TYNDP 2022

System Needs Study

Implementation Guidelines

Final Version · May 2023

entsoe

1. INTRODUCTION AND PURPOSE OF IOSN (IDENTIFICATION OF SYSTEM NEEDS)

The Identification of the System Needs (IoSN) study is carried out by ENTSO-E biannually and is the main input for a number of reports included in the TYNDP package.

The 2022 IoSN analysis is based on the TYNDP 2022 2030 and 2040 National Trends scenarios and screens the entire European perimeter to identify potential needs in terms of increase of interconnection capacities at ENTSO-E perimeter by 2030 and 2040 time horizons. For 2040 time horizon, needs in terms of flexibilities and peaking generation capacities are also investigated.

The Implementation Guideline for the Identification of the System Needs process is based on a common methodology described in this document. The Guidelines include in particular the practical implementation of the Zonal Modelling methodology, which has been practically tested during the TYNDP 2020 process. The sequential steps of the process are also defined and documented.

2. MAIN OBJECTIVES OF THE IMPLEMENTATION GUIDELINES OF THE IOSN PROCESS

Key drivers of the methodology:

1. Already in TYNDP 2014 it was discussed that a pilot market modelling process methodology using more market areas than one per country should be tested to make sure that needs in the system can be monitored at a wider granularity and scope;
2. Additionally, a separate testing team has been established within ENTSO-E aiming at the implementation of market modelling topology inspired by the EH 2050 project using 100 Zones and introducing network parameters at the connections of the defined Zones;
3. Zonal Modelling approach has been successfully tested during TYNDP 2018 process and compared with the classic conservative approach based on standard NTC model. The results have been considered consistent, so that may be further implemented fully in the TYNDP process;
4. Such a methodology except the possible transmission capacity increases can also indicate potential network overloading at the internal inter zone connections for any country at the ENTSO-E perimeter.
5. It has been indicated by several stakeholders during TYNDP 2020 process, that other technologies aside transfer capacity increases should be highlighted within the needs identification process. Therefore, within TYNDP 2022 study, storage and peaking units are also included at horizon 2040.

3. OVERVIEW OF THE PROCESS

3.1 Input Data

Preparation of the starting network

In framework of TYNDP 2022 process ENTSO-E conducted a review of the list of projects to be included in the reference networks to be used for the Cost and Benefit Analysis of infrastructure projects and as a starting point for Identification of the System Needs process.

During such process, the TYNDP 2020 project promoters were contacted and requested to review and update where relevant the list of projects to be included in different reference grids and provide clear justifications in case projects were intended to be included in any of the reference grids listed below.

ENTSO-E collected and reviewed three reference network configurations, and in particular at 2025 time horizon which constitutes the starting point for Identification of System Needs process.

For the reference network 2025, used as a starting point for the Identification of the System Needs Study, the following criteria apply for each project included in this reference network:

a) Are in the construction phase; or

b) Having successfully completed the environmental impact assessments;

Whatever criteria has been chosen, the proof of maturity had to be accompanied by a study which justified the project validity to comply with the criteria listed above. The final judgment on its validity however lied within the responsibility of ENTSO-E.

In order to verify the commissioning years of the projects, project promoters also were asked to submit a written justification on the expected commissioning years. As the commissioning date of the projects had to be agreed between the TSOs and NRAs of the countries the project is built in, being included and approved within the actual national development plan available at the time of the project collection phase was seen as a sufficient requirement for this purpose. If a more recent agreement (between TSOs and NRAs) was available at that point in time, such as e.g. quarterly monitoring updates, this information had to be used. If the above information was not available, the commissioning dates were cross - checked against the average time of similar projects.

If no agreement between project promoter(s), TSO and NRAs on the project commissioning date or if the project was not included in the NDP of a country, ENTSO-E could, based on the CBA 3.0 Guidelines, assess the commissioning date based on comparable projects. In case this assessment led to the conclusion that the delivered commissioning date has been seen as unrealistic, ENTSO-E could decide on excluding the project from the reference grid.

Input Data for 2030 time horizon

The input data for the Identification of the System Needs process for 2030 time horizon may be separated into two main parts: market data and network data.

