TYNDP 2024

Identification of System Needs

Implementation Guidelines

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1. Introduction and Purpose of the Identification of System Needs

In the ever-evolving landscape of energy supply and demand, Europe stands at the forefront of a monumental transition towards a sustainable and integrated energy system. As part of this ambitious journey, ENTSO-E TYNDP plays a key role in enabling the harmonization and optimization of Europe’s electricity infrastructure.

The Identification of system needs studies are a systematic and comprehensive examination conducted by ENTSO-E to assess the essential requirements of Europe's electricity in terms of cross-border infrastructure. It is an indispensable component in the planning and development of a robust and resilient electricity grid capable of accommodating the ever-growing share of renewable energy sources, addressing security concerns, and enhancing the overall reliability of electricity supply.

1.2 Objectives of the study

The primary objectives of the Identification of System Needs Studies are multifaceted and far-reaching. They include:

- **Assessment of Infrastructure Requirements**: The study rigorously evaluates the existing electricity grid infrastructure to identify gaps and shortcomings in the cross border and storage capacity. By understanding the current state of the system, ENTSO-E together with TSOs, NRAs and other stakeholders can make informed decisions about necessary upgrades, expansions, or enhancements to accommodate the evolving energy landscape.
- **Integration of Renewable Energy:** Europe's commitment to reducing greenhouse gas emissions necessitates a substantial increase in renewable energy sources, such as wind and solar power. The study assesses how the grid can best integrate these intermittent energy sources while maintaining grid stability.
- **Security of Supply:** Ensuring the security of electricity supply is paramount. ENTSO-E examines potential risks and vulnerabilities within the grid to develop strategies for mitigating disruptions and maintaining a consistent energy supply.
- **Cross-Border Coordination:** The study addresses the need for improved cross-border coordination and harmonization. A more interconnected grid not only enhances energy security but also paves the way for a unified European electricity market, benefitting consumers and industries alike.

1.3 Methodologies and data

ENTSO-E employs a rigorous analytical approach, relying on advanced modeling, data collection, and stakeholder engagement to conduct the Identification of System Needs Studies. Data from various sources, including national grid operators, energy market regulators, and industry experts, are combined with cutting-edge simulation tools to project the future needs of the electricity system accurately.

Implications and Stakeholder Involvement

The findings and recommendations of the studies have far-reaching implications for governments, regulatory bodies, transmission system operators, and the energy industry at large. These insights inform critical decision-making processes related to investments in infrastructure, policy development, and regulatory frameworks.

As the transition towards a greener and more interconnected electricity system becomes increasingly critical, understanding the inner workings and objectives of ENTSO-E's Identification of System Needs Studies is paramount for stakeholders, policy makers, and energy enthusiasts alike.

The present methodology builds on the methodology applied in TYNDP 2022 and TYNDP 2020. When drafting the present methodology ENTSO-E considered the feedback received in previous TYNDP editions, mainly:

- To ensure that assumptions are transparently described and explained, and that input data is easily available;
- To consider the inclusion of additional types of investment candidates in the study, especially regarding offshore hybrid infrastructure.

A high-level overview of the methodology described in the present document was presented to stakeholders in a public webinar in November 2023.

2. Main objectives of the Implementation Guidelines of the System Needs study

The purpose of the present Methodology is to provide clear and transparent guidance and overview of the studies, their inputs and outputs.

The evolution of the Methodology from one TYNDP cycle to the next reflects the complex and evolving nature of Europe's electricity grid and energy landscape together with technological improvements in approaches used within the studies performed by ENTSO-E. Here are seven key drivers that shape this methodology:

Renewable Energy Integration: The rapid growth of renewable energy sources, such as wind and solar power, is a significant driver. The methodology aims to accommodate and integrate these intermittent energy sources efficiently, ensuring grid stability and reliability as Europe strives to achieve its clean energy targets.

Energy Transition: Europe's commitment to reducing greenhouse gas emissions and transitioning to a low-carbon energy system necessitates the development of infrastructure that supports sustainable energy production and consumption. The methodology addresses the grid's role in facilitating this transition.

Energy Security: Ensuring the security of electricity supply is a fundamental driver. The methodology assesses the vulnerabilities and risks associated with the grid, enabling the development of strategies to enhance energy security, reduce blackout risks, and minimize the impact of external disruptions.

Cross-Border Electricity Flows: The ongoing effort to create a single European electricity market drives the need for a more interconnected grid. The methodology focuses on improving cross-border coordination and harmonization to enhance the flow of electricity across national borders.

Technological Advancements: Advances in grid technology, including smart grids, energy storage solutions, cross-sectorial technologies, drive the need for a methodology that can adapt to and leverage these innovations for a more efficient and responsive electricity system.

Zonal Modelling approach: zonal geographical scope has been successfully utilized within the last three ENTSO-E's TYNDP cycles and in comparison with the classic conservative approach based on standard NTC model the results have been considered consistent and granular, thus providing more insight into the system needs. The Zonal Modelling approach is in a application of the flow-based methodology.

More diverse investment candidates: It has been indicated by several stakeholders during TYNDP 2020 and TYNDP 2022 processes, that other needs aside transfer capacity increases should be highlighted within needs identification process. Therefore, within TYNDP 2024 study for all of the horizons will include also storage flexibility needs.

3. Input Data

To conduct the Identification of the System Needs studies, ENTSO-E requires a comprehensive set of datasets covering various aspects of the European electricity grid and energy landscape. In addition, for the first time in TYNDP the H2 system is modelled, adding complexity to the data collection (performed in the Scenario Building process) and the computation. These studies aim to anticipate and address future grid requirements, challenges, and opportunities. The datasets required would encompass a wide range of information, including:

Energy Production Data:

Historical and projected data on energy production from different sources, including renewables (e.g., wind, solar, hydro), conventional sources (e.g., fossil fuels, nuclear), and emerging technologies (e.g., geothermal, marine energy).

Energy Consumption Data:

Historical and projected energy consumption patterns across different sectors, such as residential, commercial, industrial, and transportation, as well as the expected impact of electric vehicles (EVs).

Grid Infrastructure Information:

Data on the existing electricity grid infrastructure, including details on transmission lines, substations, interconnectors, and their capacities together with potential investment candidates in the system starting from the common reference point.

Renewable Energy Potential:

Time series indicating the potential for renewable energy generation, including wind, solar capacity factor time series together with hydrological conditions, and other relevant environmental factors.

Generation Mix and Fuel Prices:

Information on the current and projected energy generation mix and fuel prices, which can influence investment decisions and energy generation trends.

Environmental and Regulatory Data:

Data on environmental regulations, carbon pricing mechanisms, and emissions data that impact the energy sector's sustainability.

Security and Resilience Data:

Data related to outages of the generation in the system based on the PEMMDB parameters (forced and planned outages).

Cross-Border Net Transfer Capacities:

Information on electricity exchange limits between ENTSO-E countries to assess cross-border coordination and potential improvements in interconnectivity.

Public and Stakeholder Feedback:

Input and feedback from stakeholders, including utilities, grid operators, governments, and the public, regarding their needs, concerns, and expectations for the electricity grid.

These datasets are essential for conducting in-depth analysis, modeling, and scenario planning to anticipate the future requirements of the European electricity grid.

The following tables describe more in detail the input data requirements for separate type of Identification of the System Needs studies, for input data and investment data.

Table 1 Summary of input datasets used in different Identification of the System Needs Studies

Data type	IoSN 2030	IoSN 2040	IoSN 2050
RES capacities (Solar PV, Wind Onshore, Solar CSP)	2030 NT (PEMMDB 2.5 format)	2040 NT (PEMMDB 2.5 format)	2050 NT expanded towards the 2050 DE targets (PEMMDB 3.5 format)
Batteries	2030 NT	2040 NT	2050 NT expanded towards the 2050 DE targets
Demand	2030 NT	2040 NT split based on network model	2050 DE split based on demand split ratios as prepared within 2040 IoSN Zonal demand split in proportional basis
Hydro Inflows	2030	2040	2050
Reference grid	2030	2030 (offshore grid adapted to ONDP 2040 starting grid)	2030 (offshore grid adapted to ONDP 2050 starting grid)
Thermal Capacities	2030 NT	2040 NT split based on network model per Zone	2050 NT - split between PECD Zones based on PEMMDB 3.5.
SMR	2030 NT	2040 NT	2050 DE
H2 Storages	2030	2040	2050 DE
H2 network	2030	2040	2050 DE
Electrolyzers	2030 NT	2040 NT	2050 NT expanding to 2050 DE with SB targets
Wind Offshore	2030 NT	2040 NT	2050 NT expanding to 2050 DE with ONDP targets

Table 2 summarizes the investment datasets used in each of the Identification of the System Needs studies.

Table 2 Summary of investment datasets used in different Identification of the System Needs Studies

Data type	IoSN 2030	IoSN 2040	IoSN 2050
Electricity network Onshore	Collected investment candidates within SB process +	Collected investment candidates within SB process per Zone +	Collected investment candidates within SB process per PECD Zone +
Electricity network Offshore	2030 +	2040 NT (compliant with ONDP capacities) split into Zones + ONDP corridors as conceptual candidates	2050 DE (compliant with the ONDP capacities) with split per PECD zone + ONDP corridors (2040 and 2050) as conceptual corridors with minimum built constraint
Electrolyzers	2030 +		2050 DE +
Batteries	2030 NT +	2040 NT split based on network model per Zone +	2050 DE - split between PECD Zones based on PEMMDB 3.5. +
RES capacities			2050 DE -> 2050 DE per PECD Zone

4. General Market Modelling Approach

Market wise each of the Identification of the System Needs Studies has been using the following market modelling configuration:

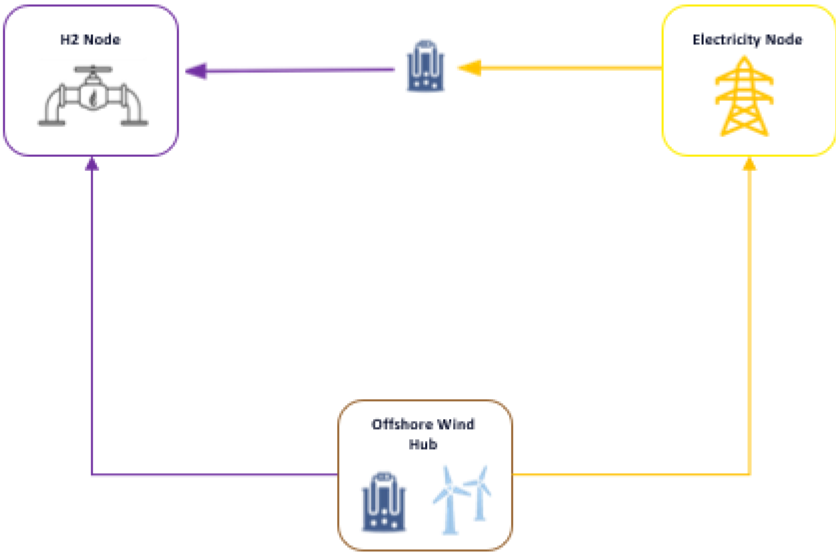


Figure 1 General Modelling Approach for IoSN Studies

Figure 1 shows the general Market Modelling Approach in IoSN studies. Each of the nodes represents certain market configuration. Electricity node represents standard ideal electricity market and includes all the electricity generation, demand, DSR and electricity connections in between different nodes representing country areas.

H2 node represents the hydrogen ideal market and includes all the hydrogen related technologies (SMR, H2 storages, H2 imports) and H2 connections in between the nodes representing H2 pipelines. H2 nodes include H2 demand.

Electrolysers represent the only direct connection between electricity and hydrogen nodes, which are constrained by the efficiency of the electrolysers in terms of allowed flow that can be allowed to be going through the link.

Offshore wind hubs in certain cases are modelled as separate electricity market node representing the offshore bidding zone in the system. Such nodes can include either Wind generation and/or electrolyser technologies. In case of electrolyser technologies included in the Offshore Wind Zone, the link between this zone and corresponding H2 node is included and is constrained as explained above by the efficiency value of the electrolyser.

5. General overview of the process

The general process comprises of 3 studies. Each study is being performed separately with certain common data elements.

In simple terms, the study process can be described as in the graph included in Figure 2:

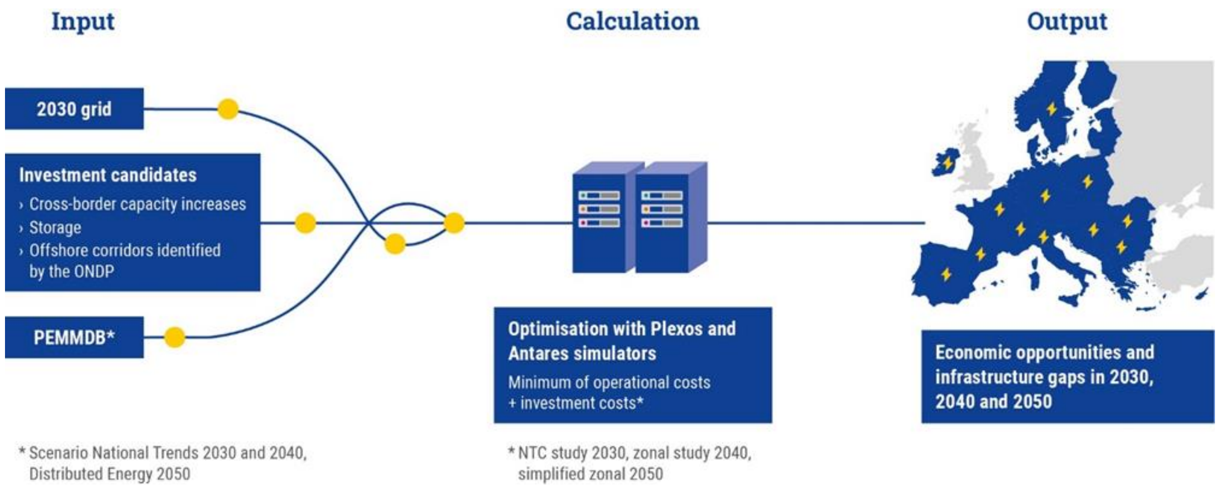


Figure 2 General Overview of the IoSN studies

All studies use the 2030 grid as the starting grid, with differences in offshore, where the starting grid in 2040 and 2050 is that of the ONDP.

PEMMDB is the Pan-European Market Modelling Database which includes all the market modelling data for each of the studies.

Calculation has been performed using Plexos software for 2030 and 2050 studies and using Antares for the 2040 study.

The final goal of each study is to identify needs in terms of electricity transmission infrastructure, battery storages and offshore infrastructure starting from 2030 grid and projected towards the study time horizon and Scenario.

5.2 Input Data for 2030 NT Scenario

The input data, whose flow is represented in Figure 3, for the Identification of the System Needs process for the 2030 time horizon is mainly related to market modelling and is described below.

Generation Data:

Generation datasets are provided in PEMMDB 2.5 format. As part of these datasets, so called common data are used. Those datasets include standard and default thermal characteristics of the thermal generating units.

Demand Data:

Historical, current, and projected electricity demand data for various zones and timeframes. Accurate demand forecasts are essential for market operation and planning. Hourly demand time series are generated using specialized simulation software – DFT (Demand Forecasting Tool).

Renewable Energy Data:

Data on the availability and forecast of renewable energy sources (e.g., wind, solar) in different zones. This data helps in assessing the impact of variable generation on market dynamics and grid operation. These type of datasets are provided in PEMMDB 2.5 format.

Fuel Price Data:

Historical and projected data on fuel prices, including coal, natural gas, oil, and carbon prices. Fuel price data is crucial for assessing the economic viability of power generation options.

Cross-Border Data:

Information on cross-border electricity flows and interconnection capacities between different zones or countries. This data is vital for assessing the integration of markets and power exchanges. The referent point for the cross-border capacities is called reference grid. The reference grid for 2030 NT is considered to be 2030 time horizon.

Weather Data:

Historical and forecasted weather data, including wind, solar capacity factor time series. Weather data is used to model the impact of weather conditions on renewable energy generation.

Investment Data:

Investment candidate data used in the Identification of the System Needs (IoSN) process by ENTSO-E refers to information regarding potential investments in the electricity grid and energy infrastructure. These investments are critical for ensuring the reliability, efficiency, and sustainability of the European electricity system. Here are the key components of investment candidate data in the IoSN process:

Infrastructure Projects:

Information on planned or proposed infrastructure projects, including new transmission lines, substations, interconnections, storages, peaking generating capacities. P2G capacities. This data outlines the scope, location, and capacity of these projects.

Investment Costs:

Detailed cost estimates for infrastructure projects, including capital expenditures (CAPEX) and operational expenditures (OPEX). These estimates are essential for budgeting and financial planning.

Technical Specifications:

Technical details about the design and specifications of infrastructure projects, including voltage levels, capacity, and environmental compliance.

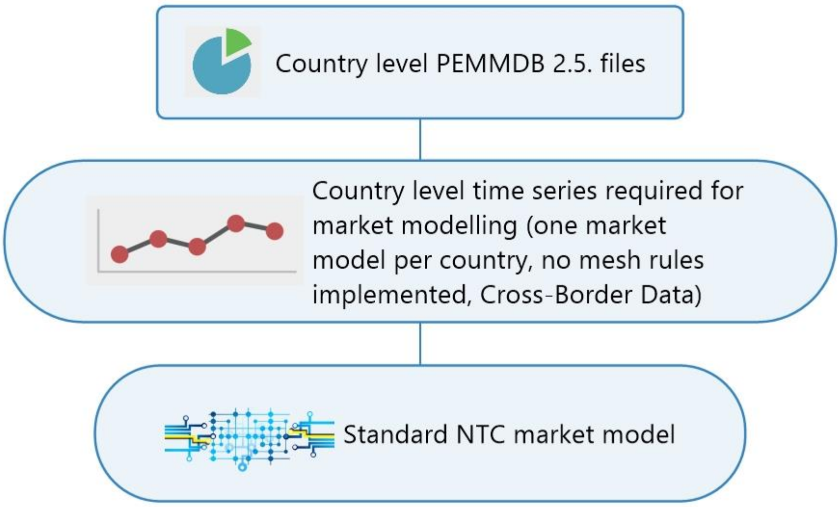


Figure 3 IoSN 2030 NT Input Data Flow Diagram

5.3 Figure 3Input Data for 2040 NT Scenario

The input data for the Identification of the System Needs process for the 2040 time horizon is separated into two main parts: market data and network data.

5.3.1 Market Data

For 2040 NT, IoSN Study Zonal Market Model (ZMM) is used by ENTSO-E for electricity market analysis and simulation. It relies on various types of datasets to create a comprehensive and accurate representation of the European electricity market and network at the same time. These datasets provide the necessary inputs for modelling and simulating of market behavior, grid operation, and electricity flows. The zonal modeling is (by its objective function) a tool to better reflect physical flows compared to the traditional NTC approach. It additionally allows for a first crude analysis of the interaction between internal networks and interconnectors. Key types of datasets used in building the Zonal Market Model include:

Generation Data:

Information on power generation units, their locations, fuel types, and capacity, including historical and forecasted generation patterns. This data helps in understanding the availability and utilization of different power sources. These type of datasets are provided in PEMMDB 2.5 format. As part of these datasets, so called common data are used. Those datasets include standard and default thermal characteristics of the thermal generating units.

Demand Data:

Historical, current, and projected electricity demand data for various zones and timeframes. Accurate demand forecasts are essential for market operation and planning. Hourly demand time series are generated using specialized simulation software – DFT (Demand Forecasting Tool).

Renewable Energy Data:

Data on the availability and forecast of renewable energy sources (e.g., wind, solar) in different zones. This data helps in assessing the impact of variable generation on market dynamics and grid operation.

Fuel Price Data:

Historical and projected data on fuel prices, including coal, natural gas, oil, and carbon prices. Fuel price data is crucial for assessing the economic viability of power generation options.

5.3.2 Network data

Transmission Network Data

Details about the physical characteristics of the transmission network, including electrical parameters and the location and capacity of transmission lines, substations, and interconnections between zones. This data is critical for simulating electricity flows and grid operation.

Load Flow Data:

Data related to electricity flows and constraints in the transmission network. Load flow data helps in understanding how electricity moves through the grid and identifying potential congestion points. Data regarding the demand, node by node or market zone by market zone, during the yearly hours are also needed.

Cross-Border Data:

Information on cross-border electricity flows and interconnection capacities between different zones or countries. This data is vital for assessing the integration of markets and power exchanges. The referent point for the cross-border capacities is called reference grid. The reference grid for 2040 NT is considered to be the 2030 time horizon.

Operational Data:

Real-time and historical operational data from grid operators, including grid constraints, outages, and system behaviour during various operating conditions.

Weather Data

Historical and forecasted weather data, including wind, solar capacity factor time series. Weather data is used to model the impact of weather conditions on renewable energy generation.

These datasets, when integrated into the Zonal Market Model, allow ENTSO-E to simulate and analyse a wide range of scenarios, including market clearing, congestion management, and the impact of policy changes on the European electricity market. The ZMM serves as a valuable tool for market operators, policymakers, and stakeholders in making informed decisions and optimizing the operation of the electricity market.

5.3.3 Zonal Modelling clustering methodology

The Zonal Model Clustering methodology used by ENTSO-E is an important analytical approach to group together similar areas or zones within the European electricity market. This clustering process helps in the efficient representation of the market and grid operation by simplifying complex market models and facilitating more accurate and manageable simulations. Here's an overview of the methodology.

1. **Data Collection:**

   The first step involves gathering a wide range of data, including information on the transmission network, power generation, market data, demand profiles, and other relevant factors. These datasets are essential for understanding the characteristics and dynamics of different zones within the market.

2. **Feature Selection:**

   In this phase, the relevant features or attributes are selected from the collected data. Features could include transmission line capacities, demand patterns, generation capacity, and interconnections between zones. The choice of features depends on the objectives of the clustering analysis.

3. **Data Preprocessing:**

   Data preprocessing is crucial for cleaning and transforming raw data into a format suitable for clustering. This includes handling missing values, normalizing data, and addressing outliers to ensure data quality.

4. **Cluster Algorithm Selection:**

   ENTSO-E would choose an appropriate clustering algorithm based on the nature of the data and the specific objectives of the analysis. Common clustering algorithms include K-Means, Hierarchical Clustering, and DBSCAN, among others.

5. **Similarity Metric Definition:**

   To group zones effectively, a similarity metric is defined to measure how closely related or similar two zones are based on the selected features. The choice of the similarity metric depends on the characteristics of the data.

6. **Cluster Creation:**

   The clustering algorithm is applied to the pre-processed data with the defined similarity metric. It groups zones into clusters based on their similarities. The algorithm identifies which zones are more closely related to each other and forms clusters accordingly.

7. **Evaluation and Validation:**

After the clusters are created, it's important to assess their quality and validity. ENTSO-E would use various metrics to evaluate the clustering results, ensuring that the clusters are meaningful and that zones within the same cluster exhibit similar characteristics.

8. **Adjustment and Refinement:**

   The clustering results may be adjusted and refined iteratively based on the evaluation and validation feedback. ENTSO-E can fine-tune the clustering to achieve better representations of the market's dynamics.

9. **Zonal Model Integration:**

   Once the zones are clustered, ENTSO-E incorporates the clustering results into their Zonal Market Model. The model uses these clusters to represent zones with similar characteristics, which simplifies the complexity of market simulations.

10. **Scenario Analysis:**

    ENTSO-E conducts scenario analyses and simulations using the Zonal Model with clustered zones. These analyses can include market clearing, congestion management, and other aspects of electricity market operation, allowing stakeholders to explore the impacts of different scenarios.

    The Zonal Model Clustering methodology, when applied effectively, provides a more manageable and insightful representation of the European electricity market. It simplifies complex market models and enhances the understanding of how different regions and zones within the market interact and influence one another. This, in turn, aids in making informed decisions, optimizing market operations, and improving overall grid management.

Figure 4 shows the IoSN input data flow diagram.

