined according to the prevailing wind direction and are specifically 4–7 times the rotor diameter in the direction of the prevailing wind. There is no fixed national minimum distance imposed between wind turbines and residences, and distances are usually determined based on noise and shadow flicker criteria. In practice, distances of 400–700 m are applied to meet the noise limits of ≤ 45 dB(A) during the day and ≤ 35 dB(A) at night.

Siting exclusion zones for onshore wind farms concern Natura 2000 areas, national parks and natural habitats, coastal wetlands, archaeological and cultural sites, as well as military zones. As for potential areas for wind farm installation, these may be in the Dobrogea Region, the Bârlad Plateau area, the

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Bărăgan Plain, and parts of the Banat region characterized by high wind potential and suitable infrastructure.

References

1. *Dragomir, G., Șerban, A., Năstase, G., & Brezeanu, A. I. (2016). Wind energy in Romania: A review from 2009 to 2016. Renewable and Sustainable Energy Reviews, 64, 129-143. (https://www.sciencedirect.com/science/article/pii/S1364032116301927)*
2. *Foanene, A., Velev, G. T., Timmerberg, J., Ormandzhiev, K. H., & Renken, F. (2018). Development of wind power in Europe. Annals of'Constantin Brancusi'University of Targu-Jiu. Engineering Series/Analele Universităţii Constantin Brâncuşi din Târgu-Jiu. Seria Inginerie. (https://www.utgjiu.ro/rev_ing/pdf/2018-3/19_A.FOANENE%20s.a.%20-DEVELOPMENT%20OF%20WIND%20POWER%20IN%20EUROPE1.pdf)*
3. *Resch, G., Liebmann, L., Hirner, R., Mezosi, A., Szabo, L., & Varga, K. (2023). Study on the wind power potential in Bulgaria, Hungary and Romania. Technical Report. (https://rekk.hu/downloads/projects/ECF%20Study%20on%20the%20Assessment%20of%20Wind%20Potentials%20-%20Country%20Report%20Hungary%20(AIT,%20REKK%20-%202023-11-30).pdf)*
4. *D'Angelo, M. (2020). Onshore Wind Energy Market Analysis of Sweden, Poland and Romania (Master's thesis), KTH School of Industrial Engineering and Management, Stockholm (https://www.diva-portal.org/smash/get/diva2:1472686/FULLTEXT01.pdf)*

Grid capability: Generally, the TSO provides a lot of information and interactive interfaces related to the status of the grid. The nation grid operates the 750 kV, 300 kV, 220 kV and 110 kV level of tension for an overall interconnection line length of 486.2 km. Moreover, based on the transformer units the total power installed amounts to 38058 MVA. A development plan targeting the year 2019 was carried out, nonetheless no further updates regarding future investments were found.

2.4.25. Slovakia

Grid requirements: The TSO is SEPS but no information was found regarding the connection requirements for wind farms and therefore the European regulation can be considered.

- Reference:
  1. *COMMISSION REGULATION (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators, COMMISSION REGULATION (EU) 2016/ 631 - of 14 April 2016 - establishing a network code on requirements for grid connection of generators.*

Land use: A lack of spatial planning for RES at the municipal level is evident, as well as an absence of a legislated framework for wind energy zones. In the context of REPowerEU, Slovakia plans to establish

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'go-to areas' (priority areas) for the development of RES projects, based on environmental, technical, and social criteria. There is no fixed national minimum distance imposed between wind turbines and residences, and distances are usually determined based on noise and shadow flicker criteria. In practice, distances of the order of 500–700 m are applied to meet the noise limits of ≤ 45 dB(A) during the day and ≤ 35 dB(A) at night.

Regarding siting exclusion zones for onshore wind farms, these comprise Natura 2000 areas, national parks and natural reserves, aviation protection zones, densely populated areas, military zones and radar operation areas, as well as cultural monuments or landscapes of particular importance. Also, the respective local authorities have the jurisdiction to reject the installation and operation of an onshore wind farm when its siting is related to areas of high tourist or cultural value. In recent years, the development of RES in the country has been determined by the National Energy and Climate Plan (NECP) and the REPowerEU initiative. Recent policy guidelines provide for the integration of renewable source zones into the NECP and the simplification of administrative procedures, in accordance with the provisions of the RED III Directive. As for potential areas for wind farm installation, these may be in the Trnava region (such as: Drahovce, Galanta), the Záhorie region (Skalica), and the Košice region. These specific areas have low population density and direct access to energy transmission networks, making them potential candidates for future wind project development.

References

1. *González, J. S., & Lacal-Arántegui, R. (2016). A review of regulatory framework for wind energy in European Union countries: Current state and expected developments. Renewable and Sustainable Energy Reviews, 56, 588-602. (https://www.sciencedirect.com/science/article/pii/S1364032115013581)*
2. *Pavlickova, K., Miklosovicova, A., & Vyskupova, M. (2014). Effects of Sustainable Energy Facilities on Landscape: A Case Study of Slovakia. In Designing Low Carbon Societies in Landscapes (pp. 109-127). Tokyo: Springer Japan. (https://link.springer.com/chapter/10.1007/978-4-431-54819-5_7)*
3. *Fryslân, L. C., & Vaseckova, M. (2024). Barriers to Renewable Energy Transition in Slovakia. (https://campus-fryslan.studenttheses.ub.rug.nl/417/1/BAS4988930MVVaseckova.pdf)*
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5. *Probala, D., Sabolová, B., & Jeňo, M. (2016). Urban wind turbines and the possibility of their use in Slovakia. Acta Technologia, 2(4), 11-16. (https://www.actatecnologia.eu/issues/2016/IV_2016_03_Probala_Sabolova_Jeno.pdf)*
6. *Dokupilová, D., Repíková, M. (2024). Decarbonising Slovakia. Pathways to climate neutrality in 2050. The Institute for Forecasting, Centre of Social and Psychological Sciences, Slovak Academy of Sciences, Bratislava,*

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(https://www.sav.sk/uploads/monography/31/410/fulltext/11281314Decarbonising_Slovakia_Pathways_2050_final.pdf)

Grid capability: The transmission system operates the 400 kV, 220 kV and 110 kV voltage levels for an overall deployed length of around 3,125 km. Currently the ten-years development plan 2020-2029 is in force, providing many detailed information regarding the current status of the grid (see Figure 64). Within the plan an increased of 1,000 MW is expected, corresponding to approximately 8 TWh in the electricity production. For this the transmission system requires an upgrade whose investment is estimated to be approximately 614.98 M€, composed of the terms shown in Figure 65.

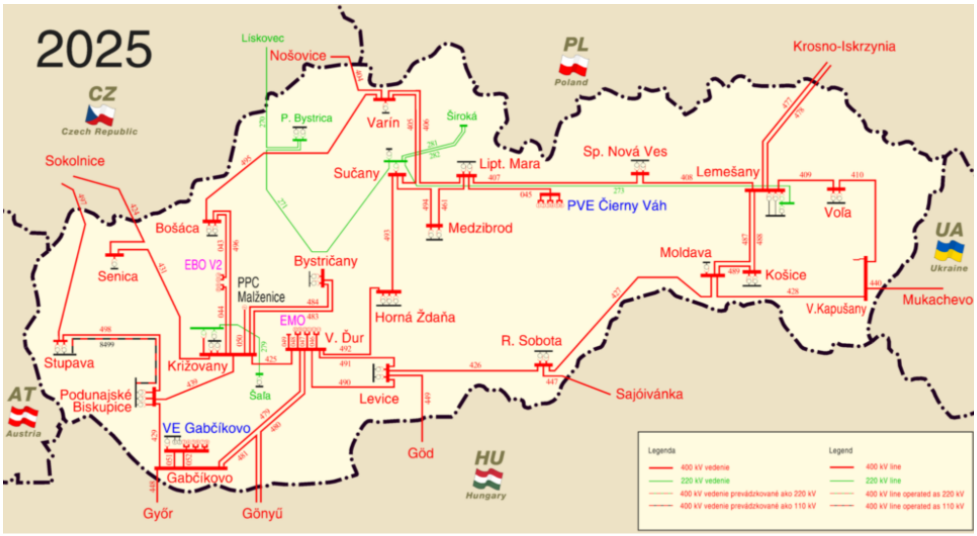

Figure 64. Slovak grid map

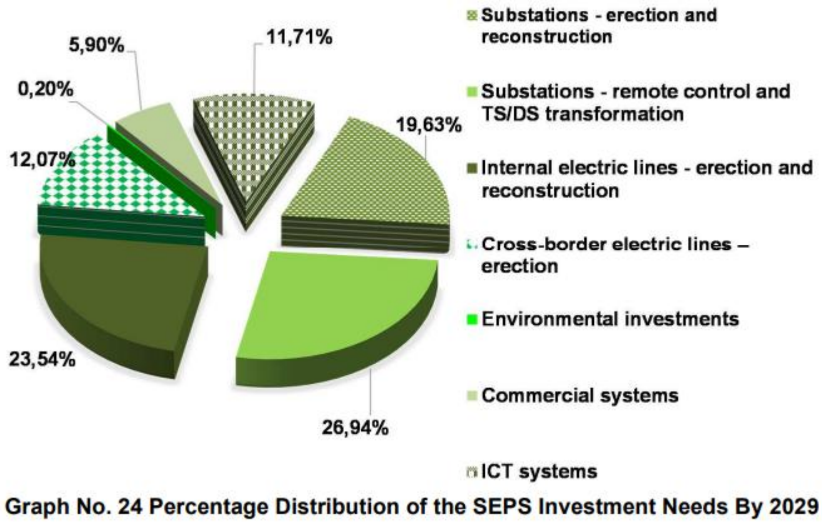

Figure 65. SEPS Investment Needs by 2029

- <u>References:</u>

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1. *SEPS, "Grid maps", [Grid maps - Slovenská elektrizačná prenosová sústava, a.s.](), Accessed on September, 2025.*
2. *SEPS, "TEN-YEAR DEVELOPMENT PLAN FOR THE PERIOD 2020-2029", April 2019.*

2.4.26. Slovenia

Grid requirements: The TSO is ELES but no information was found regarding the connection requirements for wind farms and therefore the European regulation can be considered.

- Reference:

1. *COMMISSION REGULATION (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators, COMMISSION REGULATION (EU) 2016/ 631 - of 14 April 2016 - establishing a network code on requirements for grid connection of generators.*

Land use: The installation of onshore wind farms in Slovenia requires integration into modified municipal spatial plans. The utilization of wind energy is regulated by the Spatial Planning Act and the Environmental Protection Act, which are implemented through national and municipal spatial plans. Approximately 36% of Slovenian territory is under protection status, which requires specialized scientific assessments for each project. A minimum defined distance from settlements is set at 800 m, while from urban areas, it is set at 1,200 m.

Exclusion zones comprise Natura 2000 areas, national parks, wetlands, avifauna habitats, and bird migration corridors. For the aforementioned areas, buffer zones around them are also established in several cases, which can reach up to 1 km, depending on the type of area. Recent policy initiatives in the country within the framework of the National Energy and Climate Plan (NECP) and the new Renewable Energy Promotion Act aim to simplify permitting procedures and accelerate the development of RES projects. Suitable areas for wind farm siting are suggested to be areas with moderate wind potential and low environmental sensitivity, such as: Nanos, Golič, Vremščica, Volovja Reber, Vipava valley, Trnovo Forest plateau, and selected areas of the Goriška region.

References

1. *Ryberg, D. S., Tulemat, Z., Stolten, D., & Robinius, M. (2020). Uniformly constrained land eligibility for onshore European wind power. Renewable energy, 146, 921-931. (https://www.sciencedirect.com/science/article/pii/S0960148119309619)*
2. *González, J. S., & Lacal-Arántegui, R. (2016). A review of regulatory framework for wind energy in European Union countries: Current state and expected developments. Renewable and Sustainable Energy Reviews, 56, 588-602. (https://www.sciencedirect.com/science/article/pii/S1364032115013581)*

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3. *Fuechtbauer, A. (2019). Between a rock and a hard place. Assessing policy coherence of energy, climate, and biodiversity policies in relation to hydropower developments in Slovenia. IIIEE Master Thesis.(https://lup.lub.lu.se/student-papers/search/publication/8996856)*
4. *Golobič, M. (2005). Are wind farms a problematic project?. Urbani izziv, 16(1), 156-160. (https://www.ceeol.com/search/article-detail?id=252623)*
5. *Holjevac, N., Zidar, M., Krpan, M., & Kuzle, I. (2019, October). Optimizing the Grid Connection Scheme of the Wind Power Plant. In Proceedings of the 14th Conference on Sustainable Development of Energy, Water and Environment Systems (SDEWES), Dubrovnik, Croatia (pp. 1-6). (https://windlips.com/wp-content/uploads/2019/10/SDEWES2019.1039_v3.pdf)*

Grid capability: The TSO is responsible for 669 km of 400 kV, 328 km of 220 kV and 1,862 of 110 kV transmission network. Generally, the TSO provides a lot of information and interactive interfaces related to the status of the grid. A snippet of the real-time utilization of the system is shown in Figure 66.

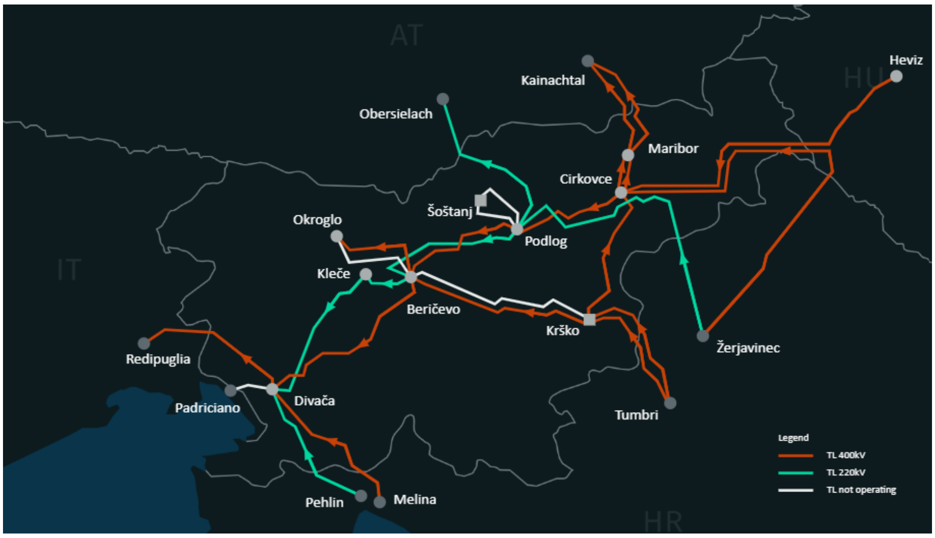

Figure 66. Slovak grid map

Within the Development Plan for the 2023-2032 period, it is possible to verify which connections are most loaded and what it is expected to be the load in 2032 without any grid reinforcement (see Figure 67). Based on this, Figure 68 shows the grid upgraded accordingly with the ten-years development plan.

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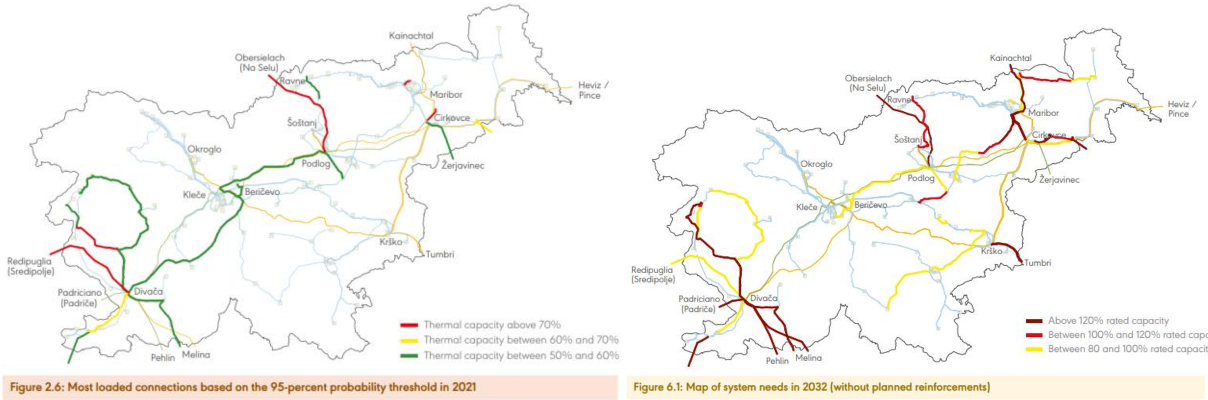

Figure 2.6: Most loaded connections based on the 95-percent probability threshold in 2021
Figure 6.1: Map of system needs in 2032 (without planned reinforcements)

Figure 67. Most loaded connection in Slovenia in 2021 on the right and load forecast in 2032 without any reinforcement on the left

Figure 6.4: Long-term development options of the Slovenian transmission network

Figure 68. Slovenian grid map based on the development plan

- References:

1. *ELES, "Slovenian Network Development Plan 2023-2032", https://www.eles.si/Portals/EN/Documents/EN/ELES_development_plan_2023-2032.pdf?ver=2023-06-16-154317-607.*

2.4.27. Spain

Grid requirements: The following information were summarized for the purpose of readability; more detailed information can be found in the provided references.