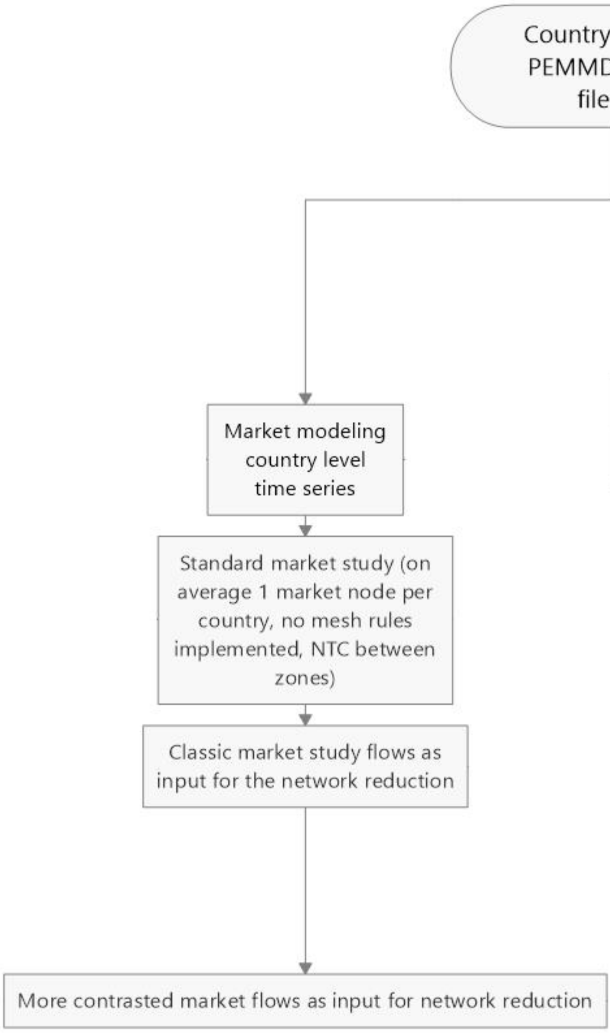


Figure 4 IoSN Network Reduction Process Methodology Options

Two models are possible. The zonal model, on the right branch of Figure 1, gives more details about network model behaviour but implies weak hypothesis about generation and load location. The NTC model, on the left of Figure 1 gives few details from network model but is accurate with generation and load location, regarding PEMMDB.

For the TYNDP 2024 process, the Zonal level market study approach (right side at the Figure1) has been used as basis for network reduction in order to save computational time in a limited timeframe available for the study.

5.4 Input Data for 2050 DE Scenario

The input data for the Identification of the System Needs process for 2050 DE Scenario is separated into two main parts: market data and network data. For this time horizon, a NTC model with PECD zone clustering of generation and load data was developed.

5.4.1 Market Data

For 2050 DE IoSN Study Simplified Zonal Market Model (SZMM) is used by ENTSO-E for electricity market analysis and simulation. It relies on various types of datasets to create a comprehensive and accurate representation of the European electricity market and network at the same time. These datasets provide the necessary inputs for modelling and simulating of market behaviour, grid operation, and electricity flows. Key types of datasets used in building the Simplified Zonal Market Model include:

Generation Data:

Information on power generation units, their locations, fuel types, and capacity, including historical and forecasted generation patterns. This data helps in understanding the availability and utilization of different power sources. This type of datasets are provided in PEMMDB 3.5 format. As part of these datasets, so called common data are used. Those datasets include standard and default thermal characteristics of the thermal generating units.

Demand Data:

Historical, current, and projected electricity demand data for various zones and timeframes. Accurate demand forecasts are essential for market operation and planning. Hourly demand time series are generated using specialized simulation software – DFT (Demand Forecasting Tool).

Renewable Energy Data:

Data on the availability and forecast of renewable energy sources (e.g., wind, solar) in different zones. This data helps in assessing the impact of variable generation on market dynamics and grid operation. Hourly time series data comes from PECD process that provides capacity factors of each RES technology.

Fuel Price Data:

Historical and projected data on fuel prices, including coal, natural gas, oil, and carbon prices. Fuel price data is crucial for assessing the economic viability of power generation options. Moreover, fuel prices indicate level of Total System Costs the is base of economical assessment of the considered new candidates projects.

Weather Data:

Historical and forecasted weather data, including wind, solar capacity factor time series. Weather data is used to model the impact of weather conditions on renewable energy generation. What is more, temperature was included in demand profile forecasts. The RES capacity factors time series used represent the 2050 DE Scenario.

5.4.2 Network data

Cross-Border Data:

Information on cross-border electricity flows and interconnection capacities between different zones or countries. This data is vital for assessing the integration of markets and power exchanges. The referent point for the cross-border capacities is called reference grid. The reference grid for 2050 DE is considered to be 2030 time horizon.

5.5 PECD Zone Modelling clustering topology

A simplified Zonal Market Model (SZMM) was used for the study. Here is an overview of the clustering methodology for the preparation of such a model:

1. PECD Zone clustering is used as reference for the 2050 IoSN market model preparation;
2. Renewable Energy Source generation capacities are estimated based on optimization process with starting point of 2050 National Trends Scenario as a starting point with investment expansion with target of 2050 Distributed Energy Scenario generating capacities;
3. Demand time series (2050DE) split between PECD Zones is performed based on demand split ratios as prepared within 2040 IoSN Zonal demand split in proportional basis;
4. NTC (2030) – split between PECD Zones based on ratios from 2040 NT IoSN process based on reference grid 2030 per bidding zone / equivalent capacities;
5. Thermal capacities – split between Zones based on PEMMDB 3.5. PECD zone split for thermal capacity for 2050 NT;
6. Hydrogen datasets – aggregated based on Scenario Building input 2050 DE (hydrogen reference grid, SMR, electrolyzers, imports);
7. Hydrogen demand – 2050 DE from Scenario Building process;
8. Battery generation capacities - are estimated based on optimization process with starting point of 2050 National Trends Scenario as a starting point with investment expansion with target of 2050 Distributed Energy Scenario generating capacities.

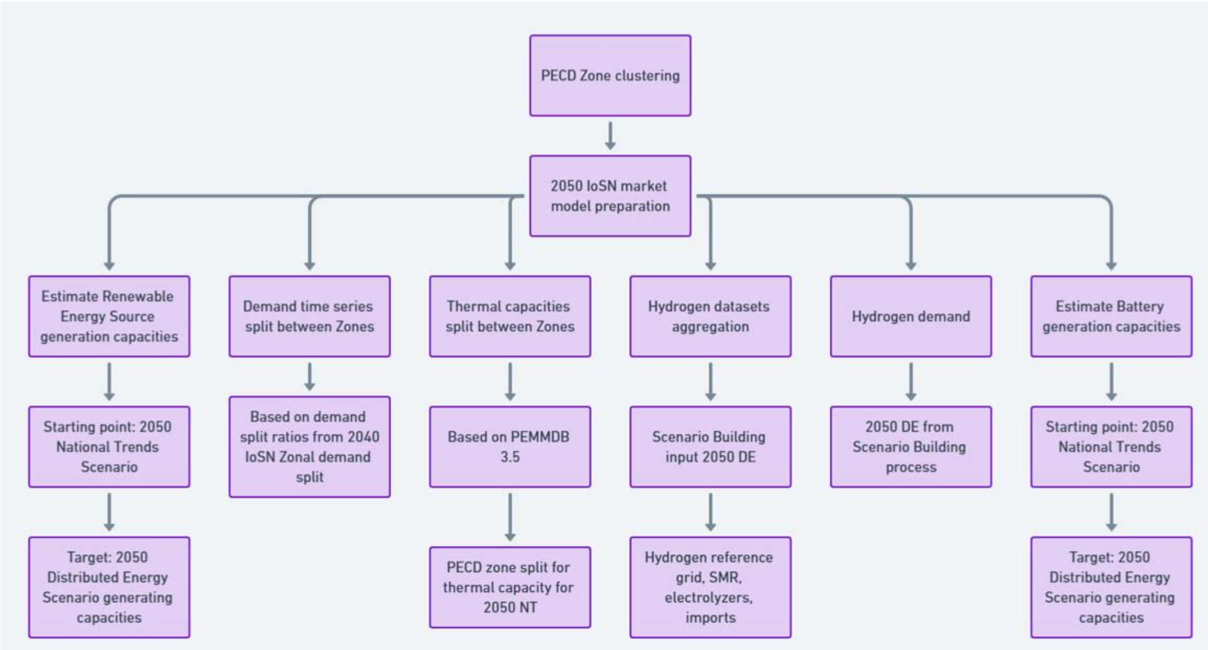


Figure 5 PECD Zone clustering for IoSN 2050 Process Diagram

The PECD Zonal Model Clustering methodology (process diagram represented in Figure 5), when applied effectively, provides a manageable and insightful representation of the European electricity market. It provides more granular and complex market models and enhances the understanding of how different regions and zones within the market interact and influence one another compared to standard NTC models which represent standard bidding zone topology similar to today's electricity market structure. This, in turn, aids in making informed decisions, optimizing market operations, and improving overall grid management.

6. Software Tools Involved

6.1 Pre-qualification test for Zonal IoSN

To identify the software tools capable to participate in the Identification of the system needs process, specific pre-qualification test has been done during previous TYNDP processes.

The key requirements for any software tool to be involved in the process were the following:

- The team has enough capacity to handle the calculations within the project plan constraints;
- The software tool used by the team has been tested on the test sample prepared and the results are comparable/similar, therefore can be considered as aligned.

6.2 Software Tools that passed the pre-qualification

According to the pre-qualification results, Antares and Plexos software tools have been qualified to be involved in the Zonal Identification of the system needs processes.

More details on the market modelling software tools that have passed the pre-qualification test, could be found through the links below:

Antares Simulator - https://antares-simulator.org/

Plexos - https://www.energyexemplar.com/plexos

However, other simulation tools are not excluded, once they demonstrate their compliance with the requirements.

7. Step-by-step Methodology Description

The IoSN methodology can be structurally split into 2 phases: Preparatory phase and Implementation phase.

7.1 Description of the Preparatory phase – 2040 NT Zonal Study

The Preparatory phase may be visualized as at the block diagram below in Figure 6 - Zonal IoSN: diagram representing the preparatory phase

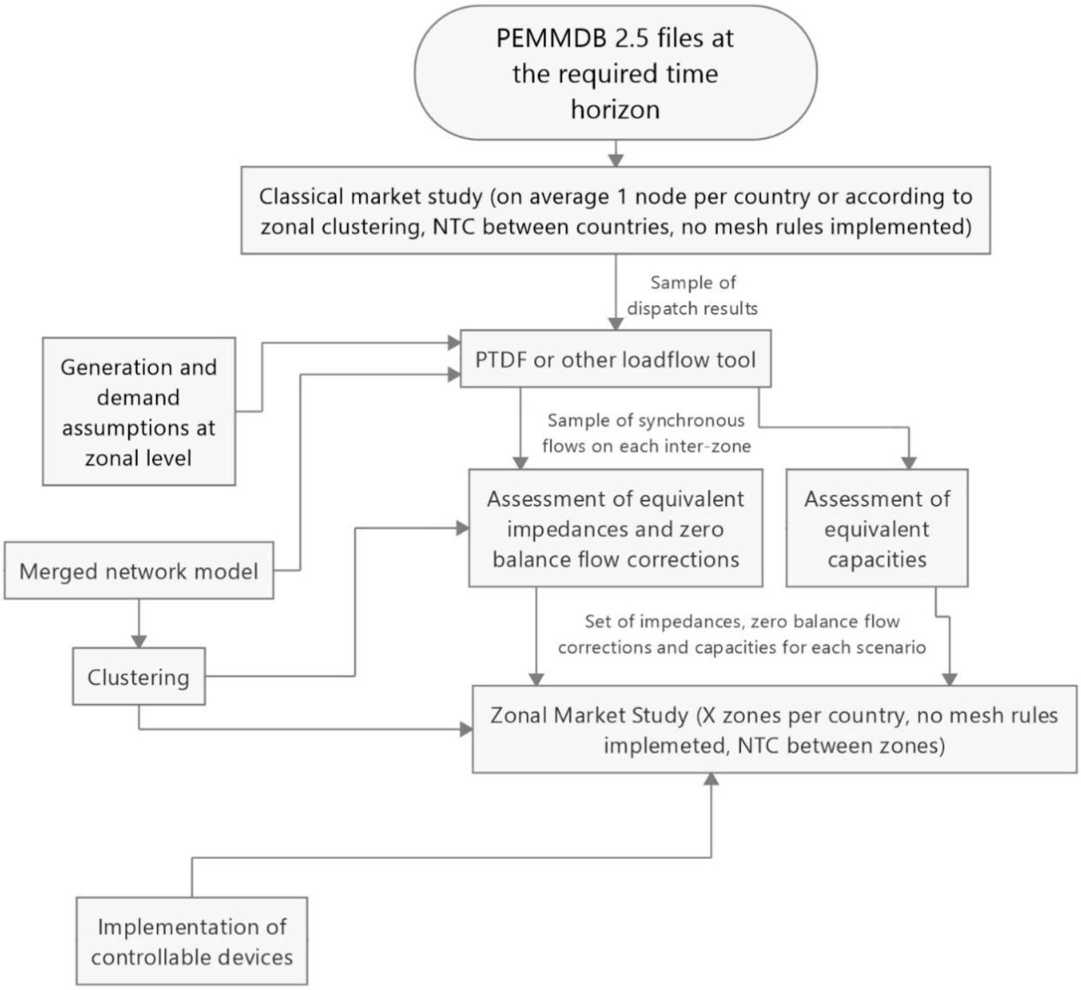


Figure 6 - Zonal IoSN: diagram representing the preparatory phase

Classical market study (1 node on average per country or Zonal clustering, NTC between countries, no mesh rule implemented)

As it could be seen in **Error! Reference source not found.**, the preparatory phase starts with a Classical market study based on a Scenario of TYNDP 2024 which is done based on a prepared dataset in PEMMDB 2.5 format received as part of the Scenario Building process.

The composition of such dataset is explained more in detail in chapter 3 of this document.

CIM merged grid model (base case)

The network model to be used as base case for IoSN 2040 of TYNDP 2024 is built from the grid model of TYNDP 2024 with 2030 NTCs used as a starting point. Several projects have then to be adapated in order to reach the grid corresponding to the reference base case NTCs for the scenario NT2040, which is used for IoSN 2040. The grid model is built in CIM (CGMES) format.

7.1.1 Clustering

The clustering has been updated/improved during TYNDP 2022 and has been kept without change for TYNDP2024.

For more details on the topic. TYNDP2022 implementation guidelines for Identification of the system needs study could be consulted: (https://eepublicdownloads.blob.core.windows.net/public-cdn-container/tyndp-documents/TYNDP2022/public/IoSN-IG.pdf)

The final results of the process of clustering is given in the following map :

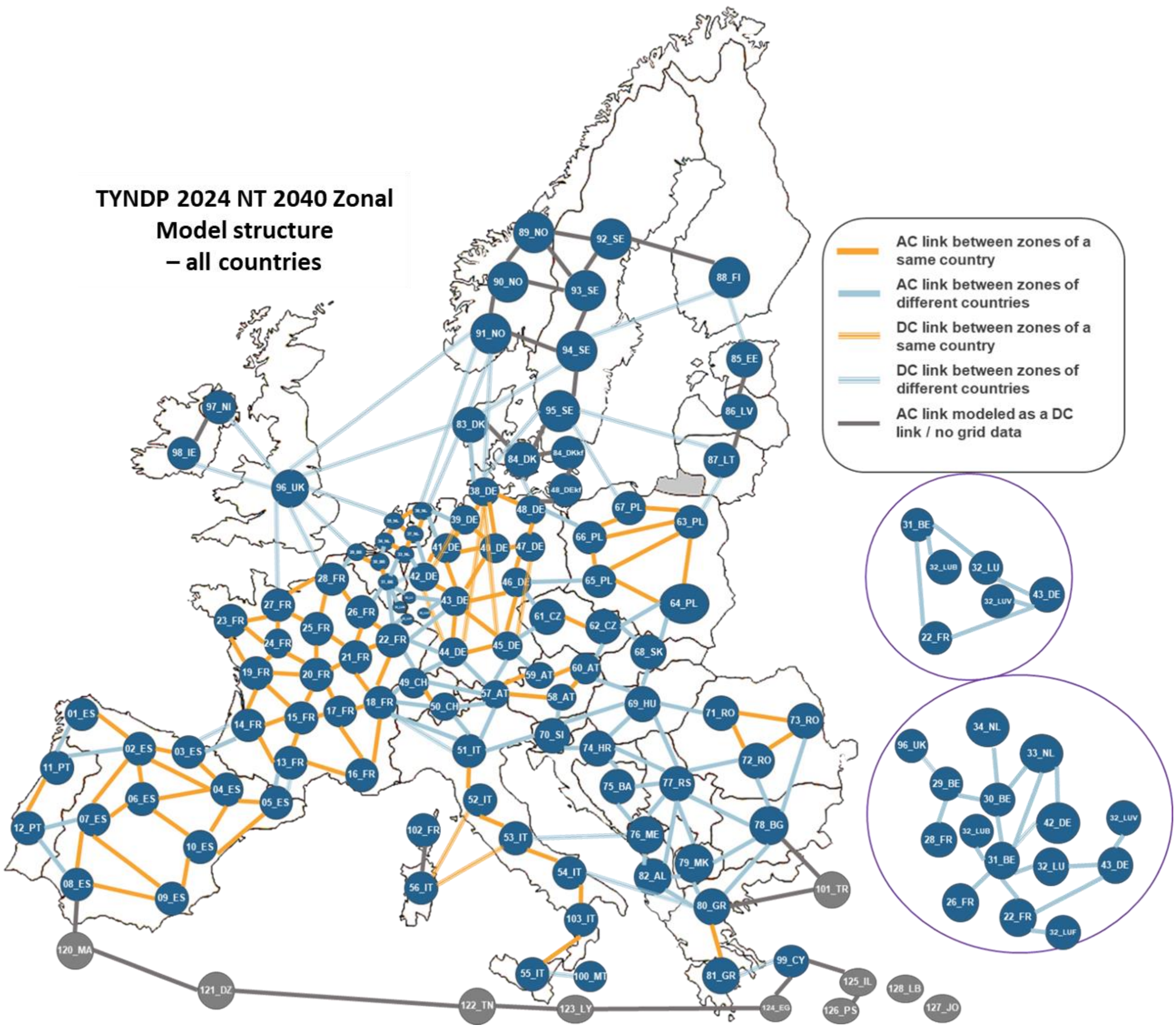


Figure 7 - TYNDP 2024 NT 2040 Zonal model structure

Table 3 gives the number of zones per country:

Table 3 Number of zones per country in each clustering set

Country	**Number of zones**
Spain	10
Portugal	2
France	16
Belgium	3
Luxembourg	1
Netherlands	5
Germany	11
Switzerland	2
Italy	7
Austria	4
Czech Republic	2
Poland	5
Slovakia	1
Hungary	1
Slovenia	1
Romania	3
Croatia	1
Bosnia	1
Montenegro	1
Serbia	1
Bulgaria	1
Macedonia	1
Greece	2
Albania	1
Denmark	2
Estonia	1
Latvia	1
Lithuania	1
Finland	1
Norway	3
Sweden	4
United Kingdom	1
Northern Ireland	1
Ireland	1
Cyprus	1
Malta	1
Turkey	1
Total	**102**

Table 4

Extra zones (Not concerned by the zonal parameter calculations)	**Number of zones**
Luxembourg (LUV, LUF and LUG)	3
Corsica	1
Denmark (Kriegersflak)	1
Germany (Kriegersflak)	1

7.1.2 GENERATION AND LOAD ASSUMPTIONS AT ZONAL LEVEL

The objective of this section is to describe the allocation of generation and load at every zone, according to the clustering topology that has been defined according to the methodology described earlier in this document.

Extract from DemandTimeries files with MED TSO data the timeseries for selected years (1995, 2008 and 2009)

DemandTimeseries are then split proportionaly to the ConformLoad in every subzone

$$Demand\ time\ series\ (subzone) = \left(Demand\ time\ series\ (zone) - NonConformDemand(zone)\right) * \frac{ConformDemand(subzone)}{ConformDemand(zone)} + ConformDemand(subzone)$$

This equation describes the splitting of demand timeserie of PEMMDB from a bidding zone among IoSN subzones. The Conform Load term implies Proportionnal Load e.g. for residential use. Non Conform Load refers to Fixed Load e.g. for industrial purpose.

For dispatchable generation, the capacity allocation per zone can be based on the merged grid model, which matches with the PEMMDB datasets per country, and per zone. With the location provided in the PEMMDB files for each generation power plant, the generation per zone is known. However, for different reasons, generation volumes are likely to be different for some types and some countries between the market data (PEMMDB) and grid model. These differences will be settled using scale factor and PEMMDB data considered as a reference.

For RES generation and load, if they were not provided by TSOs, the zonal time series have to be established from country time series. As a reminder, zonal modelling is an opportunity to study «desynchronized» time-series while taking into account spatial correlation between climatic variables. Thus, it is desired to have a common approach based on a climatic database and the construction of transfer functions in every zone.

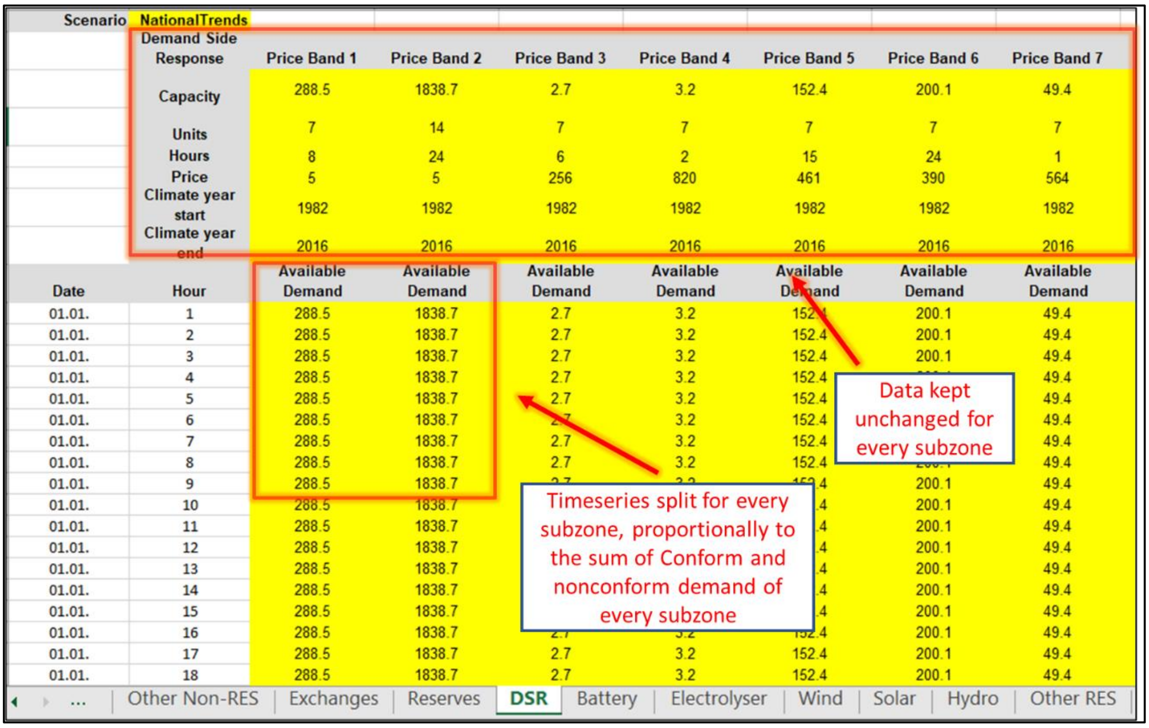
However, if such process will be difficult to be established or will cause a risk of jeopardizing of process timeline, it is suggested to infer the zonal times series from the country level time series by scale factor.

Below, details of the split approach for each type of modelled technology are provided.

DSR:

DAY AHEAD - Activation price for demand reduction (€/MWh) and Max hours to be used per day, for every Price Band: these data are kept unchanged for every subzone.

Each Available Demand Response (MW) column: data split in every subzone, proportionally to the sum of ConformLoad and NonConformLoad of every subzone.