- TSO: RED

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- Fault-ride through: Must remain connected during dops down to 0.05 p.u. for 150 ms
- Voltage limits: +- 15%
- Frequency limits: - 2.5 Hz, + 1.5 Hz
- Capability curves:

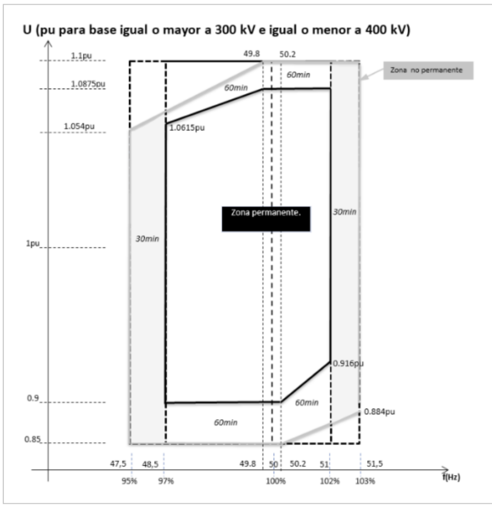

Figure 69: Capability curve of Spain

Reference:

1. *Red Eléctrica de Espana, "Desarrollo de los requisitos técnicos del Reglamento (UE) 2016/631", 2017, [Dirección Emisora].*
2. *Gobierno de Espana, "Orden TED/749/2020", https://www.boe.es/buscar/doc.php?id=BOE-A-2020-8965.*

Land use: A decentralized spatial planning approach is applied in relation to wind farms, as the siting authority belongs to the 17 Autonomous Communities under the national coordination of the Ministry for the Ecological Transition and the Demographic Challenge (MITECO). Existing spatial restrictions are defined through zone categories, which impose specific limitations and base their classification on environmental sensitivity and the land uses permitted within them. Specifically, the following zones exist: i) Natura 2000 zones and other protected areas, ii) Improvement zones, iii) Development zones, iv) Archaeological Zones of Interest, v) Zones with threatened flora or rare habitats. The defined minimum distance between wind turbines is ≥ 100 m, while there is no legislated uniform national minimum distance for wind farms from residential areas. In practice, distances of 400 to 600 meters are applied.

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Excluded from wind farm installation are Natura 2000 areas, reforestation areas, cultural and archaeological zones, recreation areas, reserve areas, active conservation areas (including forest ecosystems and mountain meadows), and protection areas (including lands with steep slopes and high erosion risk). With the recent legislative reforms (Royal Decree-Laws 6/2022 and 20/2022, as well as the +SE Plan 2023) that have been implemented, the delimitation of Renewable Acceleration Areas (RAAs) has been achieved. These are zones of low environmental conflict with accelerated permitting (≤18 months). Simplified repowering procedures for existing parks have also been defined, and finally, a faster grid connection assessment by Red Eléctrica de España has been achieved. Agricultural areas with high wind potential and developed infrastructure, such as the Communities of Castilla y León, Aragón, Navarra, and Galicia, are considered suitable for the siting of onshore wind farms.

References

1. *Wingenbach, M., Dünzen, K., Krieger, S., & Gibson, J. (2024). Overview of Renewable Energy Spatial Planning and Designation of Acceleration Areas in Selected EU Member States (https://caneurope.org/content/uploads/2024/05/RE-Spatial-Planning-Acceleration-in-EU-MS_13052024.pdf)*
2. *Ministry for the Ecological Transition and the Demographic Challenge (MITECO). (2024). Integrated National Energy and Climate Plan: Update 2023–2030. Third Vice-Presidency of the Government of Spain. Madrid: Government of Spain. NIPO: 665-20-021-X. (https://commission.europa.eu/document/download/211d83b7-b6d9-4bb8-b084-4a3bfb4cad3e_en?filename=ES%20-%20FINAL%20UPDATED%20NECP%202021-2030%20%28English%29.pdf*

Grid capability: Generally, the TSO provides a lot of information and interactive interfaces related to the status of the grid. The latest development plan applied to the period 2021-2025 and the TSO is currently defining the next development plan which is now under public consultation. Current developments can be retrieved from the interactive interfaces indicated in the reference.

- Reference:
  1. *Red Eléctrica, "Network Development Plan", Current planning | Network Development Plan, Accessed on: September, 2025.*

2.4.28. Sweden

Grid requirements: The following information were summarized for the purpose of readability; more detailed information can be found in the provided references.

- TSO: Svenska Kraftnat
- Fault-ride through: Must remain connected during dops down to 0 p.u. for 150 ms
- Voltage limits: - 10%, + 5%
- Frequency limits: - 2.5 Hz, + 2 Hz

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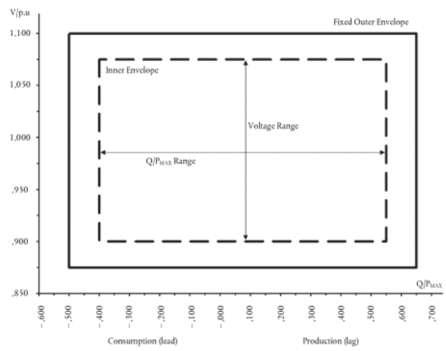
- Capability curves:

U-Q/P_{max}-profile of a synchronous power-generating module



Synchronous area	Maximum range of Q/P_{max}	Maximum range of steady-state voltage level in PU
Continental Europe	0,75	0,225
Nordic	0,95	0,150
Great Britain	0 (*) 0,33 (**)	0,225
Ireland and Northern Ireland	0,66	0,218
Baltic	0,8	0,22

Figure 70. Capability curve required in Nordic

- Reference:
    1. *COMMISSION REGULATION (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators, COMMISSION REGULATION (EU) 2016/ 631 - of 14 April 2016 - establishing a network code on requirements for grid connection of generators*.

Land use: The siting of onshore wind farms in Sweden is guided by the National Wind Strategy, which sets regional targets and the spatial development framework. Areas of national interest for wind energy have been officially designated by the Swedish Energy Agency (SEA), a fact that elevates the priority of wind energy over other land uses in spatial planning. There are defined land use restrictions that include safety zones of 250 m from road networks and power transmission lines, and distances of 500–1000 m from cultural heritage monuments and historical sites. The minimum distance for onshore wind farms from urban/tourist areas is set at 800 m, while it is set at 1,000 m from densely populated areas.

Exclusion zones for the installation and operation of wind farms are: Natura 2000 areas, urban settlements, wetlands, forests, protected natural areas, bird habitats, as well as reindeer grazing areas. Since 2009, national legislation has given municipalities the right of veto for wind energy projects within their borders, without requiring justification. During the period 2014–2018, the rejection rate for such projects amounted to approximately 11% of all proposals. Finally, unprotected forest and agricultural areas, remote from densely populated zones, which possess strong wind potential, low population density, and extensive continuous land areas, are proposed as potential siting areas for wind farms. Such areas are found in Västernorrland County (Sundsvall), Västra Götaland County, and Norrbotten County.

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2. *D'Angelo, M. (2020). Onshore Wind Energy Market Analysis of Sweden, Poland and Romania (Master's thesis), KTH School of Industrial Engineering and Management, Stockholm (https://www.diva-portal.org/smash/record.jsf?dswid=3629&pid=diva2%3A1472686)*

Grid capability: The TSO is now following the grid development plan for the 2024-2033 period.

Figure 71: Sweden's grid map

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Figure 72: Sweden's Grid Development Plan

- References:
    1. *Grid development plan 2024-2033, https://www.svk.se/siteassets/om-oss/rapporter/2024/grid_development_plan_2024-2033.pdf*
    2. *Map of the national grid, https://www.svk.se/4a818f/siteassets/english/national-grid/svk_grid.pdf*
    3. *System Development Plan 2023, https://www.statnett.no/globalassets/for-aktorer-i-kraftsystemet/planer-og-analyser/sup/system-development-plan---summary.pdf.*

2.4.29. Turkiye

Grid requirements: The TSO is TEIAS, as stated in the "System operation guidelines" in the TSO website, the limits are defined following the European regulation. Some wind farm requirements, which were defined around 2008, can be found in the paper cited in references.