Scenario	NationalTrends							
	Demand Side Response	Price Band 1	Price Band 2	Price Band 3	Price Band 4	Price Band 5	Price Band 6	Price Band 7
	Capacity	288.5	1838.7	2.7	3.2	152.4	200.1	49.4
	Units	7	14	7	7	7	7	7
	Hours	8	24	6	2	15	24	1
	Price	5	5	256	820	461	390	564
	Climate year start	1982	1982	1982	1982	1982	1982	1982
	Climate year end	2016	2016	2016	2016	2016	2016	2016
Date	Hour	Available Demand	Available Demand	Available Demand	Available Demand	Available Demand	Available Demand	Available Demand
01.01.	1	288.5	1838.7	2.7	3.2	152.4	200.1	49.4
01.01.	2	288.5	1838.7	2.7	3.2	152.4	200.1	49.4
01.01.	3	288.5	1838.7	2.7	3.2	152.4	200.1	49.4
01.01.	4	288.5	1838.7	2.7	3.2	152.4	[illegible]	49.4
01.01.	5	288.5	1838.7	2.7	3.2	152.4	[illegible]	49.4
01.01.	6	288.5	1838.7	[illegible]	3.2	152.4	[illegible]	49.4
01.01.	7	288.5	1838.7	2.7	3.2	152.4	[illegible]	49.4
01.01.	8	288.5	1838.7	2.7	3.2	152.4	[illegible]	49.4
01.01.	9	288.5	1838.7	[illegible]	[illegible]	[illegible]	200.1	49.4
01.01.	10	288.5	1838.7	[illegible]	[illegible]	[illegible]	200.1	49.4
01.01.	11	288.5	1838.7	[illegible]	[illegible]	[illegible]	200.1	49.4
01.01.	12	288.5	1838.7	[illegible]	[illegible]	[illegible]	200.1	49.4
01.01.	13	288.5	1838.7	[illegible]	[illegible]	[illegible]	200.1	49.4
01.01.	14	288.5	1838.7	[illegible]	[illegible]	[illegible]	200.1	49.4
01.01.	15	288.5	1838.7	[illegible]	[illegible]	[illegible]	200.1	49.4
01.01.	16	288.5	1838.7	[illegible]	[illegible]	[illegible]	200.1	49.4
01.01.	17	288.5	1838.7	2.7	3.2	152.4	200.1	49.4
01.01.	18	288.5	1838.7	2.7	3.2	152.4	200.1	49.4

Figure 8 – example of time series split for the DSR for every subzone

Batteries:

Installed market participating Battery storage capacities (output, MW)

Installed market participating Battery storage capacities (storage, MWh)

These datasets are split proportionally to the whole load (conform load + non conform load) of every subzone.

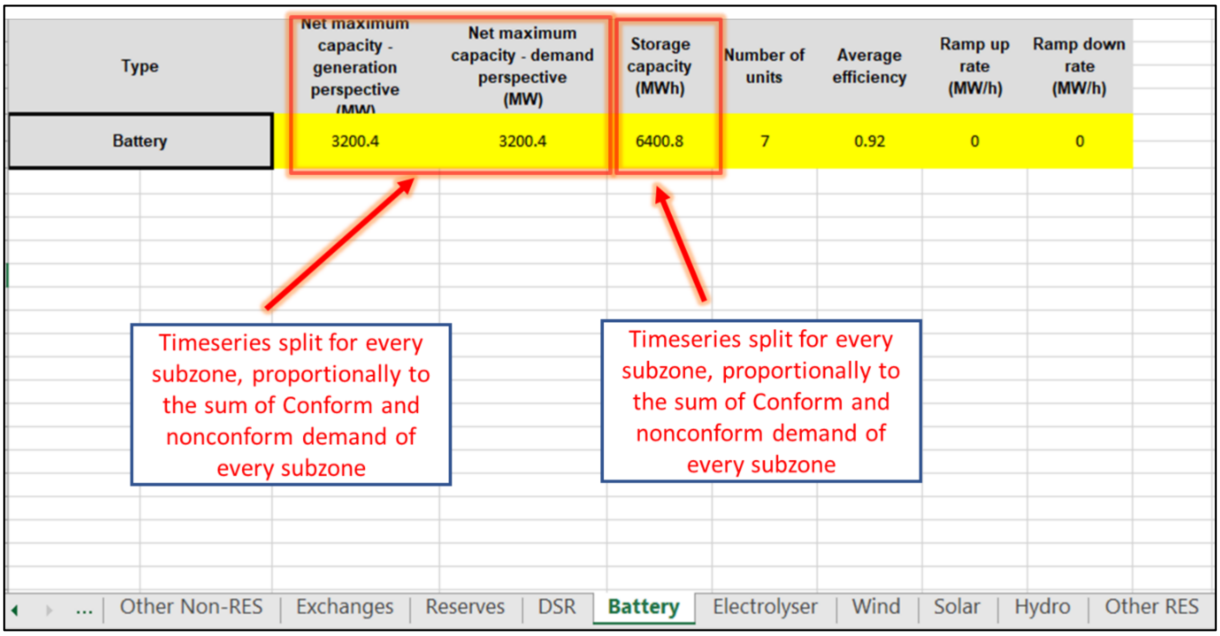


Figure 9 - example of time series split for the batteries for every subzone

Power-to-gas (P2G):

Installed market participating Electrolysers capacities (output, MW): This data will be split proportionally to the non conform load (P2G located in industrial consumers) of every subzone.

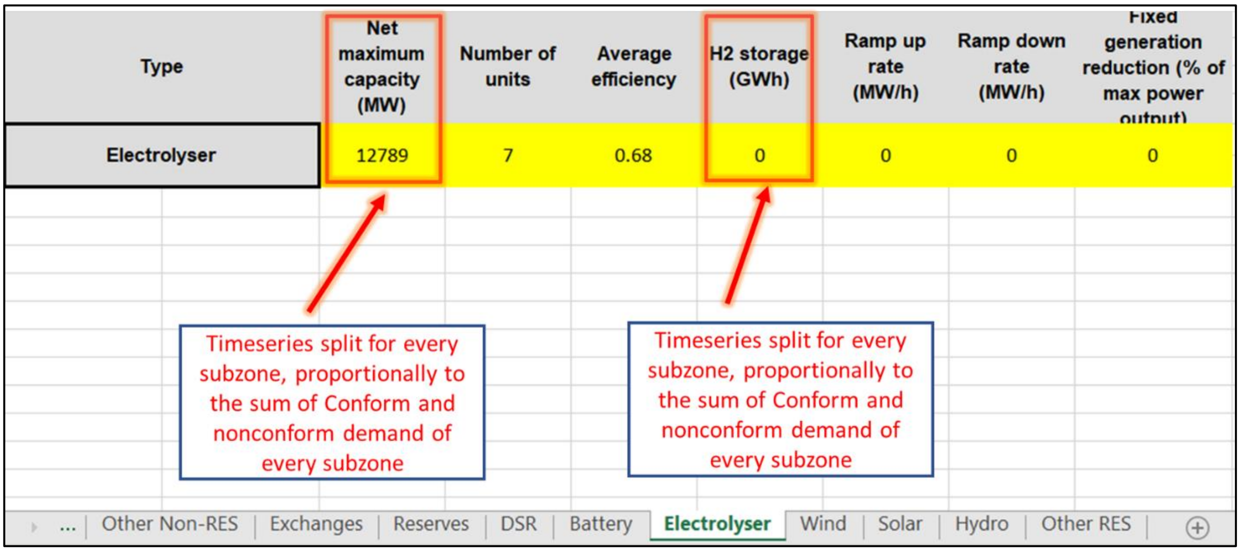


Figure 10- example of time series split for the P2G for every subzone

Other RES:¶

Other RES technology data is split proportionally to the installed capacities of Other-RES generating units (fuel type 35) located in each subzone:

TOTAL Other RES Output (MW) (excl. climate dependent bands) (timeseries)

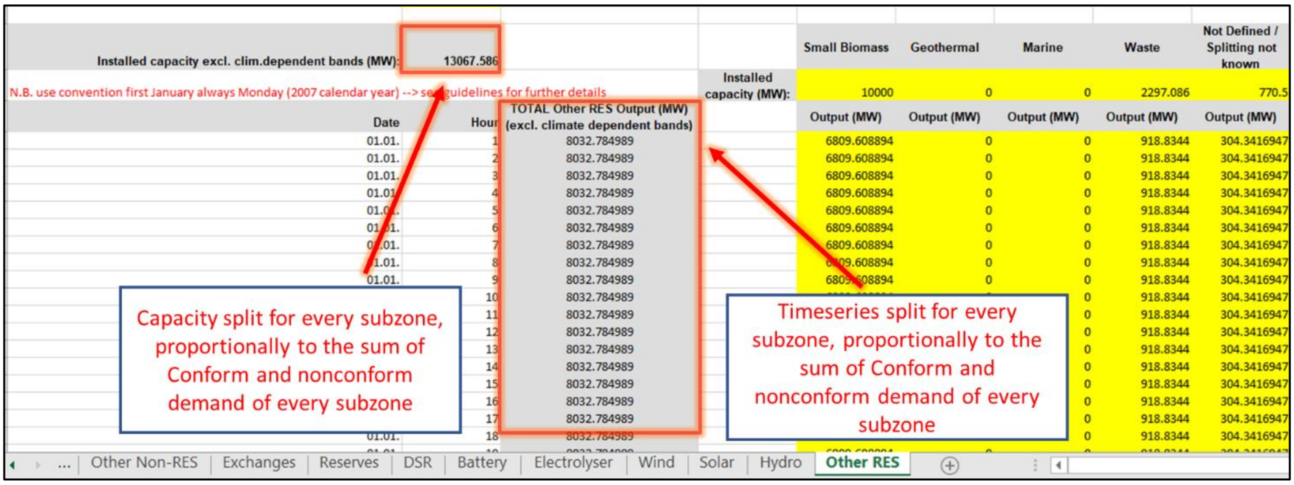


Figure 11 -example of capacity split and timeseries spit for other RES

Other Non-RES:

The following data is extracted from the PEMMDB 2.5 datasets (sheet Other Non-RES):

Unchanged data (data copied into every subzone), taken from Zero Cost/Non-market Other non-RES, Other non-RES Price Band x and Climate dependent other non-RES Band x columns:

- PEMMDB type(s),
- Market Offer Price (€/MWh),
- Avg. efficiency ratio,
- Avg. CO2 emission factor (ton/MWh)
    - Changed data: these data will be split into subzones, proportionally to the installed capacities of Other Non-RES generating units (fuel type 36) located in the subzone:
- Installed capacity (MW)
- Available capacity (MW) (timeseries)

Figure 12 - example of capacity split and timeseries spit for other non-RES generation capacities

7.1.3 INTERNAL INTERZONE EXPANSION ASSUMPTIONS

In TYNDP 2022 the optimization was made only with cross-border capacities activated. Zonal scale also allows to activate internal capacities in the zonal network model.

In TYNDP 2024 a variant of the system needs optimization was performed with internal capacities activated to compare system needs results with classic optimization where only cross-border capacities are activated. It aims to evaluate the impact of the limits of internal networks on the optimal target of interconnections.

7.2 Description of the Preparatory phase – 2030 NT Classic Study

Preparatory phase for 2030 Identification of the System Needs study implies preparation of standard market model and conducting classical market study (1 node on average per country or Zonal clustering, NTC between countries, no mesh rule implemented). A classical market study was performed based on the National Trends scenario of TYNDP 2024, using a dataset in PEMMDB 2.5 format developed as part of the Scenario Building process. The composition of such dataset is explained more in detail in chapter 3 of this document (Input data).

7.3 Step-by-Step description of the Implementation phase

7.3.1 Implementation phase for 2030 time horizon

In general, the implementation phase for the NTC IoSN process can be described in 5 consecutive steps as shown in Figure 13 : Step-by-Step NTC IoSN implementation phase process diagram**Error! Reference source not found.**:

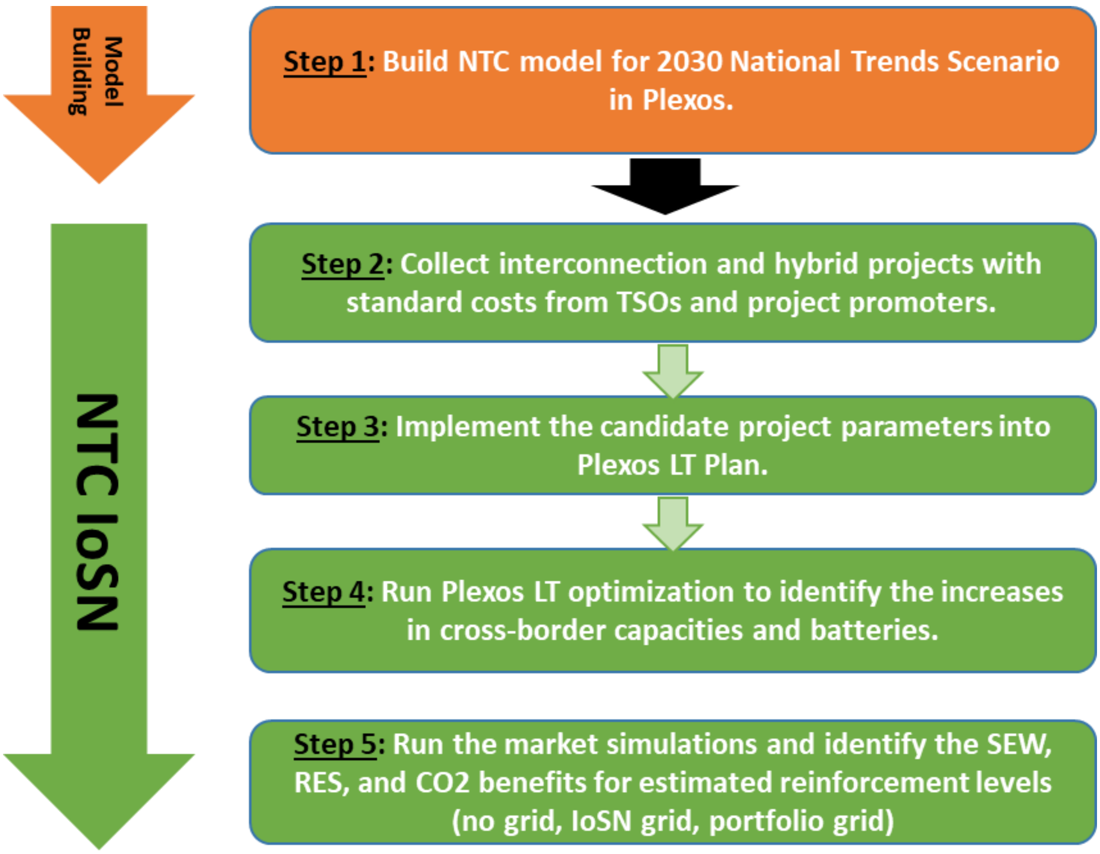


Figure 13 : Step-by-Step NTC IoSN implementation phase process diagram

Step 1 : Build NTC model for 2030 National Trends Scenario in Plexos.

Identification of the system needs for 2030 time horizon is based on NT 2030 scenario with a 2030 starting grid with the exception of countries split in different bidding zones (detailed hereafter). The model is built with PEMMDB 2.5 format data for this scenario except for batteries.

Grid – particular case of Italy, Norway, Denmark, Sweden

Identification of the system needs does not investigate the needs within internal zones of each country. Therefore, there are no investments between internal bidding zones of countries split in the model. So, in order to be coherent with the timeframe of the study, those NTCs are set to the best vision of the relevant TSO of the 2030 time horizon NTC on those inter-zones.

Storage – particular case of batteries (NT 2030 starting point)

Identification of the system needs for 2030 time horizon studies the interactions between cross-border grid investments, storage investments . Starting point for storage was set to NT 2030 levels for batteries.

Step 2 : Collect interconnection and hybrid projects with standard costs from TSOs and project promoters.

The collection of the transmission investment candidates for Scenario Building and TYNDP 2024 projects has been conducted by ENTSO-E in April-May 2023. The collection has been initiated within all the project promoters from the TYNDP 2022 list.

In parallel the collection of starting grid has been conducted with TSOs. The starting grid was representing the starting point coherent with 2025 time horizon.

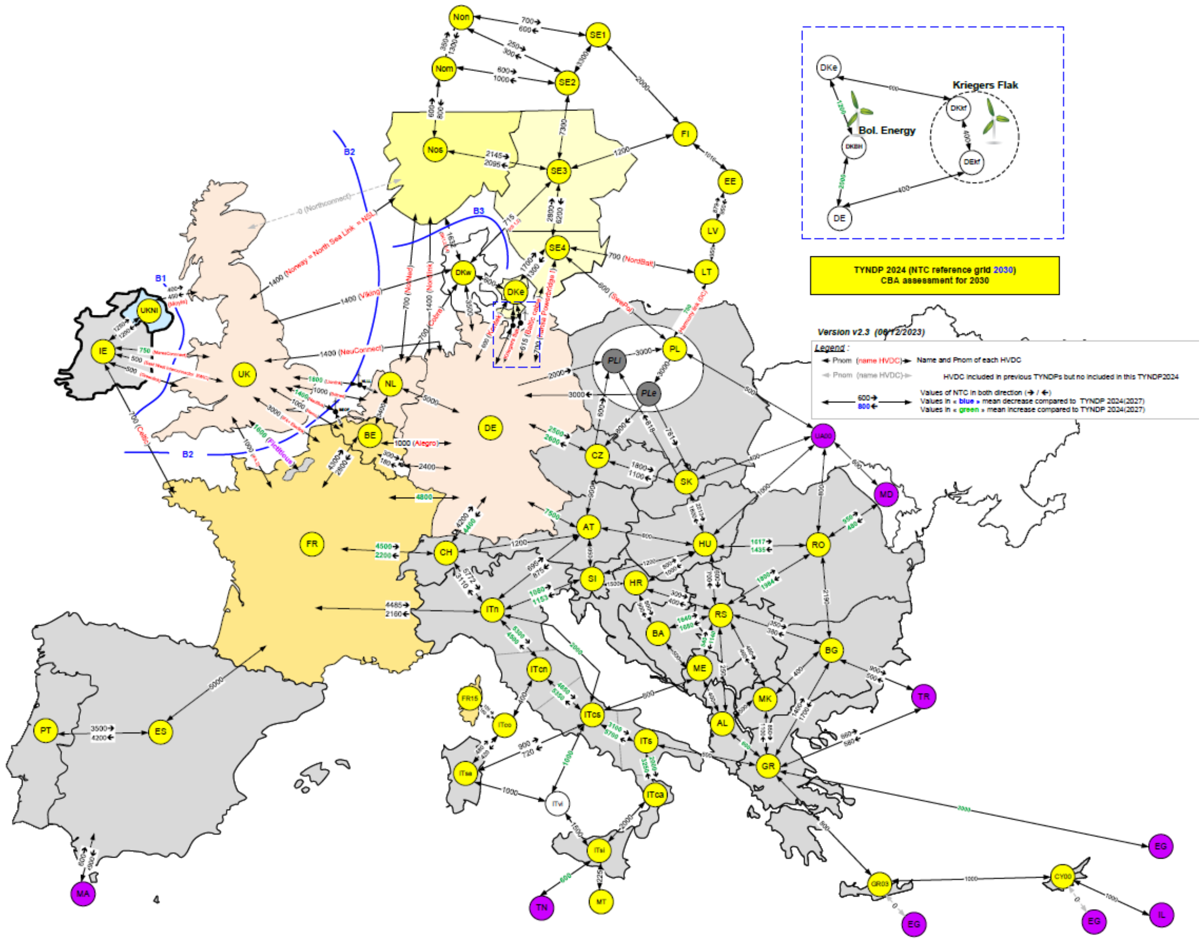


Figure 14 2030 Starting grid for investment candidate collection

The 2030 reference grid has been prepared considering most mature projects (TOOT) that were identified according to the following criteria (according to the 4th CBA Guidelines):

Proof of maturity

A project should only be included in the reference grid when its capacity is available in the year for which a simulation is performed. Hence, only those projects whose **timely commissioning is reasonably certain** are to be included in the reference network. This can be assessed by considering the **development status of the project and including the most mature projects that either**:

a) Are **in the construction** phase; or

b) Having **successfully completed the environmental impact assessments**; or

c) Are **in 'permitting'** **or 'planned, but not yet permitting'**, and their timely realisation is most likely (e.g., when the project is supported by country-specific legal requirements or the permitting and construction phase can be assumed to be short, such as for transformers, phase shifters etc.). **This requirement can be strengthened by applying further criteria**, such as:

- The project is considered in the National Development Plan of the country where it is expected to be located.
- The project fulfils the legal requirements as stated in the specific national framework where the project is expected to be located.
- The project has a defined position with respect to the Final Investment Decision related to its implementation.
- There is a documented reference to the request for permits.
- A clearly defined system need, to which a project contributes, could help to identify the reference grid.
- Year of commissioning: chosen depending on the year of the study and the scenario horizon used to perform the study.

In general, it appears reasonable to define different reference grids for different time horizons. Although the above given maturity criteria can be applied for all time horizons, the focus for defining the reference grid for the first study year of the **mid-term horizon** has to be based on **the criteria given under a) and b)**. Based on this the reference grid for the second year of the mid-term horizon and the **long-term horizon** can be defined by including projects following the criteria as given under c).

In cases where a cross-border project involves countries with different permitting processes and procedures it would be advisable to use expert evidence-based judgement.

Whatever criteria has been chosen, the proof of maturity needs to be given in the study following the guideline given in the respective implementation guidelines. It should also be mentioned that smaller projects (e.g. line upgrades) will most probably need less time to run through the approval process. This has to be considered, when defining the reference grid. In the end, the reference grid should assume the most probable and realistic grid for the respective time horizon.

The following assumptions have been considered within the data collection:

Starting grid for the investments: 2030 time horizon

1. Section "Real_XPANSION"

/!\ Cross-border potential capacity increases - Real projects - PINT projects to be studied during TYNDP 2024 or studied during TYNDP 2022 process

/!\ TSOs provide third-party project data, with an offset to the CAPEX to account for internal reinforcement if they are not provided by third-party project promoter.

/!\ Hybrid projects (crossborder potential capacity increases) were not in the scope of following collection

Data requested:

- TSO Promoter (Yes/No) – Yes, if your organization is a TSO
- Link name – Market Node A – Market Node B (FR00 – ES00)
- Node from – Market Node A which project connects
- Node to – Market Node B which project connects
- Name – Name of the project
- ID – Project ID from TYNDP 2022
- Direct capacity increase (MW) – Net Transfer Capacity increase from Market Node A to B
- Indirect capacity increase (MW) – Net Transfer Capacity increase from Market Node B to A
- CAPEX – Capital Expenses (MEuro)
- OPEX – Operational Expenses (MEuro)
- Internal reinforcement CAPEX node from – CAPEX of required internal reinforcement in Market Node A
- Internal reinforcement CAPEX node to – CAPEX of required internal reinforcement in Market Node B
- Internal reinforcement comment - comment by TSO in case of reinforcement split
- Station from Name – Name of the substation A which project connects
- Station to Name – Name of the substation B which project connects
- RDFID (station from) – RDFID of the substation A which project connects
- RDFID (Station to) – RDFID of the substation B which project connects

2. Section "Concept_XPANSION"

Minimum : 2 conceptual projects per border are required

/!\ Conceptual cross-border potential capacity increases could be introduced only by TSO-promoters due to specific knowledge on the grid and consequences for introduction of new candidates in the system

/!\ Use the same capacity increase for all conceptual cross-border potential capacity increases at the same border to decrease the load on the optimization software (Ex. if your first project adds

1000 MW transfer capacity, all other conceptual projects should add 1000 MW but with higher CAPEX/OPEX)

/!\ Use capacity increase rounded to the 100th (Ex. 600 for 620)

/!\ Minimum capacity increase for conceptual cross-border potential capacity increases is 500 MW

/!\ Conceptual cross-border potential capacity increases can only be introduced on borders where there already is exchange capacity or there are real projects

/!\ Include internal reinforcements for conceptual cross-border potential capacity increases in the dedicated column of the submission form

/!\ Hybrid projects (crossborder potential capacity increases) are not in the scope of current collection

Data requested:

- Link name – Market Node A – Market Node B (FR00 – ES00)
- Node from – Market Node A which project connects
- Node to – Market Node B which project connects
- Direct capacity increase (MW) – Net Transfer Capacity increase from Market Node A to B
- Indirect capacity increase (MW) – Net Transfer Capacity increase from Market Node B to A
- CAPEX – Capital Expenses (MEuro)
- OPEX – Operational Expenses (MEuro)
- Internal reinforcement CAPEX node from – CAPEX of required internal reinforcement in Market Node A
- Internal reinforcement CAPEX node to – CAPEX of required internal reinforcement in Market Node B
- Internal reinforcement comment - comment by TSO in case of reinforcement split
- Station from Name – Name of the substation A which project connects
- Station to Name – Name of the substation B which project connects
- RDFID (station from) – RDFID of the substation A which project connects
- RDFID (Station to) – RDFID of the substation B which project connects

3. Section "InternalGrids"

Relevant in case country has been composed of couple of internal market nodes. Direct and Indirect transfer capacity impact on top of 2030 and 2040 (2035) time horizons for the given investment candidate projects had to be provided

The starting point for the investment candidate collection is 2030 time horizon. Which means that the investment candidates should be considered on top of the reference network for 2030 time horizon.

The list of investment candidates is provided in Appendix 1 of this document.

Steps 3 : Implement the candidate project parameters into Plexos LT Plan.

This step corresponds to step x of the implementation phase for 2030 time horizon which has been described in 6.2.1.

Steps 4 : Run Plexos LT optimization to identify the increases in cross-border capacities and batteries.

This step corresponds to step x of the implementation phase for 2030 time horizon which has been described in 6.2.1.

Steps 5 : Run the market simulations and identify the SEW, RES, and CO2 benefits for estimated reinforcement levels (no grid, IoSN grid, portfolio grid)

This step corresponds to step x of the implementation phase for 2030 time horizon which has been described in 6.2.1.