- TSO: TEIAS
- Fault-ride through: Must remain connected during dops down to 0 p.u. for 150 ms
- Voltage limits: - 10%, + 5%
- Frequency limits: - 2.5 Hz, + 2 Hz
- Capability curves:

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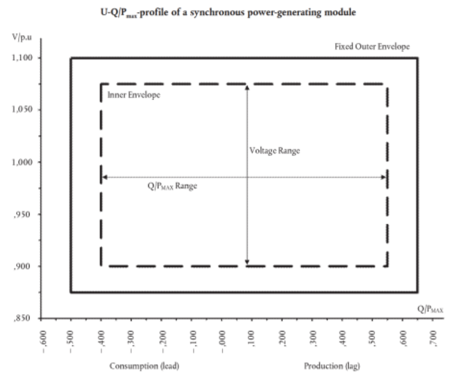

Synchronous area	Maximum range of Q/P_{max}	Maximum range of steady-state voltage level in PU
Continental Europe	0,75	0,225
Nordic	0,95	0,150
Great Britain	0 (*) 0,33 (**)	0,225
Ireland and Northern Ireland	0,66	0,218
Baltic	0,8	0,22

Figure 73. Capability curve required

- <u>Reference:</u>
    1. *Mutlu O. S. and Akpinar E., "Assessing the grid codes for wind power plants in Turkey", June 2010,*
    2. *ENTSO-E, "System Operation Guidelines Network Code Deliverables", System Opration Guidelines, accessed on October 2025.*

Land use: The development of onshore wind farms in Turkiye is governed by the Electricity Market Law (No. 6446), the Renewable Energy Sources Law (No. 5346), and the Zoning Law (No. 3194). Projects must align with national spatial plans and meet the requirements of the Environmental Impact Assessment Regulation. The General Directorate of Renewable Energy (YEGM) is responsible for assessing wind potential, while the Ministry of Environment, Urbanization and Climate Change issues land use permits and environmental impact approvals.

There is no fixed national minimum distance imposed between wind farms and residences, and distances are examined on a case-by-case basis considering the generated noise, shadow flicker, and visual impact. According to Turkiye's Noise Regulation (No. 27601/2010), operational noise must not exceed 45 dB(A) in residential areas. In practice, distances between 400 – 700 m are applied, depending on the terrain morphology, the type of wind turbines, and the building density.

Exclusion zones for the installation and operation of wind farms are determined by the Environment Law (No. 2872) and the Law on the Protection of Cultural and Natural Assets (No. 2863) and include national parks, wetlands and Natura 2000 areas, coastal protection zones within 100 meters of the coastline, military areas, as well as aeronautical or radar zones and areas of high archaeological or cultural value. Simultaneously, the National Action Plan for Wind Energy 2023–2035 is underway,

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aiming for an installed capacity of 30 GW, providing for the simplification of administrative procedures, the existence of an improved pre-assessment system for proposed locations, and the definition of incentives for the recommissioning or upgrading of existing wind farms. Finally, areas with high wind potential (>8 m/s), land slopes <6%, and proximity to transmission networks and port infrastructure are proposed as potential siting areas for wind farms. Such areas may be agricultural, pastoral, or barren lands at a moderate distance from settlements and are located in the Aegean, Marmara, and Mediterranean zones (especially İzmir, Balıkesir, Çanakkale, Hatay), as well as in Central Anatolia, Antakya, and İskenderun.

References

1. *Yildiz, S. S. (2024). Spatial multi-criteria decision making approach for wind farm site selection: A case study in Balıkesir, Turkey. Renewable and Sustainable Energy Reviews, 192, 114158. (https://www.sciencedirect.com/science/article/pii/S136403212301016X)*
2. *İpekli, Z., Keskin, S., Genç, M. S., & Genç, G. (2024). Offshore and onshore renewable energy system modelling to meet the energy demand of megacity Istanbul. Process Safety and Environmental Protection, 190, 34-45. (https://www.sciencedirect.com/science/article/pii/S0957582024009819)*
3. *Gönül, Ö., Duman, A. C., Deveci, K., & Güler, Ö. (2021). An assessment of wind energy status, incentive mechanisms and market in Turkey. Engineering Science and Technology, an International Journal, 24(6), 1383-1395. (https://www.sciencedirect.com/science/article/pii/S2215098621000811)*
4. *Ergişi, S. (2023). Techno-economic analysis of onshore and offshore wind farms in Türkiye (Master's thesis). Istanbul Technical University. (https://polen.itu.edu.tr/bitstreams/79e88575-b94d-45fa-a72a-adacce81ddbb/download)*
5. *Bilgili, M. (2009). A global review of wind power installations and their development in Turkey. CLEAN–Soil, Air, Water, 37(3), 195-202. (https://onlinelibrary.wiley.com/doi/abs/10.1002/clen.200800231)*
6. *Sevim, C. (2010). Economic evaluation of onshore wind energy plants for Turkey. Energy Sources, Part B: Economics, Planning, and Policy, 5(3), 308-313. (https://www.tandfonline.com/doi/full/10.1080/15567240903581473)*
7. *Bilgili, M., & Ünal, Ş. (2023). Technological and dimensional improvements in onshore commercial large-scale wind turbines in the world and Turkey. Clean Technologies and Environmental Policy, 25(10), 3303-3317. (https://link.springer.com/article/10.1007/s10098-023-02582-4)*
8. *Ozsahin, B., Elginoz, N., & Germirli Babuna, F. (2022). Life cycle assessment of a wind farm in Turkey. Environmental Science and Pollution Research, 29(47), 71000-71013. (https://link.springer.com/article/10.1007/s11356-022-20783-0)*
9. *Ozerdem, B., Ozer, S., & Tosun, M. (2006). Feasibility study of wind farms: A case study for Izmir, Turkey. Journal of Wind Engineering and Industrial Aerodynamics, 94(10), 725-743. (https://www.sciencedirect.com/science/article/pii/S0167610506000444)*

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10. *İlhan, A., Bilgili, M., Sarı, M., & Şahin, B. (2022). Economic analyses of onshore commercial large scale wind power plant installed in Turkey. Niğde Ömer Halisdemir Üniversitesi Mühendislik Bilimleri Dergisi, 11(1), 170-176. (https://dergipark.org.tr/en/pub/ngumuh/article/866312)*

Grid capability: Turkiye's transmission network development plan is based on government policies and projections of energy demand and is regularly updated to reflect new developments in technology and policies. The current plan includes an ambitious expansion and upgrade of Turkiye's 400-kV grid, adding an average of almost 800 km per year up to 2030 that includes new transmission corridors between demand centers in the western regions around Istanbul and new supply locations in Turkiye's northeast and south. The Turkish power system is well prepared to integrate significantly more renewable energy without the need for additional flexibility investments if the potential of existing hydropower, gas and demand side response is fully exploited. Still, some additional flexibility options will be needed once renewables share surpasses 65% of the total generation.

Figure 2: *Map of current (grey lines) and planned (red lines and dots) 400-kV transmission grid as per the updated ten year (2021-2030) prospective network development plan*

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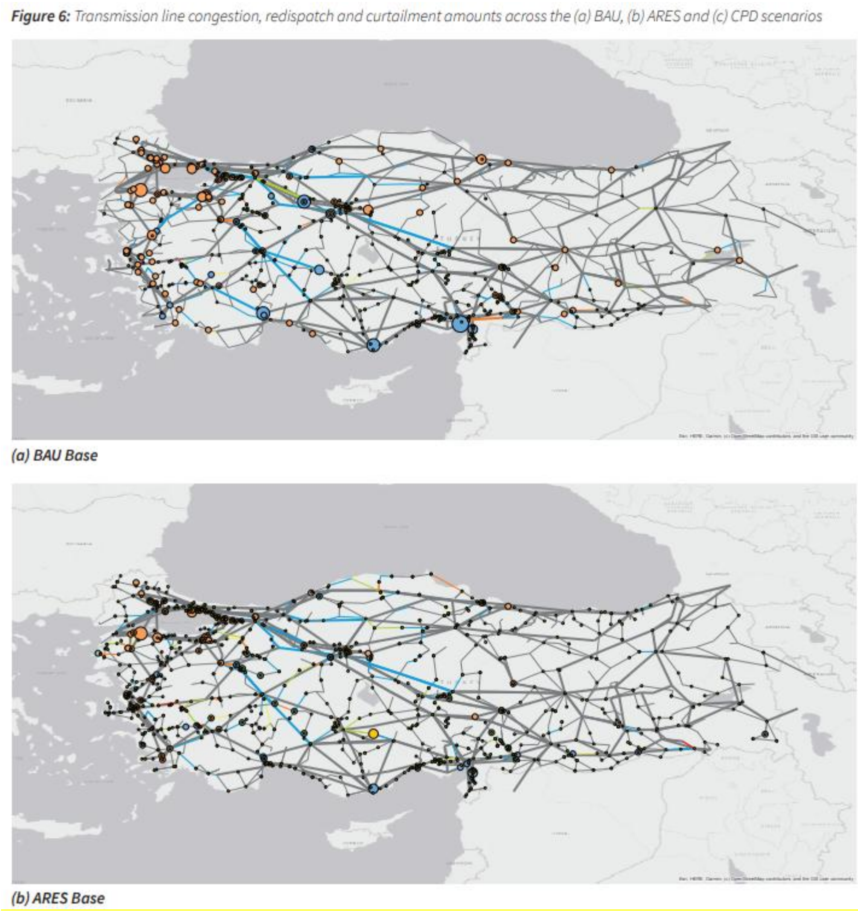

Figure 74. Turkiye grid map and development plan

- References:
    1. *SHURA Energy Transition Center, "Integration of Renewable Energy into the Turkish Electricity System, 2021*.

3. INTERACTIVE MAP

As outlined in the introduction, the objective of the interactive map is to serve as a comprehensive and easily navigable tool that centralizes the key technical requirements relevant for the development and grid connection of new renewable energy projects, particularly wind farms, across European countries, Norway and Turkiye. Given the growing complexity and country-specific variations in grid regulations, the map aims to provide an effective visualization mode that allows stakeholders to quickly identify and compare essential parameters without the need to consult fragmented and/or national sources.

To maintain consistency and usability, a deliberate effort was made to include a core set of technical indicators that are widely available and commonly reported across most EU member states. This approach helps to reduce the information gap between countries and ensures a more homogeneous and comparable dataset.

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However, due to the uneven availability of data across different countries, some technical details, particularly those that are more specific, advanced, or unique to certain national regulations, could not be uniformly integrated into the interactive map. Rather than omitting this valuable information, it has been included in this deliverable. This additional content provides a deeper dive into country-specific requirements that fall outside the common data set used in the map.

To enhance clarity and ease of access, these supplementary details are organized on a per-country basis. This structure allows users to efficiently locate relevant technical and regulatory information that may be crucial for project planning or investment decisions in a particular country. By combining the high-level overview provided by the map with detailed national insights presented in the following sections, the report aims to offer both breadth and depth, supporting informed decision-making in a diverse and evolving regulatory landscape.

3.1. Interactive map information

The "Interactive Map" described in the current deliverable is the software component that RINA-C developed within task T3.2.1. The interactive map will be embedded within the TWINVEST's Digital Twin (DT) and it will enable access to different information across European countries, Norway and Turkiye.

Interactivity: by selecting options and navigating a map, users can get detailed information (e.g. minimum distance between wind turbines, height restrictions, exclusion zones, etc.) which will guide them in the choice for new wind onshore installation.

Map visualization: the map-based representation allows users to navigate regulatory and technical information in an intuitive, geographically contextualized manner. This visual approach supports a clearer understanding of country-specific differences and territorial constraints, enabling straightforward comparison across regions. Furthermore, the ability to display multiple information layers (e.g., technical data on the power network, regulatory constraints on land use, environmental or infrastructure-related layers, etc.) provides an integrated overview of the territory, enhancing decision-making by combining diverse datasets into a single visual interface.

Data: data visualized in the map are provided by partners as result of their analyses in T3.1, T3.2, and T3.3:

- T3.1: Energy demand and price prediction in investment area
- T3.2: Grid capability assessment and regulatory mechanisms in investment area
- T3.3: Energy storage assets and flexibility

3.2. Integration within the main platform

The development of the Interactive Map (IM) was designed to facilitate its integration into the TWINVEST Digital Twin in compliance with its requirements (defined in deliverable D2.1). The map is designed as a lightweight component that can be seamlessly integrated into the main platform (DT), providing users

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with intuitive access to regulatory and technical information derived from the outputs of Tasks T3.1, T3.2, and T3.3, through a user-friendly interface. In this perspective, the IM has been developed as independent functional web component that will be accessible through the DT user interface (DT Web UI). The overall architecture of the DT is illustrated in the figure below:

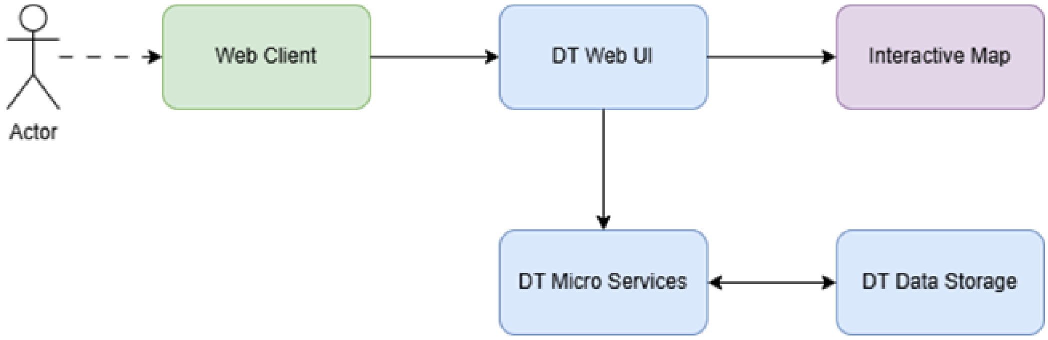

Figure 75: High-level architecture

The high-level architecture includes the following blocks:

- **Web Client**: the web-client serves as the primary user interface for interacting with the digital twin solution. It is a web-based platform designed to facilitate remote monitoring, simulation setup, and data visualization.
- **DT Web UI**: provides users with access to DT functionalities (outlined in D2.1), including simulation execution, scenario design, asset management, and real-time monitoring. It also ensures cybersecurity in the digital twin solution implementing Role-Based Access Control (RBAC) within the platform to restrict system access based on user roles, securing data transmission using TLS/SSL protocols and performing regular vulnerability assessments and penetration testing.
- **DT Micro Services**: as described in D2.1, the DT adopts a microservices architecture to ensure modularity, scalability, and maintainability. Each functional component is developed as an independent microservice, enabling greater flexibility and facilitating updates or enhancements over time. Docker is used for containerization, providing a lightweight and portable execution environment. This approach guarantees consistency across different computing setups, simplifies deployment processes, and supports efficient orchestration of services.
- **DT Data Storage**: Data Storage solutions will be implemented to manage structured data within the DT core platform.
- **Interactive Map:** A lightweight, containerized web component intended to be seamlessly integrated into the DT solution. It provides access to key functionalities, including the exploration of grid and regulatory requirements across European countries, Turkiye and Norway

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(T3.2), visualization of the European bidding zone clusters (T3.1), interactive graphs showing energy demand and price forecasts (T3.1), and access to technical documentation on storage assets (T3.3).

3.3. Application layer

The Interactive Map Application layer has been developed to provide a very light graphical user interface allowing the users to select graphical layers and documents through commands and simple interactions. Since RBAC (Role Based Access Control) is in charge to the DT main platform, no further authentication is foreseen to access the Interactive Map functionalities for already authenticated users.

Additional key points:

- **Data format**: Interactive Map data is a heterogeneous set of statical data coming from different sources and in different standard formats (especially GEOJSON, PDF, PNG files).
- **End-user:** the Interactive Map will be accessible only to users with the necessary rights and whose identity will be managed by the security layer of the main Digital Twin platform.
- **Data access**: data will be accessed programmatically, by means of the available interfaces from the DT Web UI component over HTTPS.
- **Data storage**: statical data will be stored as common JAR resources and/or into a dedicated folder.