7.3.2 Implementation phase for 2040 NT Scenario

In general, the implementation phase for the Zonal IoSN process can be described in 9 consecutive steps as shown in Figure 15 :

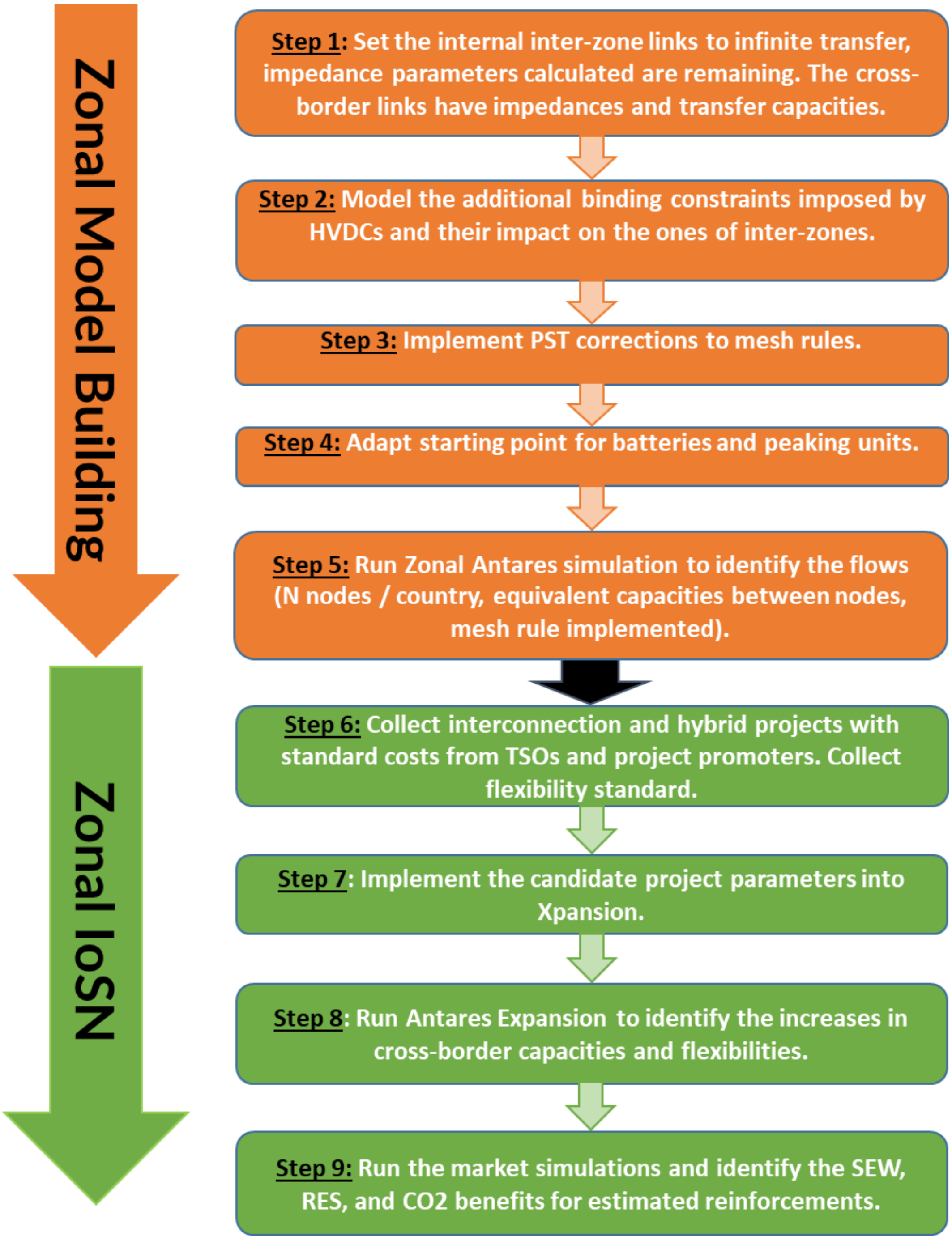


Figure 15 Step-by-Step IoSN Implementation phase process diagram for 2040 IoSN study

Step 1:

Option 1: For reference simulation, set the internal inter-zone links to infinite transfer capacity, impedance parameters are left unchanged. The cross-border links have impedances and transfer capacities.

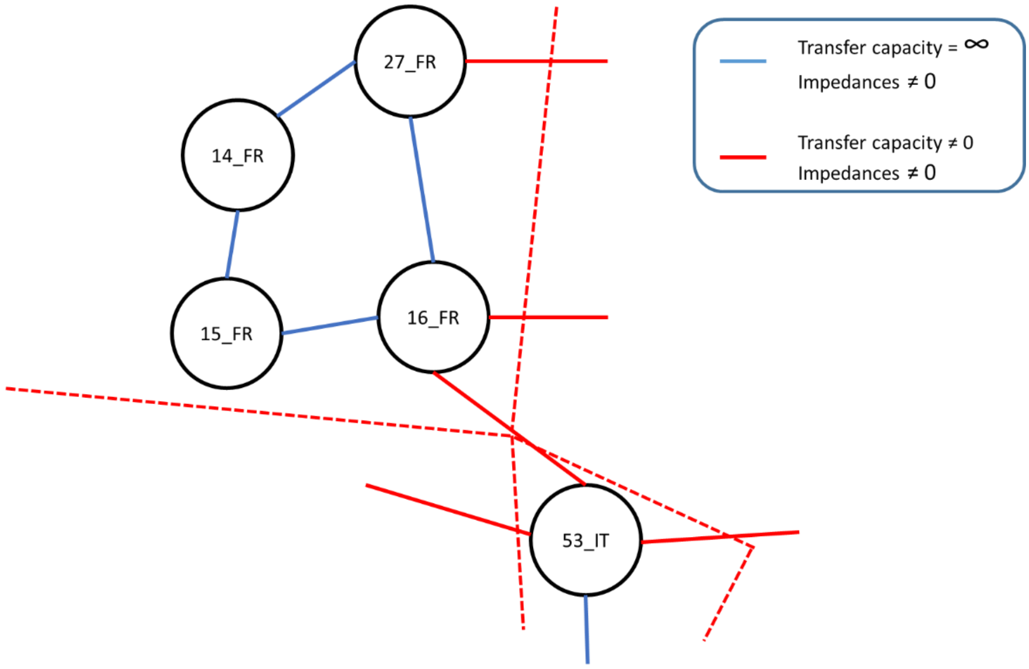


Figure 16 Starting assumptions for the Zone connections

The assumptions according to the Step 1 for reference simulation of the implementation phase are illustrated on Figure 16. It is worth mentioning that in case of need the hourly congestions could be monitored at internal inter-zone connections once the transfer capacities are calculated for these links.

Option 2: For variant internal and cross-border inter-zones links are set with capacities and impedances calculated in zonal model process.

Step 2: Additional binding constraints are imposed by HVDCs;

HVDC links have been added separately into the model. No mesh rule constraints have been applied on them, but some binding constraints might still be applied in some cases:

- To simulate an AC emulation for an HVDC,

- To specify a different direction of flow for several HVDC connections between the same countries but different zones (For example the different HVDCs between Great Britain and France or between Sweden and Germany),
- To take into account an HVDC as a critical outage (For example, to model the limitations on an AC interzone between France and Spain in case of an HVDC's outage).
- Additionally, due to specific behaviour of HVDC links in the system, separate constraints have to be added to account for these system elements. For example, HVDC connections have an impact on power loop flows in the system. If the impact is non-negligeable and can strongly modify the power flows, it may be important to consider them in the model.

The impact on an interzone can be modelled in the following way:

$\mathbf{Flow'_{A\text{-}B} = Flow_{A\text{-}B} + F0_{A\text{-}B}}$ **becomes** $\mathbf{Flow'_{A\text{-}B} = Flow_{A\text{-}B} + F0_{A\text{-}B} + F0'_{A\text{-}B}}$

With $\mathbf{F0'_{A\text{-}B} = k_1 \,.\, Flow_{HVDC1} + k_2 \,.\, Flow_{HVDC2} + \ldots}$

To calculate k_n: constant setpoint Sn on HVDCn, assessment of the induced loop flow F0n, k_n = F0n / Sn.

As an example, the table below shows, for the TYNDP 2018 ST2040 scenario, the coefficient k which represents the impact in MW on zero balance flow corrections of several HVDCs (set to 100MW) on the interzones:

HVDC interzones	04_es_21_fr	06_es_20_fr	18_fr_53_it	28_be_33_de	31_de_33_de	31_de_36_de	31_de_37_de	32_de_37_de	33_de_36_de	49_ch_53_it	53_it_59_si
06_es - 20_fr		-5									
17_fr - 53_it			-23								-6
25_fr - 28_be				-9							
28_be - 30_nl			5	-6					5		
30_nl - 31_de				11	9						
30_nl - 33_de				-17	-9				6		
36_de - 48_ch											-8
37_de - 50_at								9			
37_de - 51_at											5
41_cz - 47_sk											9
47_sk - 60_hu											11
49_ch - 50_at										7	
49_ch - 53_it			10							-10	-14
50_at - 53_it			6								
52_at - 60_hu											6
53_it - 59_si											-19
59_si - 60_hu											-6
59_si - 64_hr											-12
60_hu - 64_hr											7

Impact in MW on each cross-border inter-zone for 100 MW on the HVDC (impacts above 5% only): Scenario ST2040 of TYNDP 2018

Figure 17 - Impact in MW on each cross-border inter-zone for 100 MW on the HVDC, from ST 2040 TYNDP 2018 Scenarios

Following this logic, instead of setting the capacities of A-B in the following way :

$$(- capa\_opposit_{A\text{-}B} - F0_{A\text{-}B} \leq Flow_{A\text{-}B} \leq capa\_direct_{A\text{-}B} - F0_{A\text{-}B})$$

New binding constraint have to be set in the following way:

$$- capa\_opposit_{A\text{-}B} - F0_{A\text{-}B} \leq Flow_{A\text{-}B} + k_{HVDC1\square A\text{-}B} \times Flow_{HVDC1} + k_{HVDC2\square A\text{-}B} \times Flow_{HVDC2} + \ldots \leq capa\_direct_{A\text{-}B} - F0_{A\text{-}B}$$

In addition, the HVDC connections inside Germany have to be used in a classical way to calculate the power flow parameters. It is suggested to simulate them using AC emulation, as it is usually done for the connection between Switzerland and Italy and the one between Italy and Slovenia.

Step 3: PST corrections to mesh rules are implemented;

The corrections to account for the PSTs have to be implemented in the model.

The different PSTs taken into account in the model are located as shown at the map on Figure 18 - PST Setting in Zonal Modelbelow:

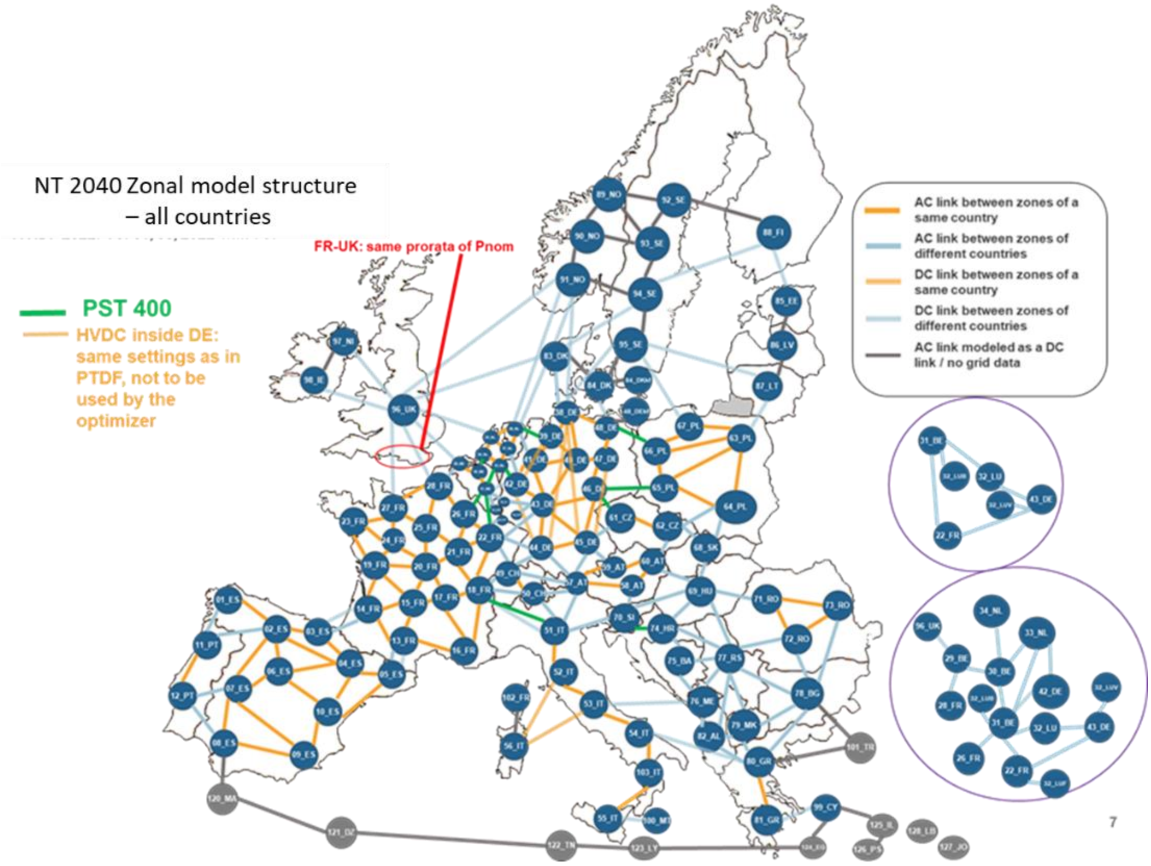


Figure 18 - PST Setting in Zonal Model

PST impact is modelled by easing the mesh rule binding constraints.

When a PST is located on an interzone, the classical mesh rule equation is:

$$X_1.F_1 + X_2.F_2 + \dots + X_n.F_n = 0$$

It evolves to:

$$\varepsilon' \leq X_1.F_1 + X_2.F_2 + \dots + X_n.F_n \leq \varepsilon,$$

Where ε’ and ε represent the minimum and maximum phase shifting capacity of the PST.

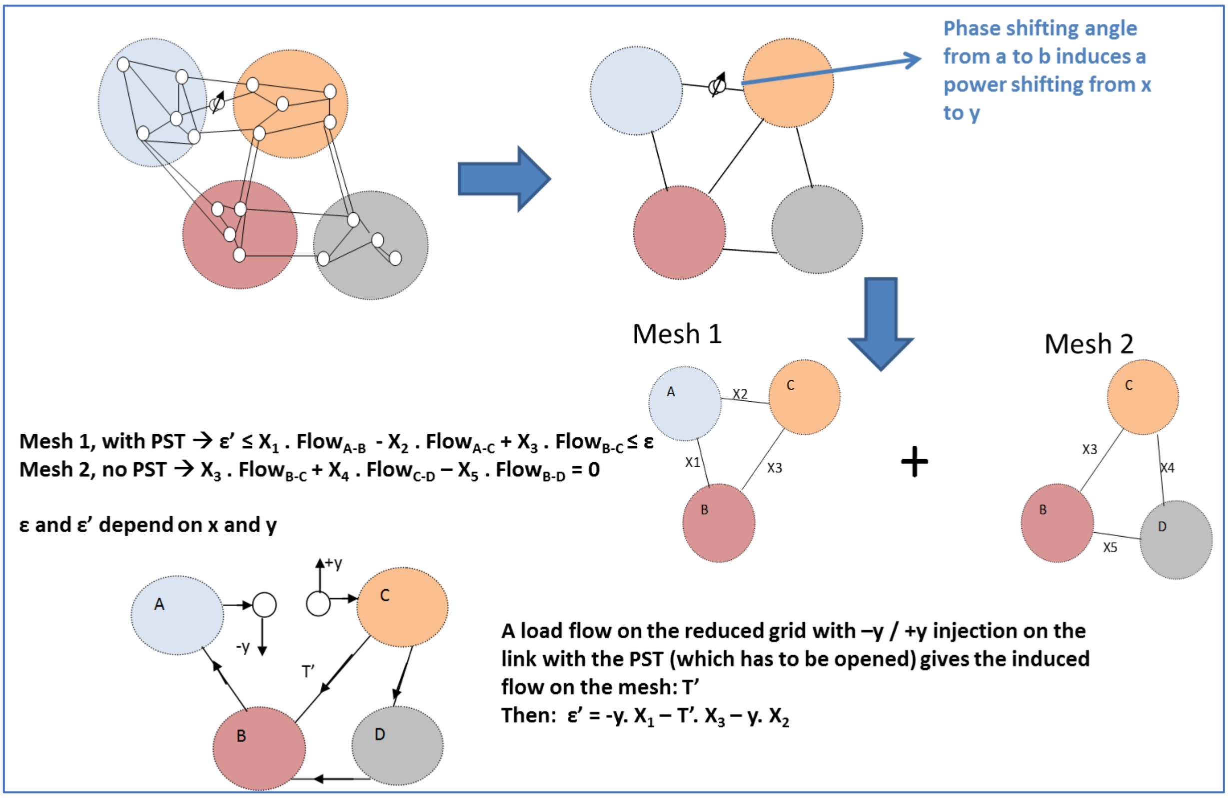


Figure 19 PST Modelling logic for Zonal Model

In case PSTs are meant to be used only when outages occur (curative actions only), they don't have to be implemented in the model.

However, it is still needed to specify if the model could use the full capacity of the PST or if a safety margin needs to be kept for real time operation. It is suggested to neutralise 1/3 of the phase shifting capacity as a safety margin.

Also, on the one hand, some PSTs of a same country/interzone may be combined into one in order to simplify the model (for example the 2 PSTs between Belgium and Netherlands). On the other hand, the PST between Diele and Meeden and the one between Diele and Conneforde should be separated because of their different behaviour. It is the same for the ones between Germany and Switzerland because of their very different tap ranges.

The rest of PSTs are modelled specifically.

Step 4: Adapt zonal model to starting points for batteries ;

Identification of the System Needs study for 2040 time horizon is based on NT 2040 scenario with a 2030 starting network. The model is built with PEMMDB 2.5 data for this scenario except for batteries.

Grid – particular case of Norway, Denmark, Sweden and Italy (except ITn bidding zone) which are not necessarily described in detail (antenna or non-synchronized zones).

IoSN does not identify the needs within internal zones of a country. Therefore, there are no investments between internal bidding zones of countries split in the model. So, in order to be coherent with the timeframe of the study, those NTCs are set to the best vision of the relevant TSO of the 2040 NTC on those interzones.

Storage – particular case of batteries (NT 2030 starting point)

Identification of the System Needs study for 2040 time horizon studies the interactions between cross-border grid investments, storage investments. Starting point for storage is set to NT 2030 levels for batteries, meaning that all batteries commissioned between NT 2030 and NT 2040 scenarios are taken out of the model, as they are added as investment candidates.

Step 5: Run Zonal simulation to identify the flows

Zonal market simulation should be performed to check the reference case congestions in the system and identify the flows.

Internal capacities are computed for the zonal model, which allows a study with or without internal constraints. While internal constraints were not taken into account in Identification of the System Needs studies during TYNDP 2022 process, they will be studied as a variant in the Identification of the System Needs study for 2040 time horizon during TYNDP 2024 process.

Step 6: Collect interconnection projects with standard costs from TSOs and project promoters. Collect hybrid interconnection projects from ONDP from regional groups.

The list of investment candidates is available as an Appendix 1 to this document.

Step 7: Implementation of the candidate project parameters (standard costs) into Investment Optimization Engine.

The candidate projects have been implemented in the Investment Optimization Engine with their relevant parameters including standard costs. For interconnectors, standard costs are calculated based on project CAPEX and OPEX given the data collection by project promoters using the following formula:

$$annualized\ costs = OPEX + CAPEX \times \left(\frac{\delta}{1-\left(\frac{1}{1+\delta}\right)^{n}}\right)$$

Where δ is the discount rate (4% for interconnectors) and n is the lifetime (25 years for interconnectors).

Storage investment assumptions are based on scenario building assumptions found below:

Table 5 Storage investment assumptions

NODE	YEAR	SCENARIO	TECHNOLOGY	CAPEX [€/MW]	OPEX[€/MW/a]
All	*2030*	*National Trends*	*Batteries Utility*	*716480.00*	*17912.00*
All	*2040*	*National Trends*	*Batteries Utility*	*627122.00*	*15678.00*
All	*2050*	*Distributed Energy*	*Batteries Prosumer*	*1038770*	*25970*
All	*2050*	*Distributed Energy*	*Batteries Utility*	*716480.00*	*17912.00*

Hybrid interconnections costs are based on the outcomes of the ONDP study performed by ENTSO-E, the investment parameters could be found below:

Table 6 Hybrid interconnection investment candidate parameters

Element	**CAPEX/OPEX**	**Unit**	Cost Set 1	**Cost Set 2**	**Cost Set 3**
			Low	**Average**	**high**
Onshore HVDC cable	CAPEX	MEUR/MW*km	0,00168	0,00274	0,0038
Offshore HVDC cable	CAPEX	MEUR/MW*km	0,00168	0,00234	0,003
Offshore HVDC converter (including platform)	CAPEX	MEUR/MW	0,55	0,625	0,7
Onshore HVDC converter	CAPEX	MEUR/MW	0,25	0,275	0,3
Offshore node expansion	CAPEX	MEUR/MW	0,165	0,1875	0,21
Onshore HVDC cable	OPEX	% of CAPEX / year	0,025	0,025	0,025
Offshore HVDC cable	OPEX	% of CAPEX / year	0,025	0,025	0,025
Offshore HVDC converter (including platform)	OPEX	% of CAPEX / year	0,015	0,015	0,015
Onshore HVDC converter	OPEX	% of CAPEX / year	0,015	0,015	0,015
Offshore node expansion	OPEX	% of CAPEX / year	0,015	0,015	0,015

Step 8: Run the Investment Optimization process to identify the increases in the cross-border capacity;

The “Capacity Expansion” problem constitutes the investigation of the optimal combination of generation new builds (and retirements) and transmission upgrades (and retirements) that minimize the Net Present Value of the Total Costs (total costs are annualized investment costs added to operational costs of the system.) of the system over a long-term planning horizon. The result of the calculation can simultaneously solve a generation and transmission capacity expansion problem (new investments/retirements locations, times and sizes) and a dispatch problem for a long-term perspective.

Antares software handles capacity expansion problems via the additional packages (not included directly in Antares) regrouped on a module called Antares Xpansion.

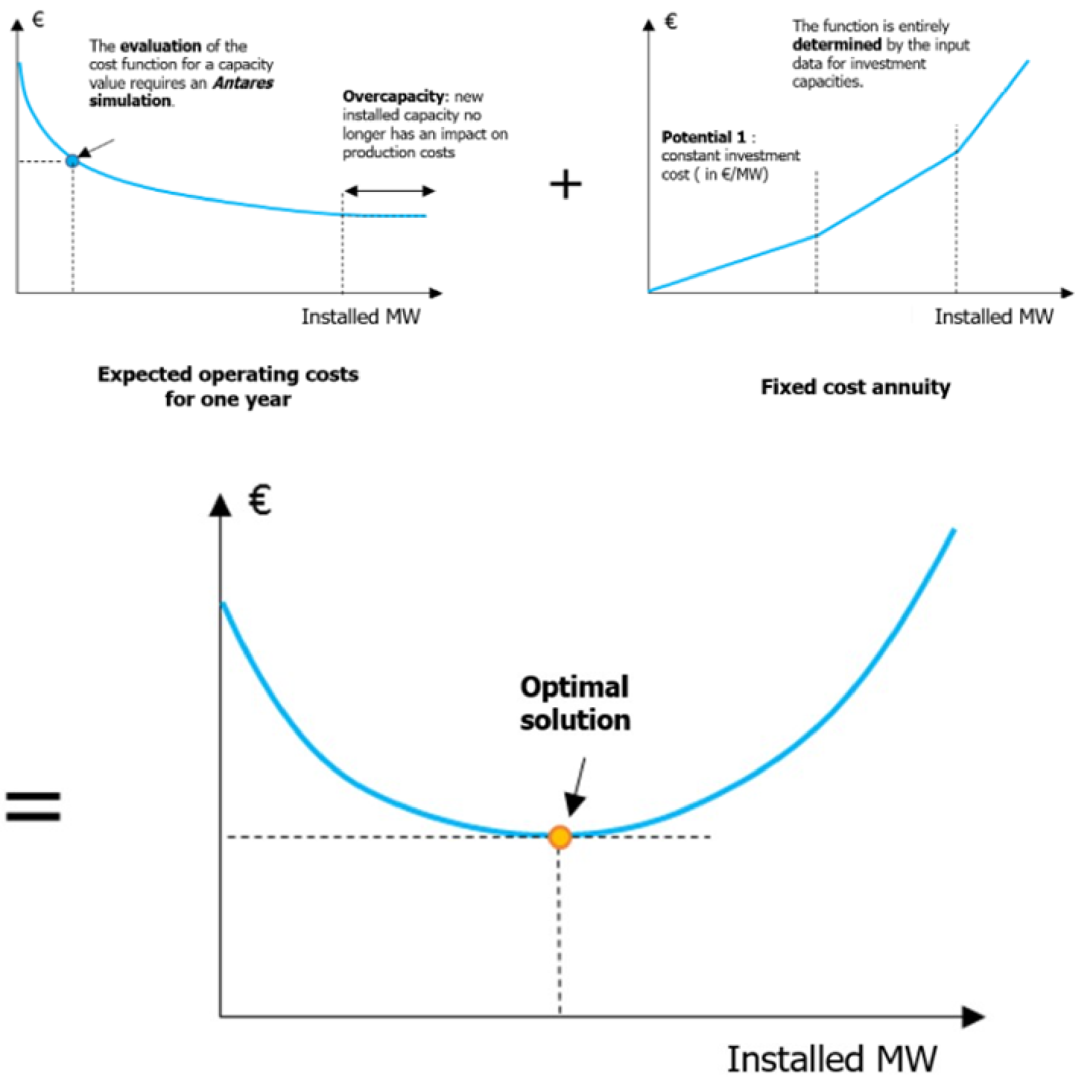


Figure 19 Expansion optimization principle

The Antares Xpansion algorithm is based on the **Benders Decomposition** technique. Benders decomposition is a solution method for solving certain large-scale optimization problems. Instead of considering all decision variables and constraints of a large-scale problem simultaneously, Benders decomposition partitions the problem into multiple smaller sub-problems. Since the computational difficulty of optimization problems increases significantly with the number of variables and constraints, solving these sub-problems iteratively can be more efficient than solving a single large problem.

The Benders decomposition is implemented by Antares Xpansion through successive iterations following the steps below:

- Proposal of investments/retirements list among the list of candidates.
- Addition of these investments/retirements to an Antares dispatch simulation; run the simulation.
- Calculation of total system cost including operational costs at this iteration and investments/retirements cost (sum of annuities of candidates retained at this iteration).
- Calculation of the optimality gap corresponding to the difference between the total cost at this iteration and the one from the previous iteration.
- If the optimality gap is larger than a certain threshold (entered as an input), go to first step for the next iteration.

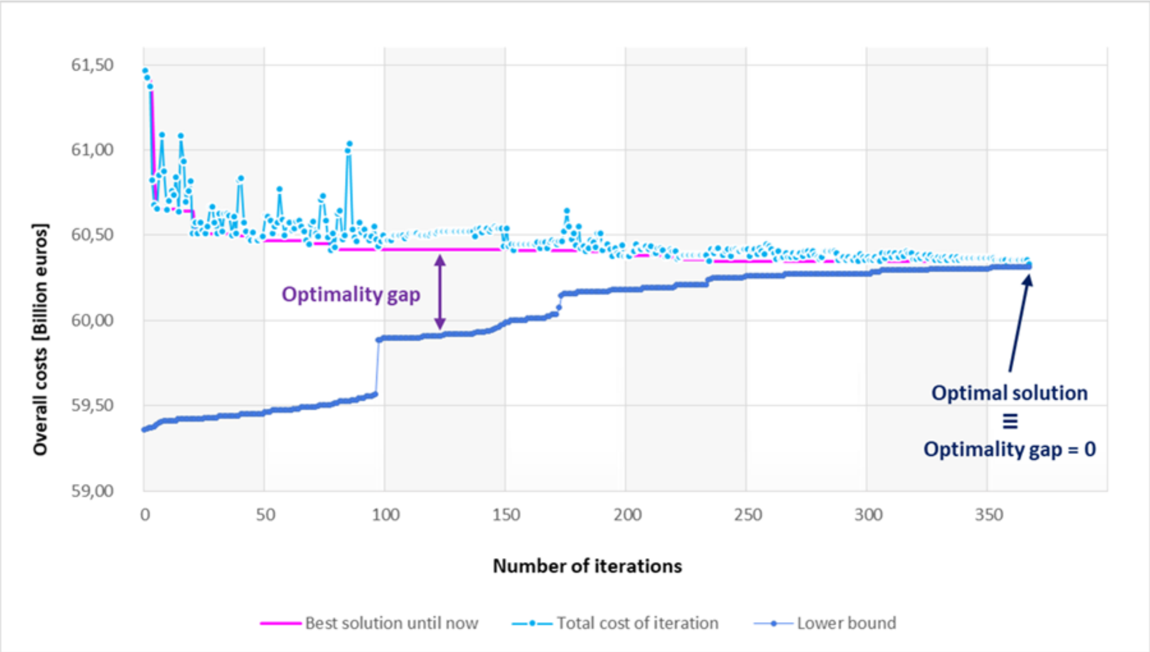


Figure 20 Example of evolution of optimality gap over Antares Xpansion iterations

The Benders method allows flexibility because of the decomposition of the problem, solving the dispatch problem in an independent manner and the possibility to run the dispatch for a sequence of multiple Monte Carlo years.

To run a capacity expansion in Antares Xpansion on cross-border interzones and flexibility production, we need to:

- Specify the Xpansion settings: type of simulation, optimaliy gap, additional constraints file name, Monte Carlo year weights file name.
- Create candidates for each interconnection candidates and specify their expansion properties:
    1. the related cross-border interzone

2. its already installed capacity
3. the project capacity
4. the project annualized costs

- Create storage candidates for each country and specify their expansion properties:
    5. the country
    6. the maximum capacity
    7. the annualized costs
- Create candidate for each hybrid interconnection candidate and specify their expansion properties :
    8. the related cross-border interzone, which can connect two offshore nodes together, or one onshore node to one offshore node, for expansion of radial connection. Different possible configurations are detailed in figures 16-20 :

Figure 21 Case 1.1 – Project between two offshore nodes

Figure 22 Case 1.2 – Project between one offshore node and one onshore node

Figure 23 Case 2.1 – Project between two offshore nodes and expansion of one radial connection

Figure 24 Case 2.2 – Project between one offshore node and one onshore node and expansion of one radial connection

Figure 25 Case 3 – Project between two offshore nodes and expansion of both radial connections

9. the already installed radial connections from onshore node to offshore node
10. the project capacity
11. the project annualized costs

- Create the Xpansion additional constraints file specifying if projects are linked together and must be simultaneaously invested in. Specifically for hybrid candidates, in cases 2.1, 2.2 and 3, an additional constraint is needed to consider interconnection projects and radial expansion as one unique project.
- Specify the weights of each Monte Carlo year in a specific file.

The optimization problem is more complex as you add more investment candidates, additional binding constraints bonding candidates and Monte Carlo years. More information on Antares Xpansion can be found at the following link. The optimization phase will be performed, as it was in TYNDP 2022, in two phases:

- The first phase considers only existing projects, collected from TSOs and project promoters. For battery and flexibility candidates, the only capacities considered in this phase are the ones removed from starting point (see starting point in step 4).
- The second phase considers as candidates real projects not invested in phase 1 and other conceptual candidates. These include conceptual interconnections, collected, from TSOs, hybrid offshore corridors defined in the ONDP, and normative flexibilities.

As for the identification of the flows on starting point, this optimization step will be performed with internal constraints as a variant.

Step 9: Run the zonal starting point and final simulations, and identify the SEW, RES and CO2 needs for the system.

Once the optimal portfolio has been identified, benefits associated with identified needs are calculated. Those benefits include Socio-Economic Welfare (SEW) as well as avoided CO2 (in million tons) and avoided curtailment (in TWh).

As for the starting point and the optimization phase, this step will be performed with internal constraints as a variant. Comparison between the different portfolios and their impact on internal constraints shall be performed.

7.3.3 Implementation phase for 2050 time horizon

In general, the implementation phase for the Simplified Zonal IoSN process can be described in 7 consecutive steps as it is shown on Figure 26 below:

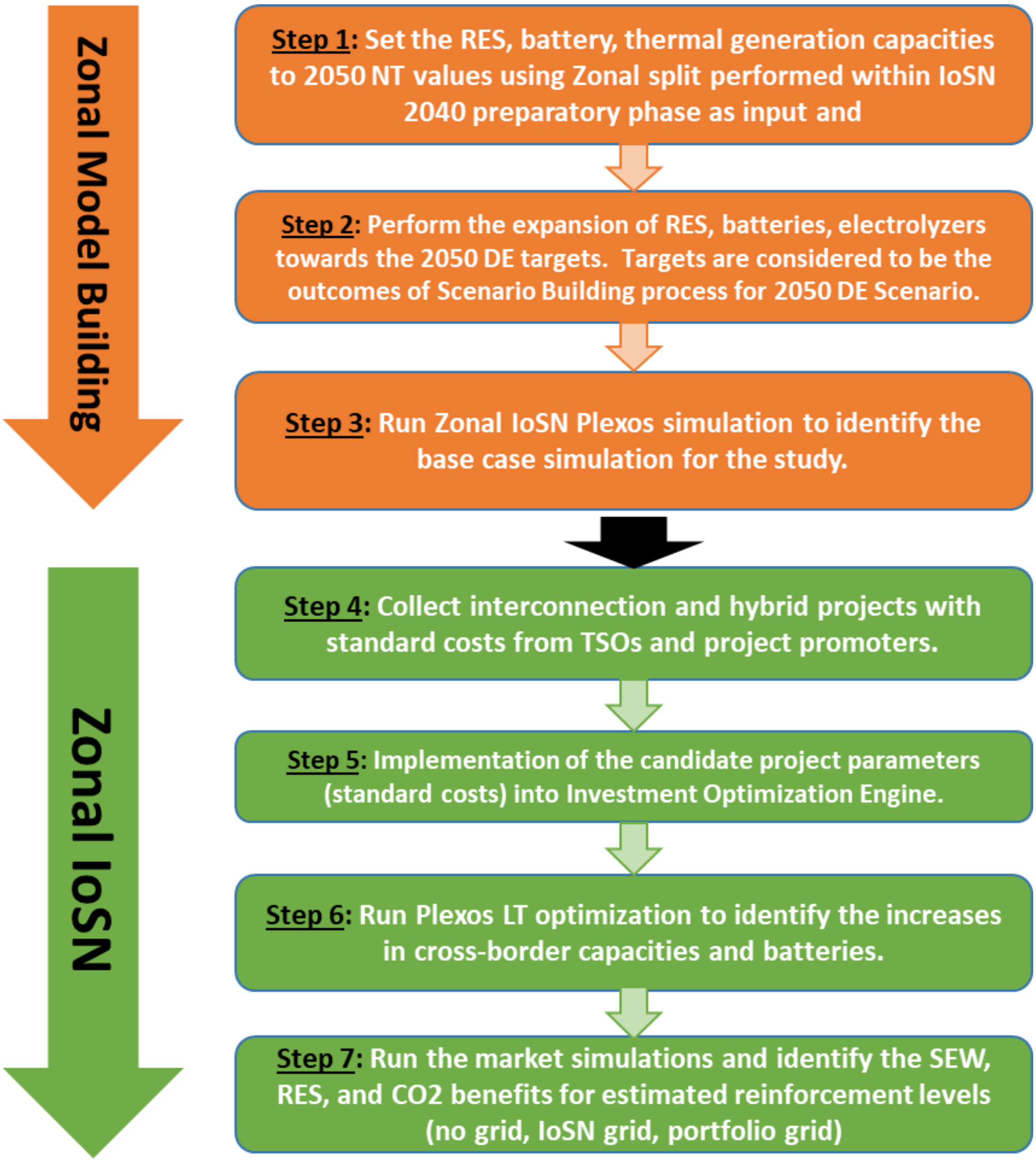


Figure 26 Step-by-Step IoSN Implementation phase process diagram for 2050 IoSN study

Each of the implementation steps will be described further.

Step 1:

At the Step 1 PEMMDB 3.5. datasets are used for 2050 time horizon to be coherent in terms of thermal generation fleet with Scenario Building process. Nuclear capacities for countries which have such technology are reduced to match the 2050 DE storyline. The split of thermal generation is performed based on the 2040

IoSN split outcomes while also performing expert based geographical matching between Zonal clustering configuration and PECD zone clustering which is available in the PEMMDB 3.5. database.

Step 2:

At the Step 2, long term optimization is performed using Plexos as a software. Technologies that are being optimized are RES generating capacities, electrolyzers, batteries. The start costs for tehnologies are those that have been used in the Scenario Building process by ENTSO-E. This way tehnologies are optimally distributed in between the Zones at the marginal difference between 2050 NT available datasets and 2050 DE Scenarios. This way a simplified Zonal Model is produced corresponding to 2050 DE Scenario.

Step 3:

At the step 3, dispatch simulation is performed using Plexos software to identify the study base case that should be used further to identify system needs.

Step 4:

Collect interconnection projects with standard costs from TSOs and project promoters. Collect hybrid interconnection projects from ONDP from regional groups.

The list of investment candidates is available as an Appendix 1 to this document.

Step 5:

The candidate projects have been implemented in the Investment Optimization Engine with their relevant parameters including standard costs. For interconnectors, annualized costs are calculated based on project CAPEX and OPEX given the data collection by project promoters using the following formula:

$$\textit{annualized costs} = OPEX + CAPEX \times \left(\frac{\delta}{1-\left(\frac{1}{1+\delta}\right)^{n}}\right)$$

Where δ is the discount rate (4% for interconnectors) and n is the lifetime (25 years for interconnectors).

Storage investment assumptions are based on scenario building assumptions found in Table 7below:

Table 7 Storage investment assumptions

NODE	YEAR	SCENARIO	TECHNOLOGY	CAPEX [€/MW]	OPEX[€/MW/a]
All	*2030*	*National Trends*	*Batteries Utility*	*716480.00*	*17912.00*
All	*2040*	*National Trends*	*Batteries Utility*	*627122.00*	*15678.00*
All	*2050*	*Distributed Energy*	*Batteries Prosumer*	*1038770*	*25970*
All	*2050*	*Distributed Energy*	*Batteries Utility*	*430050*	*10751*

Hybrid interconnections costs are based on the outcomes of the ONDP study performed by ENTSO-E, the investment parameters can be found in Table 8 below:

Table 8 Hybrid interconnection investment candidate parameters

Element	**CAPEX/OPEX**	**Unit**	Cost Set 1	**Cost Set 2**	**Cost Set 3**
			Low	**Average**	**high**
Onshore HVDC cable	CAPEX	MEUR/MW*km	0,00168	0,00274	0,0038
Offshore HVDC cable	CAPEX	MEUR/MW*km	0,00168	0,00234	0,003
Offshore HVDC converter (including platform)	CAPEX	MEUR/MW	0,55	0,625	0,7
Onshore HVDC converter	CAPEX	MEUR/MW	0,25	0,275	0,3
Offshore node expansion	CAPEX	MEUR/MW	0,165	0,1875	0,21
Onshore HVDC cable	OPEX	% of CAPEX / year	0,025	0,025	0,025
Offshore HVDC cable	OPEX	% of CAPEX / year	0,025	0,025	0,025
Offshore HVDC converter (including platform)	OPEX	% of CAPEX / year	0,015	0,015	0,015
Onshore HVDC converter	OPEX	% of CAPEX / year	0,015	0,015	0,015
Offshore node expansion	OPEX	% of CAPEX / year	0,015	0,015	0,015

Step 6:

Plexos LT Plan module is used to perform the optimization and identify most optimal set of candidates that can be implemented in the system.

Plexos LT Plan as a tool Finds the optimal combination of generation and transmission, storages and pipelines built that minimise the net present value (NPV) of the total costs in the system (incl. fixed and variable operating costs)

Below is the graph which represents the target function of the optimization performed by Plexos LT Plan.

As it could be seem at the graph, the engine strives to reach the minimum between annualized costs of the investments and production costs in the system.

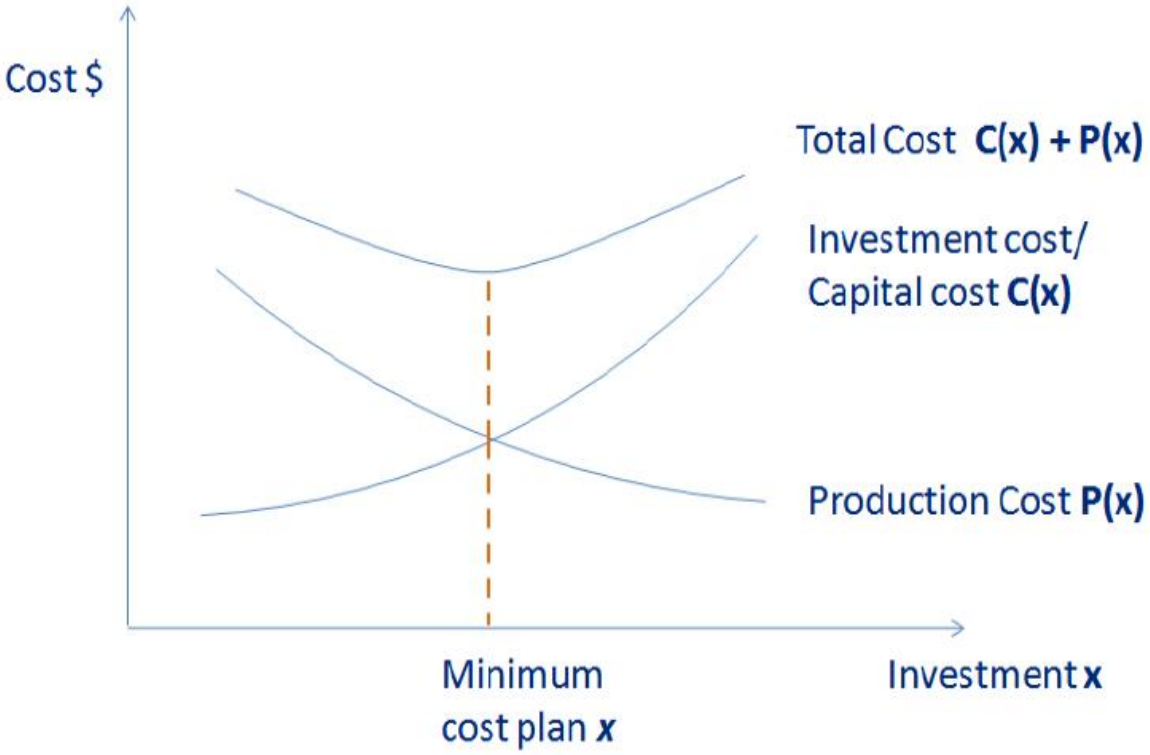


Figure 27 Cost minimization function in visual representation

Step 7:

After the optimal candidate portfolio is identified, dispatch simulation runs are performed at the case where all the selected candidates are integrated to the system and the case where all the possible candidates are integrated in the system and those are compared to the base case simulation which has been performed at the Step 3. This helps to identify prospective benefits in terms of RES integration in the system, Security of Supply and Socio Economic Welfare for the system driven by the selected candidates.

8. Climatic conditions under investigation

For the Identification of the System Needs study it was decided to use a similar approach for the definition of the climatic years for the study to the one applied in the Bidding Zone Review process. Such methodology has been developed according to Article 4.4 of the ACER Decision on the methodology and assumptions that are to be used in the bidding zone review process and for the alternative bidding zone configurations to be considered, Annex I "Methodology and assumptions that are to be used in the bidding zone review process in accordance with Article 14(5) of the Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity" regarding the selection of climate years for the analysis.

- TSOs shall jointly select three reference climate years to assess BZ configurations.
- These three years shall be selected among the thirty most recent available climate years.
- The reference climate years shall be consistently used across all BZRRs and BZ configurations. A BZRR may select additional climate years, which shall be justified and published before the modelling chain starts.
- Unless stated otherwise and duly justified, all selected reference climate years shall have the same weight in the assessment and conclusions made for each criterion and configuration. Additional climate years may also be used as a sensitivity analysis as described in paragraph **Error! Reference source not found.** of this article."

8.1 Input data and related sources

Input Datasets

The following variables have been identified as relevant for characterizing each single climate year and week:

1. Solar infeed
2. Wind infeed (as the sum of the infeed from both offshore and onshore wind farms)
3. Hydro inflows
4. Demand time series

Hourly Time Series

According to the methodology requirements, a detailed dataset of 30 years (1987[1] till 2016) from the Pan European Climate Database (PECD) covering all Bidding Zones is used as input for the assessment. For each climate year and for each existing Bidding Zone, hourly profiles are derived according to the following approach:

- **Solar infeed:** multiplying the hourly load factor PECD by the expected total installed solar capacity for the target year 2025 according to the scenario provided by each TSO for the Pan European Market Modelling DataBase (PEMMDB) in 2020;
- **Wind infeed:** summing up the expected offshore wind infeed and the onshore wind infeed, each one computed multiplying the hourly load factor from the Pan European Climate Database (PECD) by the expected (offshore/onshore) installed wind capacity for the target year 2025 according to the scenario provided by each TSO for the PEMMDB in 2020;
- **Load:** taking the hourly demand profiles from the scenarios adopted in the Mid-term Adequacy Forecast (MAF) study 2020.
- **Hydro infeed:** For each climate year and for each existing Bidding Zone from 1987 till 2016, the yearly total inflows (GWh) are computed as the sum of the following components derived from the PEMMDB in 2020:
  - **Run of River Hydro Generation** in GWh per day;
  - **Cumulated inflow into reservoirs** per week in GWh;
  - **Cumulated NATURAL inflow into the pump-storage reservoirs** per week in GWh.

  An hourly hydro infeed profile is then derived by allocating the yearly energy among the hours of the year proportionally to the hourly net load (computed as the hourly load netted by solar and wind infeed). In practice, this represents the fact that hydro will be dispatched in a water value approach: more hydro generation in cases when net load is high (high demand and low variable RES infeed) and less when net load is low (low load, high variable RES infeed).

Hourly Residual Load

Finally, for each climate year and for each Bidding Zone z, the residual load profile for each hour h is computed as follows:

$$V_{residual\ load,z,h} = V_{load,z,h} - \left(V_{solar,z,h} + V_{wind,z,h} + V_{hydro,z,h}\right)$$

[1] Even though data for the period 1982-1986 are available, the methodology requires to consider only a 30 years dataset.

Bidding Zones are then grouped into relevant macro regions according to the procedure adopted in the TYNDP (Figure 28). The residual load V for each macro region r is derived as follows:

$$V_{residual\ load,r,h} = \sum_{z \in r} V_{residual\ load,z,h}$$

Macro region	Zones										
Scandinavia	DKe	DKkf	DKw	FI	NOm	NOn	NOs	SE1	SE2	SE3	SE4
Baltic countries	LV	EE	LT								
Central west 1 FR-BE-NL	BE	FR	NL								
Central west 2 DE-CH-AT-LU	DE	DEkf	AT	CH	LUb	LUf	LUg	LUv			
South west	ES	PT									
Central east	CZ	SK	HU	PL	RO						
GB+IE	GB	IE	NI								
South east	GR	CY	BG	MK	ME	MT	HR	SI	RS	AL	BA
South central	ITcn	ITc	ITn	ITs	ITsar	ITsic					

Figure 28. Macro Regions from TYNDP

8.2 Methodology for the definition of representative climate years and weeks

The general approach for selecting representative climate years and weeks is based on three cornerstones, as presented in Figure 2 below. In the following, the approach is presented using the case of the climate year selection

In the case of definition of representative climate years, the approach is as follows:

1. **Definition of hourly** time series of **residual load** on a regional level, to capture the temporal and spatial variability of the system state due to climatic conditions;
2. **Compute delta indicators** to assess how years compare to the 30-year average on a regional level;

3. **Selection of most representative combination** of 3 years for the study (LMP analysis and Bidding Zone assessment).

Figure 29. Overview of the approach for the definition of representative years/weeks

8.2.1. Residual Load Distributions

As described in the previous section, the residual load for each region is defined on hourly resolution by deducting the RES infeed from the system load for each hour:

$$V_{residual\ load,r,h} = V_{load,r,h} - \left(V_{solar,r,h} + V_{wind,r,h} + V_{hydro,r,h}\right)$$

Two key characteristics in this representation is the hourly temporal resolution and the regional level of aggregation. The hourly resolution allows the depiction of the full variability in the system infeeds. The regional representation is needed in order to retain the information of different regions independent from one another, as an aggregation on European level leads to statistical smoothing of variability. Thus, a dataset of 8760 values (hourly residual load) is obtained per year and per region.