The user will access the application through a direct link exposed by the DT Web UI and load the main layout (orange square below) and the child view (blue square below) in a single page:

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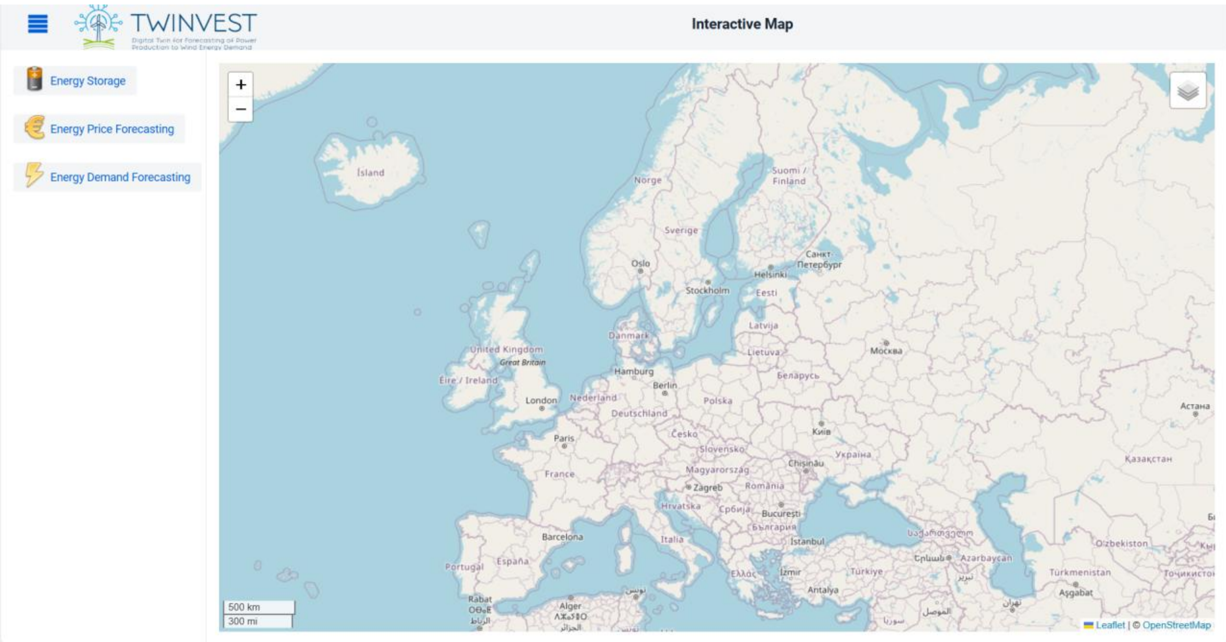
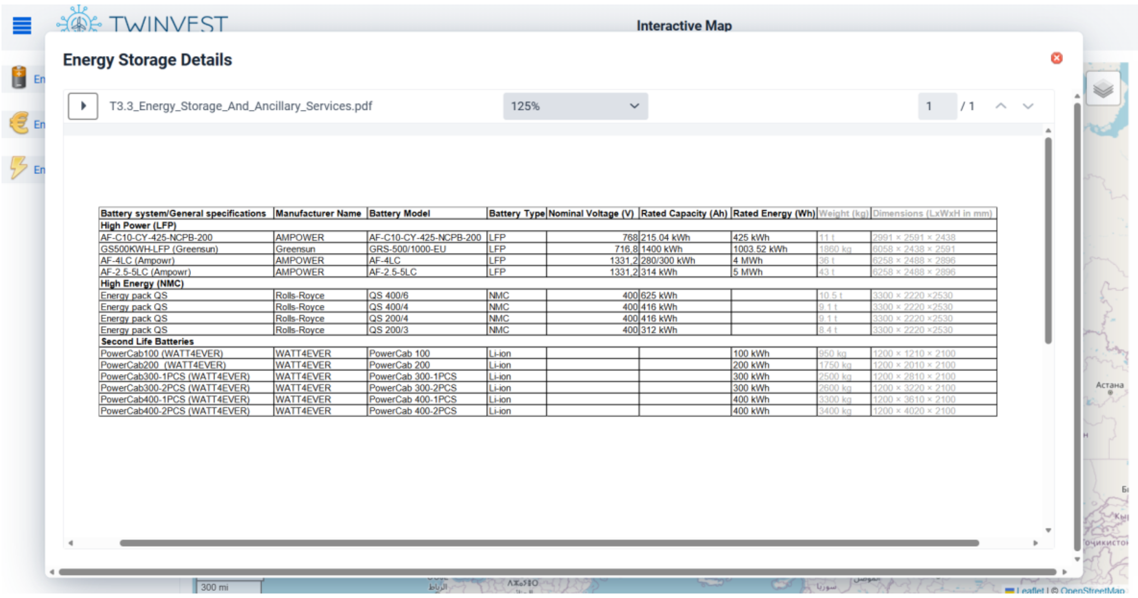


Figure 76: Interactive Map interface

The **main view** provides a sliding panel controlled by the button containing the following quick access commands:

- **Energy Storage:** to open a dialog showing storage assets (T3.3 data):



Battery system/General specifications	Manufacturer Name	Battery Model	Battery Type	Nominal Voltage (V)	Rated Capacity (Ah)	Rated Energy (Wh)	Weight (kg)	Dimensions (LxWxH in mm)
High Power (LFP)								
AF-C10-CY-425-NCPB-200	AMPOWER	AF-C10-CY-425-NCPB-200	LFP	768	215.04 kWh	425 kWh	11 t	2991 × 2591 × 2438
GS500KWH-LFP (Greensun)	Greensun	GRS-500/1000-EU	LFP	716,8	1400 kWh	1003.52 kWh	1860 kg	6058 × 2438 × 2591
AF-4LC (Ampowr)	AMPOWER	AF-4LC	LFP	1331,2	280/300 kWh	4 MWh	36 t	6258 × 2488 × 2896
AF-2.5-5LC (Ampowr)	AMPOWER	AF-2.5-5LC	LFP	1331,2	314 kWh	5 MWh	43 t	6258 × 2488 × 2896
High Energy (NMC)								
Energy pack QS	Rolls-Royce	QS 400/6	NMC	400	625 kWh		10.5 t	3300 × 2220 ×2530
Energy pack QS	Rolls-Royce	QS 400/4	NMC	400	416 kWh		9.1 t	3300 × 2220 ×2530
Energy pack QS	Rolls-Royce	QS 200/4	NMC	400	416 kWh		9.1 t	3300 × 2220 ×2530
Energy pack QS	Rolls-Royce	QS 200/3	NMC	400	312 kWh		8.4 t	3300 × 2220 ×2530
Second Life Batteries								
PowerCab100 (WATT4EVER)	WATT4EVER	PowerCab 100	Li-ion			100 kWh	950 kg	1200 × 1210 × 2100
PowerCab200 (WATT4EVER)	WATT4EVER	PowerCab 200	Li-ion			200 kWh	1750 kg	1200 × 2010 × 2100
PowerCab300-1PCS (WATT4EVER)	WATT4EVER	PowerCab 300-1PCS	Li-ion			300 kWh	2500 kg	1200 × 2810 × 2100
PowerCab300-2PCS (WATT4EVER)	WATT4EVER	PowerCab 300-2PCS	Li-ion			300 kWh	2600 kg	1200 × 3220 × 2100
PowerCab400-1PCS (WATT4EVER)	WATT4EVER	PowerCab 400-1PCS	Li-ion			400 kWh	3300 kg	1200 × 3610 × 2100
PowerCab400-2PCS (WATT4EVER)	WATT4EVER	PowerCab 400-2PCS	Li-ion			400 kWh	3400 kg	1200 × 4020 × 2100

Figure 77: Energy Storage asset: technical documentation

- **Energy Price and Energy Demand Forecasting:** to open dialogs showing the output of energy price and demand forecasting conducted in T3.1:

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Figure 78: Energy price forecasting: France, short term, AE-CLSTM model (Source: D3.1)