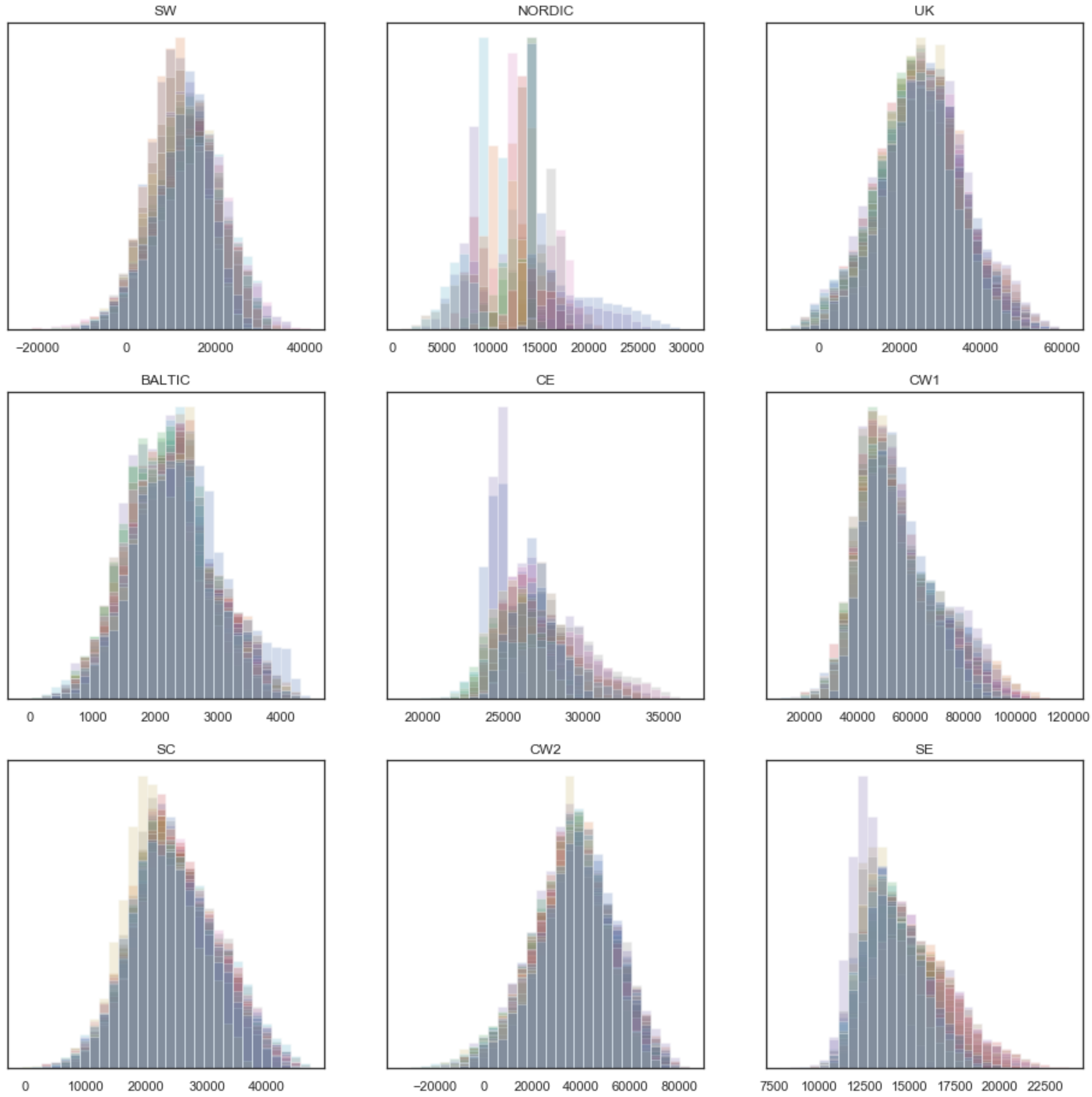


Figure 30: Distributions of residual load per region and year (each year is one color; x-axis: residual load in MW, y-axis: occurrences)

8.2.2. Delta Indicators

The goal of the assessment is to find the combination of 3 and 10 years out of the 30 years that in combination best represents the full 30 years. In this respect, the methodology compares the distributions of each possible 3 years combination to the distribution of the whole dataset (combined 30 years). In a first step, the respective distribution of all candidate combinations is defined. Then, indices are applied to enable a comparison of these distributions to the aggregated distributions.

Candidate combinations

In the first step we construct the datasets of all candidate combinations. In total, with 30 years, there are 4060 different combinations of 3 years to be checked. A combination of 3 years is noted as $g \in G$, and the combined dataset with 3*8760 data points of residual load per region is:

$$\boldsymbol{\Omega}_{r,g} = \left[\boldsymbol{V}_{load,r,g} - (\boldsymbol{V}_{solar,r,g} + \boldsymbol{V}_{wind,r,g} + \boldsymbol{V}_{hydro,r,g})\right]$$

Comparison indices

In order to compare the residual load distributions, we use two main indicators, namely the mean value that captures the information about the overall energy content of the yearly distribution, and the standard deviation (std), that captures the information on the variability of the distribution. We assess how well each candidate combination $\boldsymbol{\Omega}_{r,g}$ depicts the respective characteristics of the aggregate distribution as the difference of of the indicator to the respective indicator of the aggregate distribution $\boldsymbol{\Omega}_{r,g \in G}$.

$$\Delta\mu_{r,g} = mean(\boldsymbol{\Omega}_{r,g}) - mean(\boldsymbol{\Omega}_{r,g \in G}),$$

$$\Delta\sigma_{r,g} = std(\boldsymbol{\Omega}_{r,g}) - std(\boldsymbol{\Omega}_{r,g \in G})$$

Standardisation and weighting

In order to be able to combine the indicators, a standardization is applied, which causes the distribution of each indicator to have a mean of 0 and a std. of 1. Thus a transformation of the indicators to the same space and range in magnitude is performed. It is applied as follows:

$$I_{\mu,r,g} = \frac{\Delta\mu_{r,g} - mean(\Delta\mu_{r,g\in G})}{std(\Delta\mu_{r,g\in G})}, \qquad I_{\sigma,r,g} = \frac{\Delta\sigma_{r,g} - mean(\Delta\sigma_{r,g\in G})}{std(\Delta\sigma_{r,g\in G})}$$

Further, a regional weighting factor is applied to ensure that each region influences the assessment proportional to their relevance of the European electrical load. The applied weighting factor is the share of the region's average load in respect to the European's load:

$$w_r = \frac{\sum_{y\in CY} V_{load,r,y}}{\sum_{r\in R}\sum_{y\in CY} V_{load,r,y}}$$

Based on the preliminary data, the weighting factors shown in figure 4 are as follows:

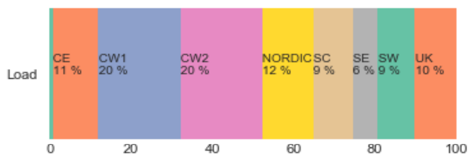


Figure 4: Weighting factors

8.2.3. Selection of candidate combination

The selection of the candidate combination done in a two-step process, as shown in the figure below.

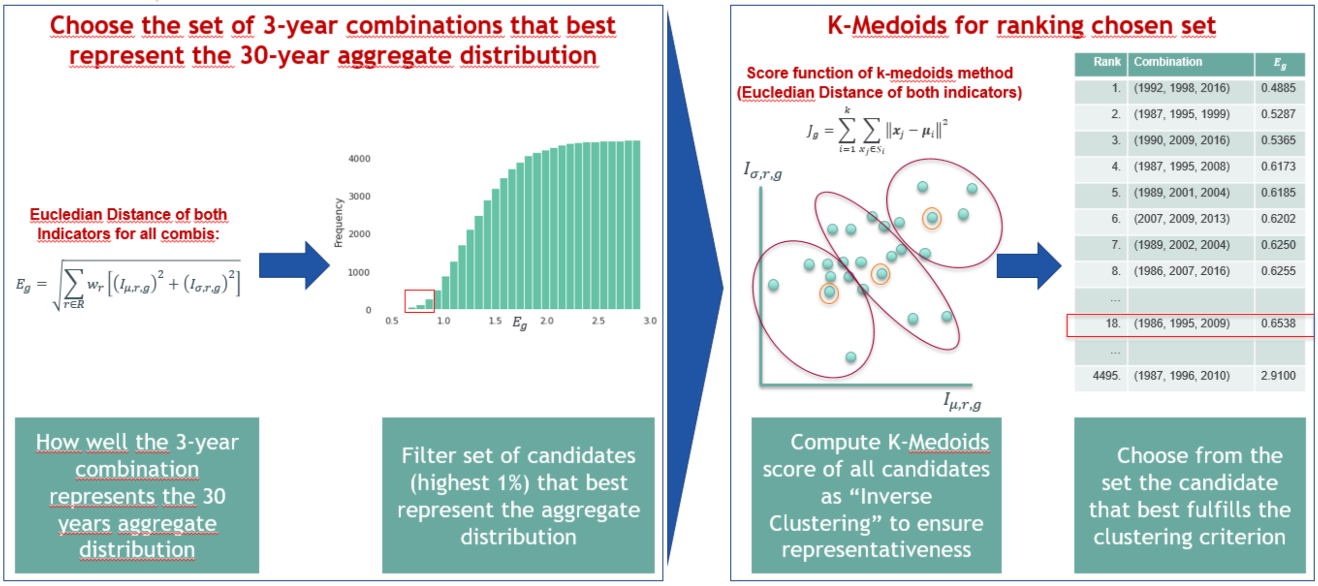


Figure 5: Two step-process for the selection of the representative candidate

1. Filtering of candidate combinations that represent the aggregate distribution

In a first step, the set of candidates that can well represent the aggregated distribution is selected. For this, the indicators for each combination of three years g are combined and weighted, using the Euclidean distance as shown below:

$$E_g = \sqrt{\sum_{r \in R} w_r \left[\left(I_{\mu,r,g}\right)^2 + \left(I_{\sigma,r,g}\right)^2 \right]}$$

The assessment operates in 18 dimensions (2 indicators * 9 regions), so the related graphs shown in this document are visualization examples. Using the indicator E_g, all 3-year-combinations are evaluated as to how well they fit the aggregate distribution. The candidates that best rank based on E_g (highest 1% from the 4600 combinations, referred to as preferred candidates), are kept and are considered able to well represent the aggregate distribution.

2. Selection of best candidate from the preferred candidates

In the next step, the assessment of how well each preferred candidate could represent the 30 years set is performed, using the same indicators (mean and std.). For doing this, the K-Medoids clustering score of all preferred candidates is assesed. The cluster score function, which is the Euclidean distance of each year to the closest medoid, is computed as:

$$J_g = \sum_{i=1}^{k} \sum_{x_j \in S_i} \left\| \boldsymbol{x}_j - \boldsymbol{\mu}_i \right\|^2$$

Here, k is the number of clusters (3 for the year selection), $\boldsymbol{x}_j$ is a specific year and $\boldsymbol{\mu}_i$ is the medoid that is closest to $\boldsymbol{x}_j$. The three medoids here are the three years in g. All preferred 3-year combinations are assessed based on this score function, and the combination with the best clustering score is chosen.

Remark on the assessment of representativeness

The described 2-step approach ensures a double depiction of representativeness by ensuring that a) the chosen combination fits the aggregate combination and b) it ranks well in an inverse clustering approach. The combination of the two approaches enables the accumulation of benefits from both assessment methods. The Euclidean distance indicator ensures that the preferred combinations represent well the aggregated distribution. However, the aggregated combination may be comprised of 3 extreme or 3 mild years, as long as the average is in the center of all combinations. The application of the k-medoids approach ensures that the final combination is representative in terms of capturing the largest space. It ensures a second layer of representativeness based on a clustering logic. In an example with two dimensions, the following graphs present the issue, which would occur in case of only using the first part of the 2-step approach. All three combinations fulfill the criterion regarding the representation of the Eucledian distance, i.e. their combination is close to the centre represented by the red triangle. The application of the K-Medoids ranking ensures that the selected combination also represents the space (i.e. to be not too close to the centre-“mild” or too close to the edges-“extreme”).

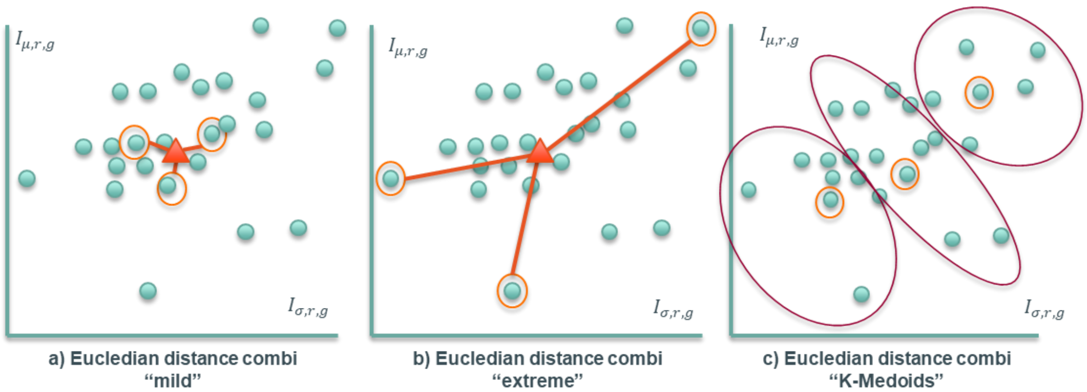


Figure 6. Examples on the selection of representative candidates

8.2.1 8.2.4 Application for week selection – specifics

Throughout the previous sections, g represented a combination of three years. For the selection of the week candidates per year, the same methodology is applied, where g now represents a combination of 8 out of 52 weeks. The method is applied in the same logic, therefore the aim is to to find the set of 8 weeks that best represents the total set of 52 weeks within a given climate year. To ensure seasonal representativeness however, an additional requirement that 2 weeks should be chosen per season is applied. The respective ranges are shown below:

Table 9 -ranges for week selection

Season	Weeks
Winter	1-9; 49-52
Spring	10-22
Summer	23-35
Autumn	36-48

With this requirement, there are 78 possible combinations of 2 weeks per season, leading to 78^4 = 37,015,056 possible combinations of weeks to be checked for each selected climate year. The analysis is performed in the steps shown above, by assessing, filtering and ranking all week combinations.

9. Selection of IoSN Investment Candidates

9.1 Interconnections

One project collection was performed in parallel with the building of scenarios to define real and conceptual candidates for interconnections. Characteristics of candidates (cost, capacities …) were provided during this collection. The list of candidates was submitted to a public consultation alongside the TYNDP2024 Scenarios input parameters, in July-August 2023. The data collection covers:

Promoter

Link name – Market Node A – Market Node B (FR00 – ES00)

Node from – Market Node A which project connects

Node to – Market Node B which project connects

Name – Name of the project

ID – Project ID from TYNDP 2020

Direct capacity increase (MW) – Net Transfer Capacity increase from Market Node A to B

Indirect capacity increase (MW) – Net Transfer Capacity increase from Market Node B to A

CAPEX – Capital Expenses (MEuro)

OPEX – Operational Expenses (MEuro)

Internal reinforcement CAPEX node from – CAPEX of required internal reinforcement in Market Node A

Internal reinforcement CAPEX node to – CAPEX of required internal reinforcement in Market Node B

Internal reinforcement comment - comment by TSO in case of reinforcement split

Station from Name – Name of the substation A which project connects

Station to Name – Name of the substation B which project connects

RDFID (station from) – RDFID of the substation A which project connects

RDFID (Station to) – RDFID of the substation B which project connects

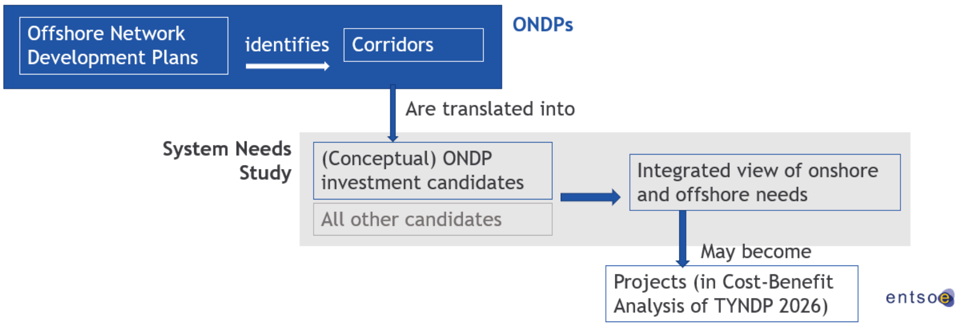
The minimum capacity increase for conceptual cross-border potential capacity increases is 500 MW (see Appendix 2 List of investment candidates).

9.2 Batterie candidates

Flexibility standard costs have been provided by Scenario Building WG and are common with top-down scenarios. Capacities of candidates are based on the difference between PEMMDBs 2030 and 2040.

9.3 Hybrid candidates

Hybrid conceptual candidates coming from ONDP exercise and collected in this exercice will be evaluated also in IoSN.



Hybrid conceptual candidates are based on identified ONDP corridors. A collection performed with regional groups, to gather following data. Each candidate defines a unique increase of capacity, so only two nodes must be given. Several candidates can then be aggregated so that they are invested with one another :

Project name

TSO or promoters' name

Onshore node A – zonal onshore node of market node A (if relevant – see different cases in chapter 7).

Offshore node A – zonal offshore node of market node A (if relevant – see different cases in chapter 7)

Onshore node B – zonal onshore node of market node B (if relevant – see different cases in chapter 7)

Offshore node B – zonal offshore node of market node B (if relevant – see different cases in chapter 7)

Capacity direct – Hybrid link capacity from start node (onshore or offshore) to end node (onshore or offshore)

Capacity indirect – Hybrid link capacity from end node (onshore or offshore) to start node (onshore or offshore)

CAPEX – Capital Expenses (MEuro)

OPEX – Operational Expenses (MEuro)

Internal reinforcement CAPEX node from – CAPEX of required internal reinforcement in Market Node A

Internal reinforcement CAPEX node to – CAPEX of required internal reinforcement in Market Node B

Length of onshore cable – Total length of onshore cable associated with the project

Length of offshore cable – Total length of offshore cable associated with the project

Number of new substations – Total number of new substations associated with the project

Number of new converter stations – Total number of new converter stations associated with the projectis

10. Interconnection Targets

The European Commission established the Expert Group on electricity interconnection targets in March 2016. The Expert Group transmitted its report to Commissioner for Climate Action and Energy Miguel Arias Cañete in October 2017. The Expert Group acknowledges that achieving the EU's energy and climate objectives requires a well-integrated European energy market. Electricity interconnectors are the physical component of making this market truly European by connecting Member States' networks offering capacity for electricity trade, improved security of supply and allowing integration of the rapidly-growing share of renewable electricity production.

The Expert Group is of the opinion that the current interconnection target of 10% by 2020 has already given an important signal to the integration of the electricity markets. However, it acknowledges that the target was set in a radically different energy era when variable renewable energy comprised only a small share of total generation. To address the new energy reality the Expert Group proposes a new approach for setting interconnection targets based on the underlying principle of maximising societal welfare. The report published by European Commission based on outcomes of the work by ITEG is available through the following link: https://energy.ec.europa.eu/system/files/2017-11/report_of_the_commission_expert_group_on_electricity_interconnection_targets_0.pdf

Firstly, the functioning of the European electricity market should be improved and based on clear, stable and non-discriminatory regulatory rules to send consistent signals - both to investors in grids as well as to users of the infrastructure. This includes an effective and rapid implementation of the network codes and guidelines adopted in the framework of the Third Energy Package. In particular, the existing interconnectors should be used efficiently and the capacity available to the market significantly increased compared to the current utilisation. For alternating current (AC) interconnectors, the net transfer capacity should be indicatively doubled. This should enable congestion management to be non-discriminatory and should maximise the European socio-economic welfare.

Secondly, new interconnectors must help exploit the benefits of market integration by enabling better prices for customers, help meet the electricity demand on the national markets and possibly offer supply of renewable electricity to neighbouring Member States. Therefore, the development of additional interconnections should be considered if any of the following three thresholds is triggered:

- Minimizing price differentials: Member States should aim to achieve yearly average of price differentials as low as possible. The Expert Group recommends €2/MWh between relevant countries, regions or bidding zones as the indicative threshold to consider developing additional interconnectors;

- Ensuring that electricity demand, including through imports, can be met in all conditions: in countries where the nominal transmission capacity of interconnectors is below 30% of their peak load options for further interconnectors should be urgently investigated.
- Enabling export potential of excess renewable production: in countries where the nominal transmission capacity of interconnectors is below 30% of their renewable installed generation capacity options for further interconnectors should urgently be investigated.

The Expert Group recommends that any project related to interconnection capacity, helping the Member States reach any of the 30% thresholds, must apply for inclusion in the Ten Year Network Development Plan and future lists of Projects of Common Interest. In addition, countries above the 30% but below 60% thresholds in relation to their peak loads and renewable installed generation capacity are requested to investigate regularly possible options of further interconnectors regularly. Thirdly, as a condition sine qua non, each new interconnector must be subject to a socioeconomic and environmental cost-benefit analysis and implemented only if the potential benefits outweigh the costs. Fourthly, involvement of citizens, civil society groups and relevant stakeholder groups potentially affected by the development of new interconnectors is necessary at an early stage of interconnector development to address perceived concerns about health issues or adverse impact on the landscape and nature ecosystems. In this regard, the Expert Group recommends that the Commission, as well as Member States continue, and step up actions to facilitate public involvement in the relevant infrastructure projects. Lastly, the Expert Group recognizes that rapid technological developments in the near future are likely to strongly influence the functioning, the nature of and need for electricity network infrastructure. While many of these developments will open up new opportunities for electricity generation, transmission, distribution and consumption, their exact impact is difficult to predict. Therefore, the Expert Group recommends to review the proposed methodological approach of measuring interconnectivity and its associated methodologies regularly but not later than in five years.

The Interconnection Targets may be checked as the very final stage of the IoSN process according to the threshold identified by Interconnection Target Group and/or those in force in the current EU legislation.

- For 2040 – can be checked at the final stage with 2030 targets. Should be checked which criteria to be used with ITEG;
- For 2030 - can be checked at the final stage with 2030 targets. Should be checked which criteria to be used with ITEG.

Table of Figures

APPENDIX 1. INTERCONNECTION CANDIDATES (CAPACITY INCREASES) – CAPACITIES AND COST ASSUMPTIONS

The following capacity increases were proposed to the optimiser for 2030 IoSN Study.

Link to the data in spreadsheet format: https://eepublicdownloads.blob.core.windows.net/public-cdn-container/tyndp-documents/TYNDP2024/investmentCandidates_and_CostAssumptions.xlsx

Table 10 2030 IoSN Interconnection Candidates

BORDER	FROM NODE	TO NODE	SCENARIO	DIRECT CAPACITY INCREASE (MW)	INDIRECT CAPACITY INCREASE (MW)	CAPEX (M€)	OPEX (M€)
ITCS-ME00 Real	ITCS	ME00	All	600	600	424	0.8
BE00-LUG1 Real	BE00	LUG1	All	500	500	210	0.6
IE00-UKNI Real	IE00	UKNI	All	1120	1120	363	0.95
FI00-SE01 Real	FI00	SE01	All	900	800	270	0.3
LT00-SE04 Real	LT00	SE04	All	0	0	284	0.2
SE02-SE03 Real	SE02	SE03	All	2000	2000	2800	1
FR00-UK00 Real	FR00	UK00	All	1250	1250	1343	21
BE00-DE00 Real	BE00	DE00	All	2000	2000	1585	16
DE00-CH00 Real	DE00	CH00	All	600	100	59.6	0.47
FI00-SE03 Real	FI00	SE03	All	800	800	700	0.75
HR00-RS00 Real	HR00	RS00	All	746	306	44	0.4
FR00-UK00 Real	FR00	UK00	All	2000	2000	1560	18
HU00-RO00 Real	HU00	RO00	All	1410	740	185.425	0.566
DE00-SE04 Real	DE00	SE04	All	700	700	600	1
ES00-FR00 Real	ES00	FR00	All	1500	1500	2372	6.03
ES00-FR00 Real	ES00	FR00	All	1500	1500	2609	9.5
BE00-FR00 Real	BE00	FR00	All	1000	1000	148	0.5
FR00-UK00 Real	FR00	UK00	All	1250	1250	885	23.8
AT00-SI00 Real	AT00	SI00	All	500	500	249	0.2
CZ00-SK00 Real	CZ00	SK00	All	500	500	116.749	0.62
BG00-RS00 Real	BG00	RS00	All	490	270	242.5	2.76
BA00-HR00 Real	BA00	HR00	All	644	298	485.9	0.9311
BE00-NL00 Real	BE00	NL00	All	1000	1000	1090	5.5
AT00-ITN1 Real	AT00	ITN1	All	500	500	140	0.5
GR00-MK00 Real	GR00	MK00	All	500	500	5.625	0.215
BE00-NL00 Real	BE00	NL00	All	1000	1000	84	0.1

SE02-SE03 Real	SE02	SE03	All	1000	1000	2500	1
UK00-UKNI Real	UK00	UKNI	All	700	700	710	15
DE00-NL00 Real	DE00	NL00	All	1000	1000	200	1.6
UK00-BE00 Real	UK00	BE00	All	1400	1400	937	35
UK00-DE00 Real	UK00	DE00	All	1400	1400	1675	37
DKW1-UK00 Real	DKW1	UK00	All	1400	1400	1492	37
DE00-CH00 Real	DE00	CH00	All	1000	1000	1096	8.8
TR00-BG00 Real	TR00	BG00	All	1100	700	74.4	1.99
GR00-TR00 Real	GR00	TR00	All	600	600	93	1.8
LV00-SE03 Real	LV00	SE03	All	500	500	799	12
HU00-RS00 Real	HU00	RS00	All	240	640	120.1	1.22
EE00-LV00 Real	EE00	LV00	All	1000	1000	1225	3.98
EE00-FI00 Real	EE00	FI00	All	700	700	1043	1.76
FI00-SE01 Real	FI00	SE01	All	800	800	270	0.3
DKW1-SE03 Real	DKW1	SE03	All	700	700	317	1
DE00-CH00 Real	DE00	CH00	All	0	200	471.96	2.36
GR00-ITS1 Real	GR00	ITS1	All	1000	1000	1250	0.24
CH00-ITN1 Real	CH00	ITN1	All	1000	1000	1250.00	0.3
AL00-GR00 Real	AL00	GR00	All	200	200	67.70	0.9
FR00-UK00 Real	FR00	UK00	All	1000	1000	1052.00	24.2
UK00-NL00 Real	UK00	NL00	All	1200	1200	1327.40	43.303
NOS-DKW Real	NOS	DKW	All	700	700	540.00	5
DE00-LUG Real	DE00	LUG	All	1200	1200	187.00	1.5
LV00-LT00 Real	LV00	LT00	All	1000	1000	356.50	3.56
ITN1-ES00 Real	ITN1	ES00	All	2000	2000	3081.60	20
EE00-DE00 Real	EE00	DE00	All	700	2000	6600.00	33
RO00-HU00 Real	RO00	HU00	All	2500	2500	7284.00	14.56
GR00-DE00 Real	GR00	DE00	All	3000	3000	8100.00	81
DE00-CH00 Real	DE00	CH00	All	1500	0	140.00	0.7
HU00-SK00 Real	HU00	SK00	All	100	760	16.09	0.3
AT00-ITN1 Real	AT00	ITN1	All	150	150	148.18	0.4
AT00-CH00 Concept 1	AT00	CH00	All	500	500	433.53	3.47
AT00-CH00 Concept 2	AT00	CH00	All	500	500	416.53	3.33
AT00-DE00 Concept 1	AT00	DE00	All	1000	1000	1385.06	11.08
AT00-DE00 Concept 2	AT00	DE00	All	1000	1000	1489.92	11.92
AT00-DE00 Concept 3	AT00	DE00	All	1000	1000	2285.92	18.29

AT00-DE00 Concept 4	AT00	DE00	All	1000	1000	5674.1	45.39
AT00-ITN1 Concept 1	AT00	ITN1	All	500	500	741.2	3.71
AT00-ITN1 Concept 2	AT00	ITN1	All	500	500	781.2	3.91
AT00-SI00 Concept 1	AT00	SI00	All	500	500	547.24	4.38
AT00-SI00 Concept 2	AT00	SI00	All	500	500	656.3	5.25
AT00-SI00 Concept 3	AT00	SI00	All	500	500	744.55	5.96
BE00-DE00 Concept 1	BE00	DE00	All	1000	1000	965	5.8
BE00-DE00 Concept 2	BE00	DE00	All	1000	1000	1550	6.4
BE00-FR00 Concept 1	BE00	FR00	All	1000	1000	762	5.52
BE00-FR00 Concept 2	BE00	FR00	All	1000	1000	722	5.16
BE00-NL00 Concept 1	BE00	NL00	All	1000	1000	968.2	3.84
BE00-NL00 Concept 2	BE00	NL00	All	1000	1000	1184	6.84
BE00-UK00 Concept 1	BE00	UK00	All	2000	2000	2617	11
BG00-TR00 Concept 1	BG00	TR00	All	500	500	110.5	2.25
BG00-TR00 Concept 2	BG00	TR00	All	500	500	222.7	2.32
CH00-FR00 Concept 1	CH00	FR00	All	1000	1000	755	2.2
CH00-FR00 Concept 2	CH00	FR00	All	1000	1000	1290	3
CH00-ITN1 Concept 1	CH00	ITN1	All	1000	1000	1406	5.2
CH00-ITN1 Concept 2	CH00	ITN1	All	1000	1000	1600	6.2
DE00-CH00 Concept 1	DE00	CH00	All	1000	1000	1100	8.768
DE00-CH00 Concept 2	DE00	CH00	All	1000	1000	1900	15.2
DE00-FR00 Concept 1	DE00	FR00	All	1000	1000	1312	9.7
DE00-FR00 Concept 2	DE00	FR00	All	1000	1000	1405	9.64
ES00-FR00 Concept 1	ES00	FR00	All	1500	1500	2977	10.6
ES00-FR00 Concept 2	ES00	FR00	All	1500	1500	4065	11.7
ES00-PT00 Concept 1	ES00	PT00	All	500	500	81	0.2
ES00-PT00 Concept 2	ES00	PT00	All	500	500	110	0.1
ES00-PT00 Concept 3	ES00	PT00	All	500	500	131	0.3
ES00-PT00 Concept 4	ES00	PT00	All	500	500	151.6	0.4

FR00-IE00 Concept 1	FR00	IE00	All	700	700	1800	32
FR00-IE00 Concept 2	FR00	IE00	All	700	700	2450	32
FR00-ITN1 Concept 1	FR00	ITN1	All	1000	1000	1560	7.8
FR00-ITN1 Concept 2	FR00	ITN1	All	1000	1000	2540	11.7
FR00-UK00 Concept 1	FR00	UK00	All	1300	1300	1350	4
FR00-UK00 Concept 2	FR00	UK00	All	1300	1300	1635	20
GR00-TR00 Concept 1	GR00	TR00	All	500	500	347.8	1.84
GR00-TR00 Concept 2	GR00	TR00	All	500	500	477.8	1.84
ITN1-SI00 Concept 1	ITN1	SI00	All	500	500	540	2.7
ITN1-SI00 Concept 2	ITN1	SI00	All	500	500	640	3.2
ITSI-TN00 Concept 1	ITSI	TN00	All	500	500	950	4.7
ITSI-TN00 Concept 2	ITSI	TN00	All	500	500	1150	5.7
NL00-UK00 Concept 1	NL00	UK00	All	1000	1000	1510	4
NL00-UK00 Concept 2	NL00	UK00	All	1000	1000	1520	4
NOS0-UK00 Concept 1	NOS0	UK00	All	1000	1000	2390	0
UK00-IE00 Concept 1	UK00	IE00	All	700	700	850	8
UK00-UKNI Concept 1	UK00	UKNI	All	700	700	950	8
DE00-NL00 Concept 1	DE00	NL00	All	1000	1000	2075	1.6
DE00-NL00 Concept 2	DE00	NL00	All	1000	1000	2125	2
BE00-LUG1 Concept 1	BE00	LUG1	All	500	500	210	0.6
NOS0-UK00 Concept 2	NOS0	UK00	All	1000	1000	2800	0
AL00-ME00 Concept 1	AL00	ME00	All	500	500	9.4	0.0606
AL00-ME00 Concept 2	AL00	ME00	All	500	500	10.5	0.0738
AL00-RS00 Concept 1	AL00	RS00	All	500	500	24.5	0.294
AL00-RS00 Concept 2	AL00	RS00	All	500	500	92.8	0.5976
AL00-MK00 Concept 1	AL00	MK00	All	500	500	47.7	1.856
AL00-MK00 Concept 2	AL00	MK00	All	500	500	77.7	2.928
AL00-GR00 Concept 1	AL00	GR00	All	500	500	232	1.4
AL00-GR00 Concept 2	AL00	GR00	All	500	500	240	1.4

AL00-ME00 Concept 3	AL00	ME00	All	500	500	12.5	0.0606
AL00-ME00 Concept 4	AL00	ME00	All	500	500	36	0.4
AT00-CZ00 Concept 1	AT00	CZ00	All	500	500	365.38	1.95
AT00-CZ00 Concept 2	AT00	CZ00	All	500	500	499.18	2.48
AT00-CZ00 Concept 3	AT00	CZ00	All	500	500	1314.5	5.49
AT00-HU00 Concept 1	AT00	HU00	All	1000	1000	866.4	8.66
AT00-HU00 Concept 2	AT00	HU00	All	1000	1000	1703.05	17.03
BA00-ME00 Concept 1	BA00	ME00	All	500	500	18.86	0.188
BA00-ME00 Concept 2	BA00	ME00	All	500	500	24	0.24
BA00-HR00 Concept 1	BA00	HR00	All	500	500	162	8.05
BA00-HR00 Concept 2	BA00	HR00	All	500	500	117	5.75
BA00-HR00 Concept 3	BA00	HR00	All	500	500	132.1	0.1
BA00-ME00 Concept 3	BA00	ME00	All	500	500	36.88	0.2943
BA00-ME00 Concept 4	BA00	ME00	All	500	500	29.46	0.1923
BA00-RS00 Concept 1	BA00	RS00	All	500	500	54.58	0.3
BA00-RS00 Concept 2	BA00	RS00	All	500	500	62.48	0.3
BG00-GR00 Concept 1	BG00	GR00	All	500	500	221	1.1
BG00-GR00 Concept 2	BG00	GR00	All	500	500	225	1.24
BG00-RO00 Concept 1	BG00	RO00	All	500	500	221	1.105
BG00-RO00 Concept 2	BG00	RO00	All	500	500	219	1.095
BG00-RS00 Concept 1	BG00	RS00	All	500	500	283.44	0.61
BG00-RS00 Concept 2	BG00	RS00	All	500	500	283.44	0.61
BG00-MK00 Concept 1	BG00	MK00	All	500	500	110.8	2.76
BG00-MK00 Concept 2	BG00	MK00	All	500	500	181	2.71
CZ00-DE00 Concept 1	CZ00	DE00	All	500	500	1550	12.4
CZ00-DE00 Concept 2	CZ00	DE00	All	500	500	3243	0.344
CZ00-DE00 Concept 3	CZ00	DE00	All	500	500	3244	0.344
CZ00-DE00 Concept 4	CZ00	DE00	All	500	500	3245	0.344
CZ00-PL00 Concept 1	CZ00	PL00	All	1000	1000	779	11

CZ00-PL00 Concept 2	CZ00	PL00	All	1000	1000	10000	150
CZ00-SK00 Concept 1	CZ00	SK00	All	500	500	345.3	2.775
CZ00-SK00 Concept 2	CZ00	SK00	All	500	500	396.24	3.21
DE00-DKE1 Concept 1	DE00	DKE1	All	500	500	383.3	9
DE00-DKE1 Concept 2	DE00	DKE1	All	500	500	384.3	9
DE00-DKE1 Concept 3	DE00	DKE1	All	500	500	385.3	9
DE00-DKE1 Concept 4	DE00	DKE1	All	500	500	386.3	9
DE00-DKE1 Concept 5	DE00	DKE1	All	500	500	387.3	9
DE00-DKE1 Concept 6	DE00	DKE1	All	500	500	388.3	9
DE00-DKW1 Concept 1	DE00	DKW1	All	2000	2000	4800	38
DE00-NOS0 Concept 1	DE00	NOS0	All	1000	1000	4000	16
DE00-NOS0 Concept 2	DE00	NOS0	All	1000	1000	4000	150
DE00-PL00 Concept 1	DE00	PL00	All	2000	2000	1080	1
DE00-PL00 Concept 2	DE00	PL00	All	2000	2000	10000	1
DE00-SE04 Concept 1	DE00	SE04	All	500	500	478.6	1
DE00-SE04 Concept 2	DE00	SE04	All	500	500	479.6	1
DE00-SE04 Concept 3	DE00	SE04	All	500	500	480.6	1
DE00-SE04 Concept 4	DE00	SE04	All	500	500	481.6	1
DE00-SE04 Concept 5	DE00	SE04	All	500	500	482.6	1
DE00-SE04 Concept 6	DE00	SE04	All	500	500	483.6	1
CZ00-DE00 Concept 5	CZ00	DE00	All	500	500	3246	0.344
CZ00-DE00 Concept 6	CZ00	DE00	All	500	500	3247	0.344
DKE1-SE04 Concept 1	DKE1	SE04	All	500	500	150	0
DKE1-SE04 Concept 2	DKE1	SE04	All	500	500	150	0.1
DKE1-DKW1 Concept 1	DKE1	DKW1	All	600	600	600	0
DKE1-SE04 Concept 3	DKE1	SE04	All	500	500	150	0
DKE1-SE04 Concept 4	DKE1	SE04	All	500	500	150	0.1
DKW1-NOS0 Concept 1	DKW1	NOS0	All	1000	1000	1150	0
DKW1-NOS0 Concept 2	DKW1	NOS0	All	1000	1000	850	0

DKW1-SE03 Concept 1	DKW1	SE03	All	500	500	471	1
DKW1-SE03 Concept 2	DKW1	SE03	All	500	500	472	1.1
DKW1-NL00 Concept 1	DKW1	NL00	All	1000	1000	3250	4
DKW1-NL00 Concept 2	DKW1	NL00	All	1000	1000	3850	4
DKW1-SE03 Concept 3	DKW1	SE03	All	500	500	471.4	1
DKW1-SE03 Concept 4	DKW1	SE03	All	500	500	471.4	1.1
DKW1-SE03 Concept 5	DKW1	SE03	All	500	500	471.4	1
DKW1-SE03 Concept 6	DKW1	SE03	All	500	500	471.4	1.1
EE00-FI00 Concept 1	EE00	FI00	All	700	700	850	4
EE00-FI00 Concept 2	EE00	FI00	All	700	700	900	4
EE00-LV00 Concept 1	EE00	LV00	All	1000	1000	1150	6
EE00-LV00 Concept 2	EE00	LV00	All	1000	1000	1200	6
FI00-NON1 Concept 1	FI00	NON1	All	500	500	1000	0
FI00-SE01 Concept 1	FI00	SE01	All	800	800	300	0.3
FI00-SE01 Concept 2	FI00	SE01	All	800	800	300	0.3
FI00-SE02 Concept 1	FI00	SE02	All	500	500	450	1
FI00-SE02 Concept 2	FI00	SE02	All	500	500	450	1
FI00-SE03 Concept 1	FI00	SE03	All	500	500	450	1
FI00-SE03 Concept 2	FI00	SE03	All	500	500	450	1
FI00-NON1 Concept 2	FI00	NON1	All	500	500	1000	0
FI00-SE01 Concept 3	FI00	SE01	All	800	800	300	0.3
FI00-SE02 Concept 3	FI00	SE02	All	500	500	450	1
FI00-SE02 Concept 4	FI00	SE02	All	500	500	450	0.1
FI00-SE03 Concept 3	FI00	SE03	All	500	500	450	1
FI00-SE03 Concept 4	FI00	SE03	All	500	500	450	1.1
GR00-ITS1 Concept 1	GR00	ITS1	All	500	500	1700	3.2
GR00-ITS1 Concept 2	GR00	ITS1	All	500	500	2000	3.3
GR00-MK00 Concept 1	GR00	MK00	All	500	500	48	0.66
GR00-MK00 Concept 2	GR00	MK00	All	500	500	118.75	0.94

HR00-HU00 Concept 1	HR00	HU00	All	500	500	410.4	4.104
HR00-HU00 Concept 2	HR00	HU00	All	500	500	624.6	6.246
HR00-RS00 Concept 1	HR00	RS00	All	500	500	89.45	2.84
HR00-RS00 Concept 2	HR00	RS00	All	500	500	124.23	3.55
HR00-SI00 Concept 1	HR00	SI00	All	1000	1000	91.1	4.355
HR00-SI00 Concept 2	HR00	SI00	All	1000	1000	126	3.51
HU00-SI00 Concept 1	HU00	SI00	All	500	500	183.6	1.836
HU00-SI00 Concept 2	HU00	SI00	All	500	500	327.6	5.22
HU00-SK00 Concept 1	HU00	SK00	All	500	500	441.5	1.53
HU00-SK00 Concept 2	HU00	SK00	All	500	500	303	3276
HU00-RO00 Concept 1	HU00	RO00	All	2000	2000	1939	58.17
HU00-RO00 Concept 2	HU00	RO00	All	2000	2000	2500	0
HU00-RS00 Concept 1	HU00	RS00	All	500	500	478.18	3.4
HU00-RS00 Concept 2	HU00	RS00	All	500	500	2500	0
HU00-SK00 Concept 3	HU00	SK00	All	500	500	441.5	1.53
HU00-SK00 Concept 4	HU00	SK00	All	500	500	303	3.276
ITCS-ME00 Concept 1	ITCS	ME00	All	500	500	750	3.7
ITCS-ME00 Concept 2	ITCS	ME00	All	500	500	900	4.5
LT00-LV00 Concept 1	LT00	LV00	All	500	500	300.7	0.3
LT00-LV00 Concept 2	LT00	LV00	All	500	500	369	1
LT00-LV00 Concept 3	LT00	LV00	All	500	500	430.28	1.6
LT00-SE04 Concept 1	LT00	SE04	All	500	500	1025	10.3
LT00-SE04 Concept 2	LT00	SE04	All	500	500	1850	18.5
ME00-RS00 Concept 1	ME00	RS00	All	500	500	54.82	0.072
ME00-RS00 Concept 2	ME00	RS00	All	500	500	83.5	0.068
MK00-RS00 Concept 1	MK00	RS00	All	500	500	95.34	2.46
MK00-RS00 Concept 2	MK00	RS00	All	500	500	144.78	1.39
NL00-NOS0 Concept 1	NL00	NOS0	All	1000	1000	2600	4
NL00-NOS0 Concept 2	NL00	NOS0	All	1000	1000	2610	4

NOM1-SE02 Concept 1	NOM1	SE02	All	500	500	250	0
NOM1-SE02 Concept 2	NOM1	SE02	All	500	500	250	0.1
NON1-SE01 Concept 1	NON1	SE01	All	500	500	250	0
NON1-SE01 Concept 2	NON1	SE01	All	500	500	250	0.1
NON1-SE02 Concept 1	NON1	SE02	All	500	500	250	0
NON1-SE02 Concept 2	NON1	SE02	All	500	500	250	0.1
NOS0-SE03 Concept 1	NOS0	SE03	All	500	500	250	0
NOS0-SE03 Concept 2	NOS0	SE03	All	500	500	250	0.1
NOS0-SE03 Concept 3	NOS0	SE03	All	500	500	250	0
NOS0-SE03 Concept 4	NOS0	SE03	All	500	500	250	0.1
PL00-SE04 Concept 1	PL00	SE04	All	500	500	1640	31
PL00-SE04 Concept 2	PL00	SE04	All	500	500	1690	31
PL00-SK00 Concept 1	PL00	SK00	All	1000	1000	1338	19
PL00-SK00 Concept 2	PL00	SK00	All	1000	1000	10000	150
RO00-RS00 Concept 1	RO00	RS00	All	500	500	149.01	1.402
RO00-RS00 Concept 2	RO00	RS00	All	500	500	248.9	2.377
SE01-SE02 Concept 1	SE01	SE02	All	1000	1000	630	1
SE01-SE02 Concept 2	SE01	SE02	All	1000	1000	630	1
SE02-SE03 Concept 1	SE02	SE03	All	1000	1000	780	1
SE02-SE03 Concept 2	SE02	SE03	All	1000	1000	780	1
SE03-SE04 Concept 1	SE03	SE04	All	1000	1000	550	1
SE03-SE04 Concept 2	SE03	SE04	All	1000	1000	550	1p

The capacity increases listed in this appendix include projects in the TYNDP 2024 portfolio and conceptual increases that do not correspond to existing projects. Cost assumptions are theoretical assumptions that include the assumed costs of reinforcement of internal networks that would be necessary for the cross-border capacity increases. When there are several values on the same border, a sequential consideration of the capacity increases has been proposed to the optimiser.

BORDER	FROM NODE	TO NODE	YEAR	SCENARIO	DIRECT CAPACITY INCREASE (MW)	INDIRECT CAPACITY INCREASE (MW)	CAPEX (M€)	OPEX (M€)
ITCS-ME00 Real	ITCS	ME00	2030	All	600	600	424	0.8
BE00-LUG1 Real	BE00	LUG1	2030	All	500	500	210	0.6
IE00-UKNI Real	IE00	UKNI	2030	All	1120	1120	363	0.95
FI00-SE01 Real	FI00	SE01	2030	All	900	800	270	0.3
LT00-SE04 Real	LT00	SE04	2030	All	0	0	284	0.2
SE02-SE03 Real	SE02	SE03	2030	All	2000	2000	2800	1
FR00-UK00 Real	FR00	UK00	2030	All	1250	1250	1343	21
BE00-DE00 Real	BE00	DE00	2030	All	2000	2000	1585	16
DE00-CH00 Real	DE00	CH00	2030	All	600	100	59.6	0.47
FI00-SE03 Real	FI00	SE03	2030	All	800	800	700	0.75
HR00-RS00 Real	HR00	RS00	2030	All	746	306	44	0.4
FR00-UK00 Real	FR00	UK00	2030	All	2000	2000	1560	18
HU00-RO00 Real	HU00	RO00	2030	All	1410	740	185.425	0.566
DE00-SE04 Real	DE00	SE04	2030	All	700	700	600	1
ES00-FR00 Real	ES00	FR00	2030	All	1500	1500	2372	6.03
ES00-FR00 Real	ES00	FR00	2030	All	1500	1500	2609	9.5
BE00-FR00 Real	BE00	FR00	2030	All	1000	1000	148	0.5
FR00-UK00 Real	FR00	UK00	2030	All	1250	1250	885	23.8
AT00-SI00 Real	AT00	SI00	2030	All	500	500	249	0.2
CZ00-SK00 Real	CZ00	SK00	2030	All	500	500	116.749	0.62
BG00-RS00 Real	BG00	RS00	2030	All	490	270	242.5	2.76
BA00-HR00 Real	BA00	HR00	2030	All	644	298	485.9	0.9311
BE00-NL00 Real	BE00	NL00	2030	All	1000	1000	1090	5.5
AT00-ITN1 Real	AT00	ITN1	2030	All	500	500	140	0.5
GR00-MK00 Real	GR00	MK00	2030	All	500	500	5.625	0.215
BE00-NL00 Real	BE00	NL00	2030	All	1000	1000	84	0.1
SE02-SE03 Real	SE02	SE03	2030	All	1000	1000	2500	1
UK00-UKNI Real	UK00	UKNI	2030	All	700	700	710	15
DE00-NL00 Real	DE00	NL00	2030	All	1000	1000	200	1.6
UK00-BE00 Real	UK00	BE00	2030	All	1400	1400	937	35