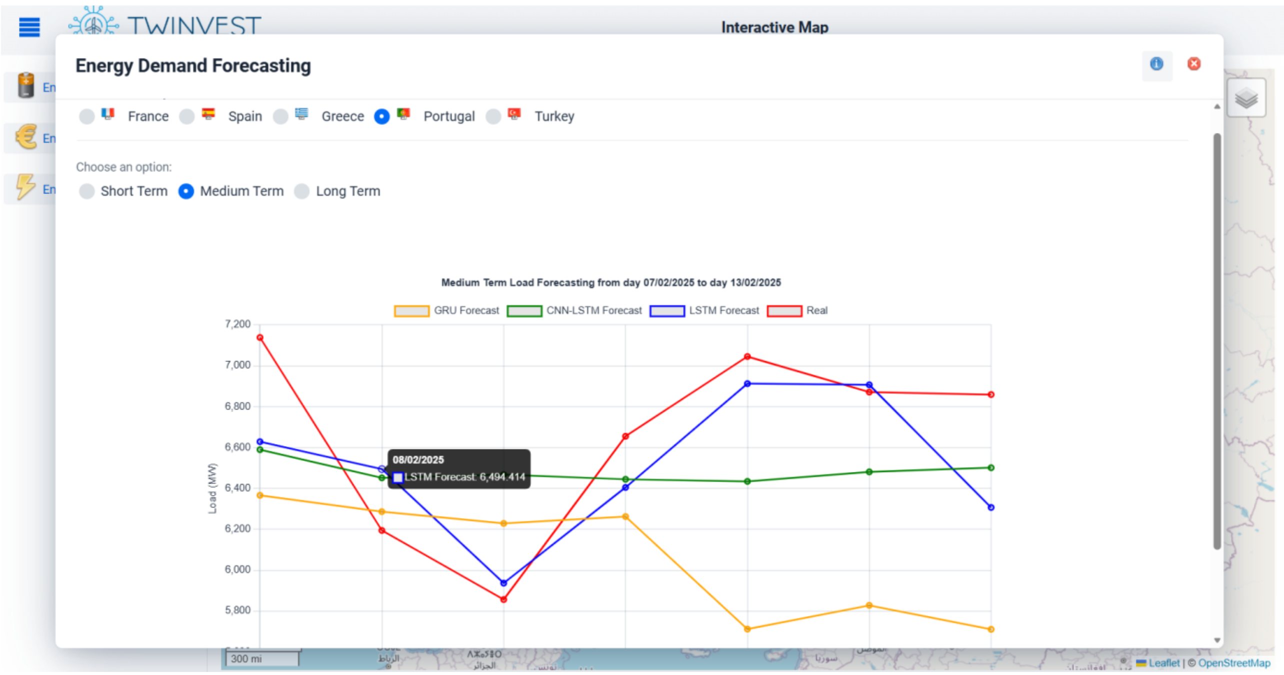

Figure 79: Energy demand forecasting: Portugal, medium term, LSTM model (Source: D3.1)

The **child view** provides the map with a layer control button enabling the user to show on the map geo-referenced information by selecting one of the following options (layers):

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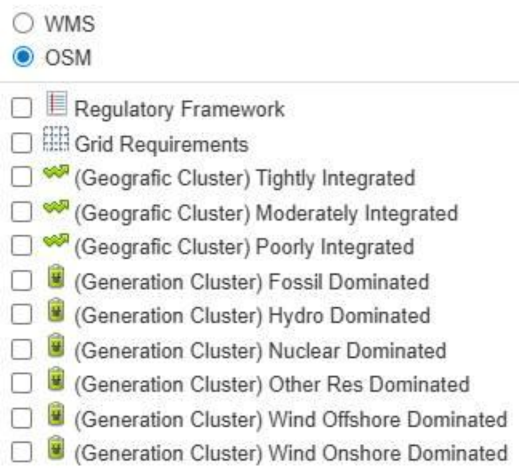

By clicking the "**Regulatory Framework**" and/or the "**Grid Requirements**" layer a cluster of draggable markers is shown on the map (one marker for each country) and by selecting them a popup window will be shown reporting all the available data (regulatory or grid requirements, capability curves and reference links) collected throughout T3.2. An example of informative popup window showing Germany's **grid requirements** is shown in the figure below:

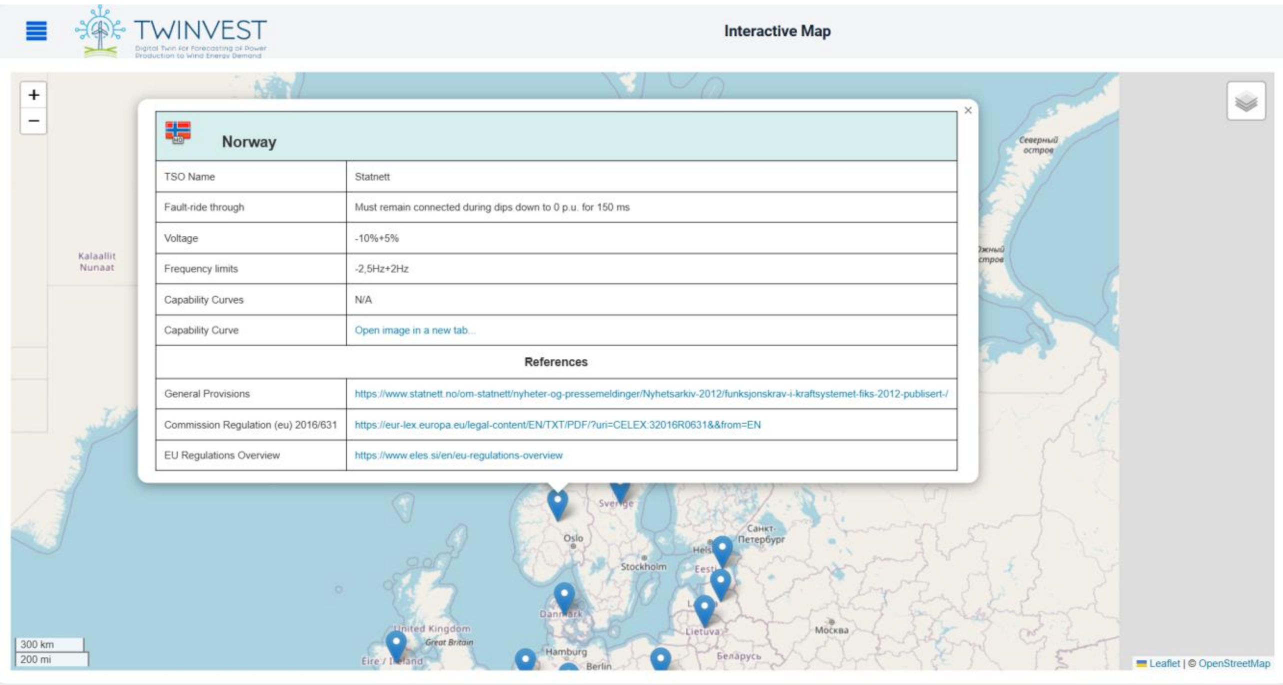

Figure 80: Grid requirement: Norway (Source: D3.2)

The picture below illustrates another example of the popup window layout, in this case displaying the regulatory requirements of Malta.

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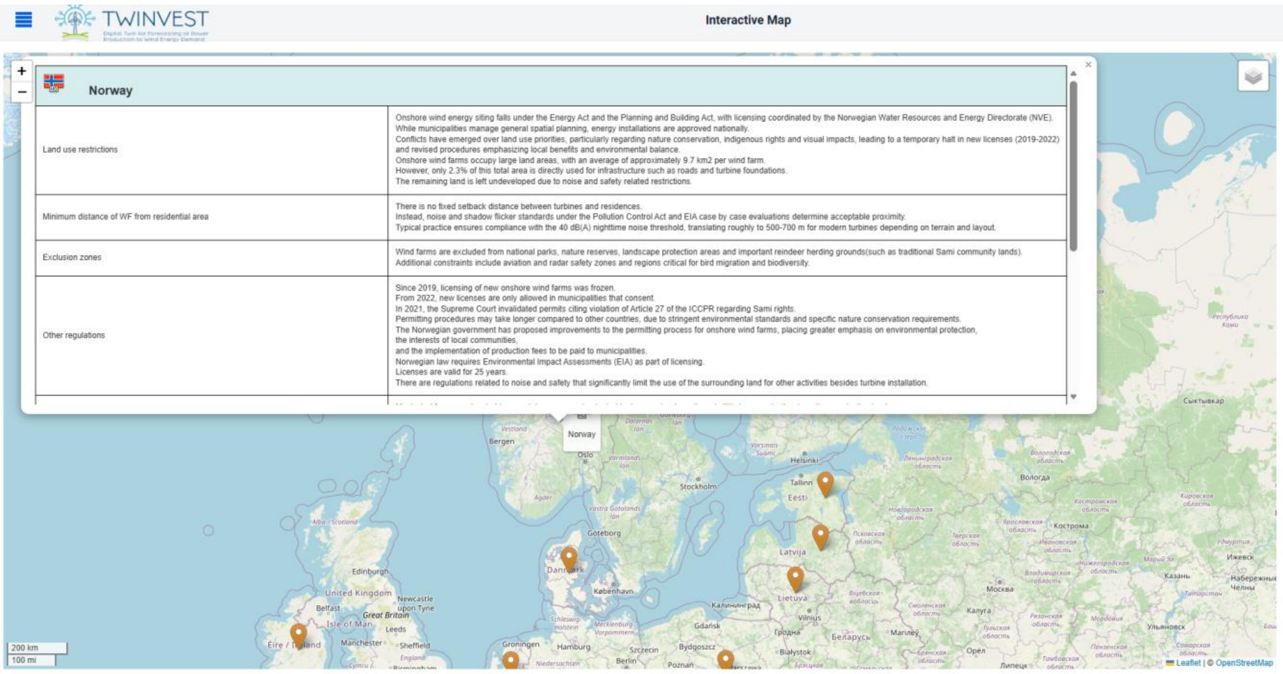

Figure 81: Regulatory requirements: Norway (Source: D3.2)

While **grid requirements** and **regulatory requirements** are visualised using a **country-level** spatial granularity and marker with informative popup window, the results of the clustering analyses carried out in T3.1 (i.e., geographic clustering and generation mix clustering) are instead represented using the ENTSOE's **bidding zone** subdivision[1] (*bidding zone* is the largest geographical area in which bids and offers from market participants can be matched without the need to allocate cross-zonal capacity).

To optimise the visual representation of these clusters on the map, the **thematic map solution** has been adopted, assigning each bidding zone a specific colour corresponding to its corresponding cluster. This allows users to clearly distinguish between zones with tightly/poorly integrated market or with similar generation mix and facilitates comparative analysis across bidding zones. The image below provides an example of the geographic clustering of bidding zones, illustrating the bidding zones classified as *Tightly Integrated Markets*.

[1] https://www.entsoe.eu/network_codes/bzr/

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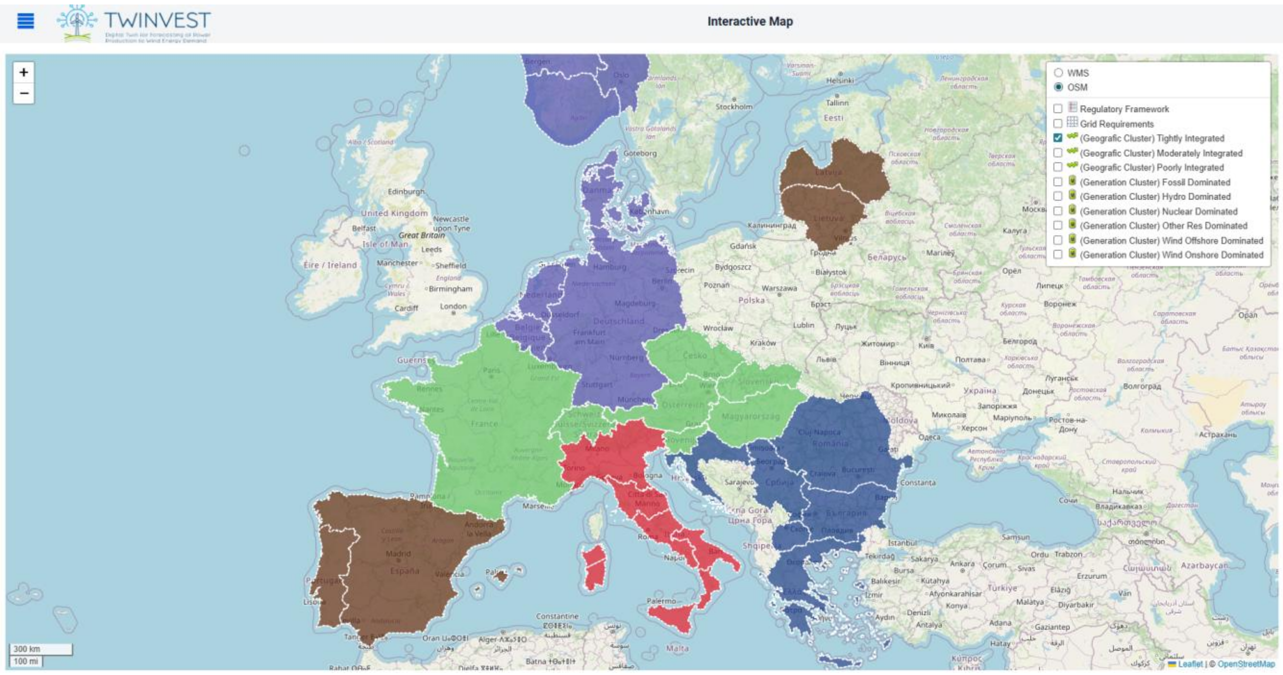

Figure 82: Thematic map: bidding zones clustering by geographical position (Source: D3.1)

The visual representation of bidding zones clustering by generation mix has been implemented following the same principle of geographic clustering. The following image shows as an example the nuclear dominated countries across the EU:

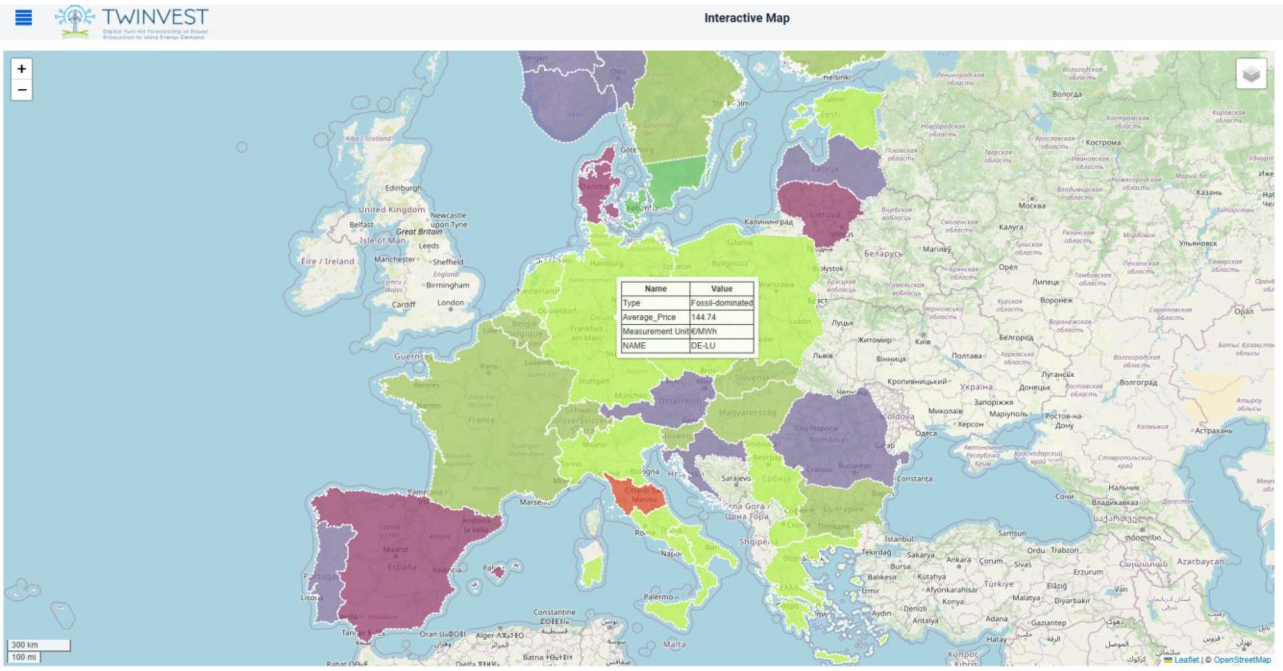

Figure 83: Thematic map: bidding zones clustering by generation (Source: D3.1)

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4. CONCLUSIONS

This report provides a comprehensive technical assessment of the regulatory framework governing the connection of power plants to national electricity grids across the European Union. For every EU Member State, the relevant grid-connection requirements were identified, analyzed, and, wherever possible, precisely referenced to national legislation, technical codes, or regulatory authority guidance. In cases where national information was incomplete, inaccessible, or insufficiently detailed, the report relies instead on the corresponding provisions of European-level legislation and network codes in order to ensure full regulatory traceability and consistency.

Overall, the depth and completeness of the collected data can be considered highly satisfactory. The majority of EU Member States are covered with exhaustive details including exact connection requirements, applicable voltage categories, and the role of Transmission System Operators (TSOs) and Distribution System Operators (DSOs). Only in a limited number of cases were European fallback references required.

In addition to grid-connection regulations, the report also investigates national land-use frameworks relevant to power-plant deployment. For each Member State, spatial planning rules, zoning constraints, environmental permitting requirements, and, where available, renewable-energy prioritization zones were studied and summarized. This dual focus (connection + land-use) enables a complete understanding of feasibility for new generation assets.

The ultimate objective of this report is to support the development of an interactive European regulatory map. This digital interface will allow users to click on any EU Member State and immediately access a structured, highly navigable overview of its specific connection rules and land-use framework. The resulting map is designed to be a comprehensive, single-source reference and a user-friendly tool enabling fast comparison, due-diligence screening, market-entry support, and regulatory intelligence across all EU countries. Norway and Turkiye were added to the list of studied countries, thanks to the presence of members in the working group that have experience in those states.

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