UK00-DE00 Real	UK00	DE00	2030	All	1400	1400	1675	37
DKW1-UK00 Real	DKW1	UK00	2030	All	1400	1400	1492	37
DE00-CH00 Real	DE00	CH00	2030	All	1000	1000	1096	8.8
TR00-BG00 Real	TR00	BG00	2030	All	1100	700	74.4	1.99
GR00-TR00 Real	GR00	TR00	2030	All	600	600	93	1.8
LV00-SE03 Real	LV00	SE03	2030	All	500	500	799	12
HU00-RS00 Real	HU00	RS00	2030	All	240	640	120.1	1.22
EE00-LV00 Real	EE00	LV00	2030	All	1000	1000	1225	3.98
EE00-FI00 Real	EE00	FI00	2030	All	700	700	1043	1.76
FI00-SE01 Real	FI00	SE01	2030	All	800	800	270	0.3
DKW1-SE03 Real	DKW1	SE03	2030	All	700	700	317	1
DE00-CH00 Real	DE00	CH00	2030	All	0	200	471.96	2.36
GR00-ITS1 Real	GR00	ITS1	2030	All	1000	1000	1250	0.24
CH00-ITN1 Real	CH00	ITN1	2030	All	1000	1000	1250.00	0.3
AL00-GR00 Real	AL00	GR00	2030	All	200	200	67.70	0.9
FR00-UK00 Real	FR00	UK00	2030	All	1000	1000	1052.00	24.2
UK00-NL00 Real	UK00	NL00	2030	All	1200	1200	1327.40	43.303
NOS-DKW Real	NOS	DKW	2030	All	700	700	540.00	5
DE00-LUG Real	DE00	LUG	2030	All	1200	1200	187.00	1.5
LV00-LT00 Real	LV00	LT00	2030	All	1000	1000	356.50	3.56
ITN1-ES00 Real	ITN1	ES00	2030	All	2000	2000	3081.60	20
EE00-DE00 Real	EE00	DE00	2030	All	700	2000	6600.00	33
RO00-HU00 Real	RO00	HU00	2030	All	2500	2500	7284.00	14.56
GR00-DE00 Real	GR00	DE00	2030	All	3000	3000	8100.00	81
DE00-CH00 Real	DE00	CH00	2030	All	1500	0	140.00	0.7
HU00-SK00 Real	HU00	SK00	2030	All	100	760	16.09	0.3
AT00-ITN1 Real	AT00	ITN1	2030	All	150	150	148.18	0.4
AT00-CH00 Concept 1	AT00	CH00	2030	All	500	500	433.53	3.47
AT00-CH00 Concept 2	AT00	CH00	2030	All	500	500	416.53	3.33
AT00-DE00 Concept 1	AT00	DE00	2030	All	1000	1000	1385.06	11.08
AT00-DE00 Concept 2	AT00	DE00	2030	All	1000	1000	1489.92	11.92
AT00-DE00 Concept 3	AT00	DE00	2040	All	1000	1000	2285.92	18.29
AT00-DE00 Concept 4	AT00	DE00	2040	All	1000	1000	5674.1	45.39
AT00-ITN1 Concept 1	AT00	ITN1	2030	All	500	500	741.2	3.71
AT00-ITN1 Concept 2	AT00	ITN1	2030	All	500	500	781.2	3.91
AT00-SI00 Concept 1	AT00	SI00	2030	All	500	500	547.24	4.38
AT00-SI00 Concept 2	AT00	SI00	2040	All	500	500	656.3	5.25

AT00-SI00 Concept 3	AT00	SI00	2040	All	500	500	744.55	5.96
BE00-DE00 Concept 1	BE00	DE00	2030	All	1000	1000	965	5.8
BE00-DE00 Concept 2	BE00	DE00	2040	All	1000	1000	1550	6.4
BE00-FR00 Concept 1	BE00	FR00	2040	All	1000	1000	762	5.52
BE00-FR00 Concept 2	BE00	FR00	2040	All	1000	1000	722	5.16
BE00-NL00 Concept 1	BE00	NL00	2030	All	1000	1000	968.2	3.84
BE00-NL00 Concept 2	BE00	NL00	2030	All	1000	1000	1184	6.84
BE00-UK00 Concept 1	BE00	UK00	2040	All	2000	2000	2617	11
BG00-TR00 Concept 1	BG00	TR00	2040	All	500	500	110.5	2.25
BG00-TR00 Concept 2	BG00	TR00	2040	All	500	500	222.7	2.32
CH00-FR00 Concept 1	CH00	FR00	2040	All	1000	1000	755	2.2
CH00-FR00 Concept 2	CH00	FR00	2040	All	1000	1000	1290	3
CH00-ITN1 Concept 1	CH00	ITN1	2030	All	1000	1000	1406	5.2
CH00-ITN1 Concept 2	CH00	ITN1	2030	All	1000	1000	1600	6.2
DE00-CH00 Concept 1	DE00	CH00	2030	All	1000	1000	1100	8.768
DE00-CH00 Concept 2	DE00	CH00	2040	All	1000	1000	1900	15.2
DE00-FR00 Concept 1	DE00	FR00	2040	All	1000	1000	1312	9.7
DE00-FR00 Concept 2	DE00	FR00	2040	All	1000	1000	1405	9.64
ES00-FR00 Concept 1	ES00	FR00	2040	All	1500	1500	2977	10.6
ES00-FR00 Concept 2	ES00	FR00	2040	All	1500	1500	4065	11.7
ES00-PT00 Concept 1	ES00	PT00	2040	All	500	500	81	0.2
ES00-PT00 Concept 2	ES00	PT00	2040	All	500	500	110	0.1
ES00-PT00 Concept 3	ES00	PT00	2040	All	500	500	131	0.3
ES00-PT00 Concept 4	ES00	PT00	2040	All	500	500	151.6	0.4
FR00-IE00 Concept 1	FR00	IE00	2030	All	700	700	1800	32
FR00-IE00 Concept 2	FR00	IE00	2030	All	700	700	2450	32
FR00-ITN1 Concept 1	FR00	ITN1	2030	All	1000	1000	1560	7.8
FR00-ITN1 Concept 2	FR00	ITN1	2030	All	1000	1000	2540	11.7
FR00-UK00 Concept 1	FR00	UK00	2040	All	1300	1300	1350	4
FR00-UK00 Concept 2	FR00	UK00	2040	All	1300	1300	1635	20
GR00-TR00 Concept 1	GR00	TR00	2040	All	500	500	347.8	1.84
GR00-TR00 Concept 2	GR00	TR00	2040	All	500	500	477.8	1.84
ITN1-SI00 Concept 1	ITN1	SI00	2040	All	500	500	540	2.7
ITN1-SI00 Concept 2	ITN1	SI00	2040	All	500	500	640	3.2
ITSI-TN00 Concept 1	ITSI	TN00	2030	All	500	500	950	4.7
ITSI-TN00 Concept 2	ITSI	TN00	2030	All	500	500	1150	5.7
NL00-UK00 Concept 1	NL00	UK00	2030	All	1000	1000	1510	4
NL00-UK00 Concept 2	NL00	UK00	2030	All	1000	1000	1520	4

NOS0-UK00 Concept 1	NOS0	UK00	2040	All	1000	1000	2390	0
UK00-IE00 Concept 1	UK00	IE00	2030	All	700	700	850	8
UK00-UKNI Concept 1	UK00	UKNI	2030	All	700	700	950	8
DE00-NL00 Concept 1	DE00	NL00	2030	All	1000	1000	2075	1.6
DE00-NL00 Concept 2	DE00	NL00	2040	All	1000	1000	2125	2
BE00-LUG1 Concept 1	BE00	LUG1	2040	All	500	500	210	0.6
NOS0-UK00 Concept 2	NOS0	UK00	2040	All	1000	1000	2800	0
AL00-ME00 Concept 1	AL00	ME00	2040	All	500	500	9.4	0.0606
AL00-ME00 Concept 2	AL00	ME00	2040	All	500	500	10.5	0.0738
AL00-RS00 Concept 1	AL00	RS00	2040	All	500	500	24.5	0.294
AL00-RS00 Concept 2	AL00	RS00	2040	All	500	500	92.8	0.5976
AL00-MK00 Concept 1	AL00	MK00	2040	All	500	500	47.7	1.856
AL00-MK00 Concept 2	AL00	MK00	2040	All	500	500	77.7	2.928
AL00-GR00 Concept 1	AL00	GR00	2040	All	500	500	232	1.4
AL00-GR00 Concept 2	AL00	GR00	2040	All	500	500	240	1.4
AL00-ME00 Concept 3	AL00	ME00	2040	All	500	500	12.5	0.0606
AL00-ME00 Concept 4	AL00	ME00	2040	All	500	500	36	0.4
AT00-CZ00 Concept 1	AT00	CZ00	2030	All	500	500	365.38	1.95
AT00-CZ00 Concept 2	AT00	CZ00	2030	All	500	500	499.18	2.48
AT00-CZ00 Concept 3	AT00	CZ00	2040	All	500	500	1314.5	5.49
AT00-HU00 Concept 1	AT00	HU00	2030	All	1000	1000	866.4	8.66
AT00-HU00 Concept 2	AT00	HU00	2040	All	1000	1000	1703.05	17.03
BA00-ME00 Concept 1	BA00	ME00	2040	All	500	500	18.86	0.188
BA00-ME00 Concept 2	BA00	ME00	2040	All	500	500	24	0.24
BA00-HR00 Concept 1	BA00	HR00	2040	All	500	500	162	8.05
BA00-HR00 Concept 2	BA00	HR00	2040	All	500	500	117	5.75
BA00-HR00 Concept 3	BA00	HR00	2040	All	500	500	132.1	0.1
BA00-ME00 Concept 3	BA00	ME00	2040	All	500	500	36.88	0.2943

BA00-ME00 Concept 4	BA00	ME00	2040	All	500	500	29.46	0.1923
BA00-RS00 Concept 1	BA00	RS00	2040	All	500	500	54.58	0.3
BA00-RS00 Concept 2	BA00	RS00	2040	All	500	500	62.48	0.3
BG00-GR00 Concept 1	BG00	GR00	2040	All	500	500	221	1.1
BG00-GR00 Concept 2	BG00	GR00	2040	All	500	500	225	1.24
BG00-RO00 Concept 1	BG00	RO00	2040	All	500	500	221	1.105
BG00-RO00 Concept 2	BG00	RO00	2040	All	500	500	219	1.095
BG00-RS00 Concept 1	BG00	RS00	2040	All	500	500	283.44	0.61
BG00-RS00 Concept 2	BG00	RS00	2040	All	500	500	283.44	0.61
BG00-MK00 Concept 1	BG00	MK00	2040	All	500	500	110.8	2.76
BG00-MK00 Concept 2	BG00	MK00	2040	All	500	500	181	2.71
CZ00-DE00 Concept 1	CZ00	DE00	2040	All	500	500	1550	12.4
CZ00-DE00 Concept 2	CZ00	DE00	2040	All	500	500	3243	0.344
CZ00-DE00 Concept 3	CZ00	DE00	2040	All	500	500	3244	0.344
CZ00-DE00 Concept 4	CZ00	DE00	2040	All	500	500	3245	0.344
CZ00-PL00 Concept 1	CZ00	PL00	2040	All	1000	1000	779	11
CZ00-PL00 Concept 2	CZ00	PL00	2040	All	1000	1000	10000	150
CZ00-SK00 Concept 1	CZ00	SK00	2040	All	500	500	345.3	2.775
CZ00-SK00 Concept 2	CZ00	SK00	2040	All	500	500	396.24	3.21
DE00-DKE1 Concept 1	DE00	DKE1	2030	All	500	500	383.3	9
DE00-DKE1 Concept 2	DE00	DKE1	2030	All	500	500	384.3	9
DE00-DKE1 Concept 3	DE00	DKE1	2040	All	500	500	385.3	9
DE00-DKE1 Concept 4	DE00	DKE1	2040	All	500	500	386.3	9
DE00-DKE1 Concept 5	DE00	DKE1	2040	All	500	500	387.3	9
DE00-DKE1 Concept 6	DE00	DKE1	2040	All	500	500	388.3	9
DE00-DKW1 Concept 1	DE00	DKW1	2040	All	2000	2000	4800	38
DE00-NOS0 Concept 1	DE00	NOS0	2040	All	1000	1000	4000	16
DE00-NOS0 Concept 2	DE00	NOS0	2040	All	1000	1000	4000	150
DE00-PL00 Concept 1	DE00	PL00	2040	All	2000	2000	1080	1
DE00-PL00 Concept 2	DE00	PL00	2040	All	2000	2000	10000	1
DE00-SE04 Concept 1	DE00	SE04	2040	All	500	500	478.6	1
DE00-SE04 Concept 2	DE00	SE04	2040	All	500	500	479.6	1
DE00-SE04 Concept 3	DE00	SE04	2040	All	500	500	480.6	1

DE00-SE04 Concept 4	DE00	SE04	2040	All	500	500	481.6	1
DE00-SE04 Concept 5	DE00	SE04	2040	All	500	500	482.6	1
DE00-SE04 Concept 6	DE00	SE04	2040	All	500	500	483.6	1
CZ00-DE00 Concept 5	CZ00	DE00	2040	All	500	500	3246	0.344
CZ00-DE00 Concept 6	CZ00	DE00	2040	All	500	500	3247	0.344
DKE1-SE04 Concept 1	DKE1	SE04	2040	All	500	500	150	0
DKE1-SE04 Concept 2	DKE1	SE04	2040	All	500	500	150	0.1
DKE1-DKW1 Concept 1	DKE1	DKW 1	2030	All	600	600	600	0
DKE1-SE04 Concept 3	DKE1	SE04	2030	All	500	500	150	0
DKE1-SE04 Concept 4	DKE1	SE04	2040	All	500	500	150	0.1
DKW1-NOS0 Concept 1	DKW1	NOS 0	2040	All	1000	1000	1150	0
DKW1-NOS0 Concept 2	DKW1	NOS 0	2040	All	1000	1000	850	0
DKW1-SE03 Concept 1	DKW1	SE03	2030	All	500	500	471	1
DKW1-SE03 Concept 2	DKW1	SE03	2030	All	500	500	472	1.1
DKW1-NL00 Concept 1	DKW1	NL00	2040	All	1000	1000	3250	4
DKW1-NL00 Concept 2	DKW1	NL00	2040	All	1000	1000	3850	4
DKW1-SE03 Concept 3	DKW1	SE03	2030	All	500	500	471.4	1
DKW1-SE03 Concept 4	DKW1	SE03	2030	All	500	500	471.4	1.1
DKW1-SE03 Concept 5	DKW1	SE03	2035	All	500	500	471.4	1
DKW1-SE03 Concept 6	DKW1	SE03	2035	All	500	500	471.4	1.1
EE00-FI00 Concept 1	EE00	FI00	2030	All	700	700	850	4
EE00-FI00 Concept 2	EE00	FI00	2040	All	700	700	900	4
EE00-LV00 Concept 1	EE00	LV00	2030	All	1000	1000	1150	6
EE00-LV00 Concept 2	EE00	LV00	2040	All	1000	1000	1200	6
FI00-NON1 Concept 1	FI00	NON 1	2040	All	500	500	1000	0
FI00-SE01 Concept 1	FI00	SE01	2030	All	800	800	300	0.3
FI00-SE01 Concept 2	FI00	SE01	2040	All	800	800	300	0.3
FI00-SE02 Concept 1	FI00	SE02	2030	All	500	500	450	1
FI00-SE02 Concept 2	FI00	SE02	2040	All	500	500	450	1
FI00-SE03 Concept 1	FI00	SE03	2030	All	500	500	450	1
FI00-SE03 Concept 2	FI00	SE03	2040	All	500	500	450	1
FI00-NON1 Concept 2	FI00	NON 1	2040	All	500	500	1000	0
FI00-SE01 Concept 3	FI00	SE01	2040	All	800	800	300	0.3
FI00-SE02 Concept 3	FI00	SE02	2040	All	500	500	450	1

FI00-SE02 Concept 4	FI00	SE02	2040	All	500	500	450	0.1
FI00-SE03 Concept 3	FI00	SE03	2040	All	500	500	450	1
FI00-SE03 Concept 4	FI00	SE03	2040	All	500	500	450	1.1
GR00-ITS1 Concept 1	GR00	ITS1	2040	All	500	500	1700	3.2
GR00-ITS1 Concept 2	GR00	ITS1	2040	All	500	500	2000	3.3
GR00-MK00 Concept 1	GR00	MK00	2040	All	500	500	48	0.66
GR00-MK00 Concept 2	GR00	MK00	2040	All	500	500	118.75	0.94
HR00-HU00 Concept 1	HR00	HU00	2040	All	500	500	410.4	4.104
HR00-HU00 Concept 2	HR00	HU00	2040	All	500	500	624.6	6.246
HR00-RS00 Concept 1	HR00	RS00	2040	All	500	500	89.45	2.84
HR00-RS00 Concept 2	HR00	RS00	2040	All	500	500	124.23	3.55
HR00-SI00 Concept 1	HR00	SI00	2040	All	1000	1000	91.1	4.355
HR00-SI00 Concept 2	HR00	SI00	2030	All	1000	1000	126	3.51
HU00-SI00 Concept 1	HU00	SI00	2030	All	500	500	183.6	1.836
HU00-SI00 Concept 2	HU00	SI00	2030	All	500	500	327.6	5.22
HU00-SK00 Concept 1	HU00	SK00	2030	All	500	500	441.5	1.53
HU00-SK00 Concept 2	HU00	SK00	2030	All	500	500	303	3276
HU00-RO00 Concept 1	HU00	RO00	2040	All	2000	2000	1939	58.17
HU00-RO00 Concept 2	HU00	RO00	2040	All	2000	2000	2500	0
HU00-RS00 Concept 1	HU00	RS00	2040	All	500	500	478.18	3.4
HU00-RS00 Concept 2	HU00	RS00	2040	All	500	500	2500	0
HU00-SK00 Concept 3	HU00	SK00	2040	All	500	500	441.5	1.53
HU00-SK00 Concept 4	HU00	SK00	2040	All	500	500	303	3.276
ITCS-ME00 Concept 1	ITCS	ME00	2030	All	500	500	750	3.7
ITCS-ME00 Concept 2	ITCS	ME00	2030	All	500	500	900	4.5
LT00-LV00 Concept 1	LT00	LV00	2030	All	500	500	300.7	0.3
LT00-LV00 Concept 2	LT00	LV00	2030	All	500	500	369	1
LT00-LV00 Concept 3	LT00	LV00	2030	All	500	500	430.28	1.6
LT00-SE04 Concept 1	LT00	SE04	2040	All	500	500	1025	10.3
LT00-SE04 Concept 2	LT00	SE04	2040	All	500	500	1850	18.5
ME00-RS00 Concept 1	ME00	RS00	2040	All	500	500	54.82	0.072
ME00-RS00 Concept 2	ME00	RS00	2040	All	500	500	83.5	0.068
MK00-RS00 Concept 1	MK00	RS00	2040	All	500	500	95.34	2.46

MK00-RS00 Concept 2	MK00	RS00	2040	All	500	500	144.78	1.39
NL00-NOS0 Concept 1	NL00	NOS 0	2040	All	1000	1000	2600	4
NL00-NOS0 Concept 2	NL00	NOS 0	2040	All	1000	1000	2610	4
NOM1-SE02 Concept 1	NOM1	SE02	2040	All	500	500	250	0
NOM1-SE02 Concept 2	NOM1	SE02	2040	All	500	500	250	0.1
NON1-SE01 Concept 1	NON1	SE01	2040	All	500	500	250	0
NON1-SE01 Concept 2	NON1	SE01	2040	All	500	500	250	0.1
NON1-SE02 Concept 1	NON1	SE02	2040	All	500	500	250	0
NON1-SE02 Concept 2	NON1	SE02	2040	All	500	500	250	0.1
NOS0-SE03 Concept 1	NOS0	SE03	2040	All	500	500	250	0
NOS0-SE03 Concept 2	NOS0	SE03	2040	All	500	500	250	0.1
NOS0-SE03 Concept 3	NOS0	SE03	2040	All	500	500	250	0
NOS0-SE03 Concept 4	NOS0	SE03	2040	All	500	500	250	0.1
PL00-SE04 Concept 1	PL00	SE04	2040	All	500	500	1640	31
PL00-SE04 Concept 2	PL00	SE04	2040	All	500	500	1690	31
PL00-SK00 Concept 1	PL00	SK00	2040	All	1000	1000	1338	19
PL00-SK00 Concept 2	PL00	SK00	2040	All	1000	1000	10000	150
RO00-RS00 Concept 1	RO00	RS00	2040	All	500	500	149.01	1.402
RO00-RS00 Concept 2	RO00	RS00	2040	All	500	500	248.9	2.377
SE01-SE02 Concept 1	SE01	SE02	2040	All	1000	1000	630	1
SE01-SE02 Concept 2	SE01	SE02	2040	All	1000	1000	630	1
SE02-SE03 Concept 1	SE02	SE03	2040	All	1000	1000	780	1
SE02-SE03 Concept 2	SE02	SE03	2040	All	1000	1000	780	1
SE03-SE04 Concept 1	SE03	SE04	2040	All	1000	1000	550	1
SE03-SE04 Concept 2	SE03	SE04	2040	All	1000	1000	550	1

APPENDIX 2. HYBRID CANDIDATES (CAPACITY INCREASES) – CAPACITIES ASSUMPTIONS

Hybrid candidates for IoSN are taken from identified ONDP corridors. Costs of these projects were collected from TSOs. The following table gives the best vision of every capacity increase considered in IoSN regarding hybrid projects.

Link to the data in spreadsheet format: https://eepublicdownloads.blob.core.windows.net/public-cdn-container/tyndp-documents/TYNDP2024/investmentCandidates_and_CostAssumptions.xlsx

Table 11 Hybrid Candidates for 2040 IoSN Study

Onshore node country A	Offshore node country A	Onshore node country B	Offshore node country B	Direct capacity increase (MW)	Indirect capacity increase (MW)
N/A	DE01	N/A	DKNS/DKW12	2000	2000
N/A	IE01	96_UK	N/A	2000	2000
N/A	EE_off1	48_DE	N/A	2000	2000
N/A	DE02	N/A	UK041_OFF	2000	2000
83_DK	DKNS / DKW12	N/A	N/A	1000	1000
36_BE	N/A	N/A	NL_67	2000	2000
N/A	NL_67	N/A	DE02	2000	2000
N/A	DE_BS	95_SE	N/A	1000	1000
N/A	NOS22_OFF	N/A	DKNS/DKW12	1000	1000
N/A	DE02	N/A	NOS22_OFF	2000	2000
N/A	IE04	N/A	OFF_NODE_FR08	700	700
N/A	BE02_OFF	N/A	UK011_OFF	1000	1000
N/A	IE03	96_UK	N/A	1000	1000
N/A	VI_H_DKNS	N/A	DE03	2000	2000
N/A	DE01	N/A	UK041_OFF	2000	2000
N/A	UK02_OFF	N/A	IE_05	500	500
N/A	IE_02	96_UK	N/A	500	500
N/A	NOS22_OFF	N/A	UK041_OFF	500	500

Table 12 Hybrid Candidates for 2050 IoSN Study

From Node	To Node	Border	A->B	B->A
29_BE00	NL_67	29_BE00 - NL_67	2000	2000
DE_BS	95_SE00	DE_BS - 95_SE00	2000	2000
DE_BS	95_SE00	DE_BS - 95_SE00	1000	1000
DE01	UK041	DE01 - UK041	2000	2000
DE02	NOS22_OFF	DE02 - NOS22_OFF	2000	2000
DE02	UK041	DE02 - UK041	2000	2000
DE03	UK032	DE03 - UK032	2000	2000
DKNS / DKW12	83_DK00	DKNS / DKW12 - 83_DK00	1000	1000
DKNS / DKW12	DE01	DKNS / DKW12 - DE01	2000	2000
DKNS / DKW12	DE03	DKNS / DKW12 - DE03	2000	2000
EE_Offshore 1	FI_Virtual Offshore Wind 5	EE_Offshore 1 - FI_Virtual Offshore Wind 5	1000	1000
EE_Offshore 1	48_DE00	EE_Offshore 1 - 48_DE00	2000	2000
FI_Virtual Offshore Wind 2	SE2_3	FI_Virtual Offshore Wind 2 - SE2_3	500	500
FI_Virtual Offshore Wind 6	SE4_5	FI_Virtual Offshore Wind 6 - SE4_5	1300	1300
FI_Virtual Offshore Wind 7	SE2_4	FI_Virtual Offshore Wind 7 - SE2_4	1000	1000
IE_01	96_UK00	IE_01 - 96_UK00	2000	2000
IE_02	96_UK00	IE_02 - 96_UK00	1000	1000
IE_02	96_UK00	IE_02 - 96_UK00	500	500
IE_03	96_UK00	IE_03 - 96_UK00	1000	1000

IE_04	96_UK00	IE_04 - 96_UK00	500	500
IE_04	OFF_NODE_FR08	IE_04 - OFF_NODE_FR08	700	700
IE_05	98_IE00	IE_05 - 98_IE00	1000	1000
LT_Offshore Wind III	DKBH	LT_Offshore Wind III - DKBH	1000	1000
LT_Offshore Wind IV	48_DE00	LT_Offshore Wind IV - 48_DE00	2000	2000
LV_OW60	SE4_5	LV_OW60 - SE4_5	700	700
LV_OW60	48_DE00	LV_OW60 - 48_DE00	2000	2000
NL_67	DE02	NL_67 - DE02	2000	2000
NL_PZA	DKNS / DKW12	NL_PZA - DKNS / DKW12	2000	2000
NOS22_OFF	35_NL00	NOS22_OFF - 35_NL00	2000	2000
NOS22_OFF	DKNS / DKW12	NOS22_OFF - DKNS / DKW12	1000	1000
OFF_NODE_FR08	98_IE00	OFF_NODE_FR08 - 98_IE00	700	700
UK02	IE_05	UK02 - IE_05	500	500

APPENDIX 3. STARTING GRID

Link to the data spreadsheet format: https://eepublicdownloads.blob.core.windows.net/public-cdn-container/tyndp-documents/TYNDP2024/forconsultation/StartingGrid2030.xlsx