Market Data:

- Generation data in PEMMDB 2.3. format;
- Fuel Prices according to the published dataset as part of Scenario Building report;
- Common generation data;
- Maintenance and forced outage profiles;
- Reference grid NTC dataset – 2025 time horizon;
- Market/Zonal model clustering topology;
- Hydro constraints and inflow data;
- RES full-load hourly time series (Pan-European Climatic Database);
- Load time series;

Fixed Exchanges with countries outside the model boundaries;

Potential NTC increases given by project promoters & TSOs

Network Data:

- Network model for 2030 time horizon based on the TYNDP 2020 model, with 2025 MAF NTCs;
- Zone clustering considering grid topology (Comprehensive list of substations (or list of inter-zones lines) for each zone with perfect match between this list and the grid model);

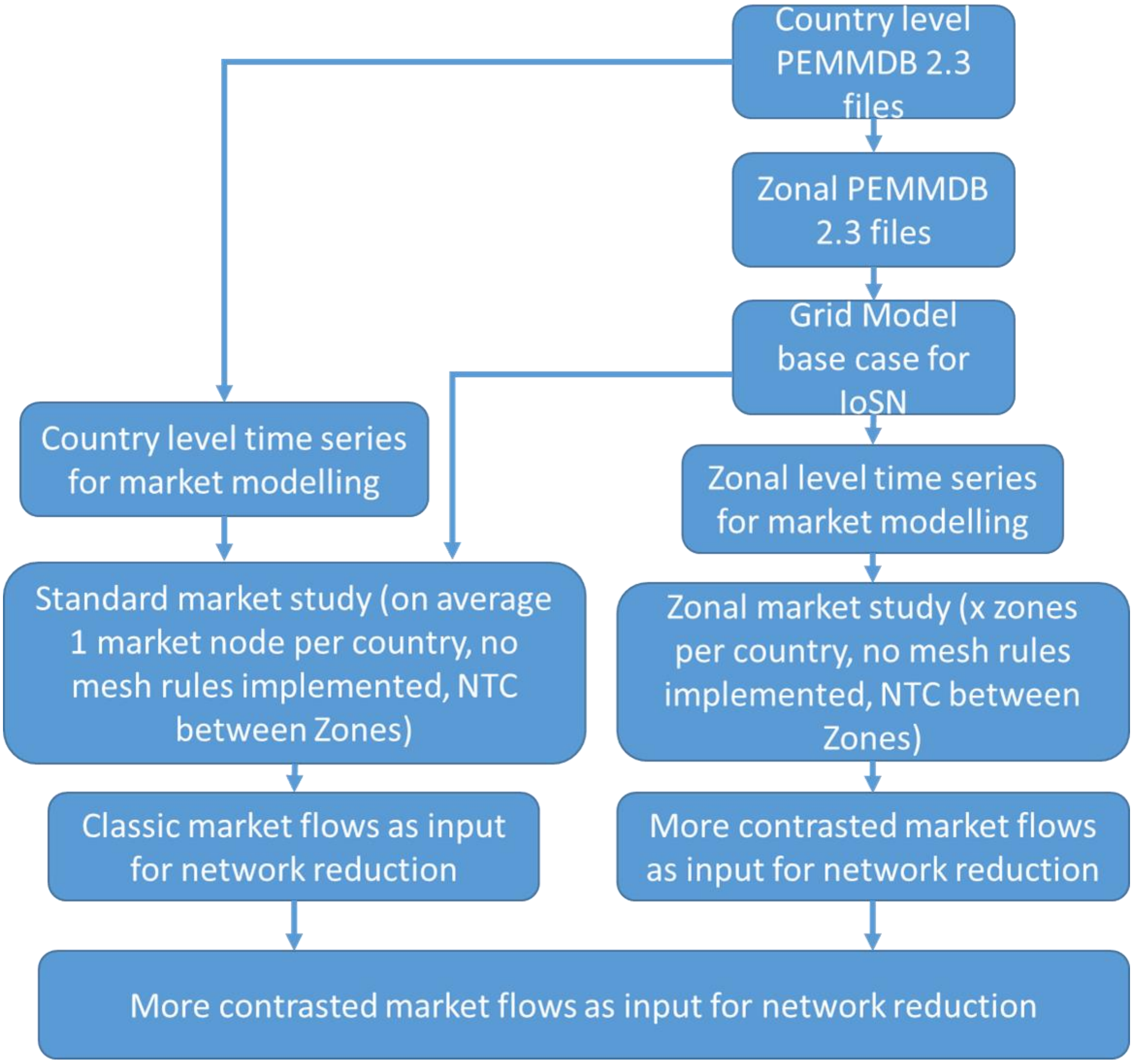


Figure 1 IoSN Input Data Flow Diagram

For the TYNDP 2022 process, the standard market study approach (left side of Figure1) has been used as basis for network reduction.

Input Data for 2040 time horizon

<u>Market Data:</u>

- Generation data in PEMMDB 2.3. format;
- Fuel Prices according to the published dataset as part of Scenario Building report;
- Common generation data;
- Maintenance and forced outage profiles;

- Reference grid NTC dataset – 2025 time horizon;
- Market model clustering topology;
- Hydro constraints and inflow data;
- RES full-load hourly time series (Pan-European Climatic Database);
- Load time series;
- Potential NTC increase given by project promoters & TSOs
  Storage and peaking flexibility potential increases, using parameters used within Scenario Building process

The input data flow for 2040 NT IoSN is illustrated in Figure 2.

Input data flow:

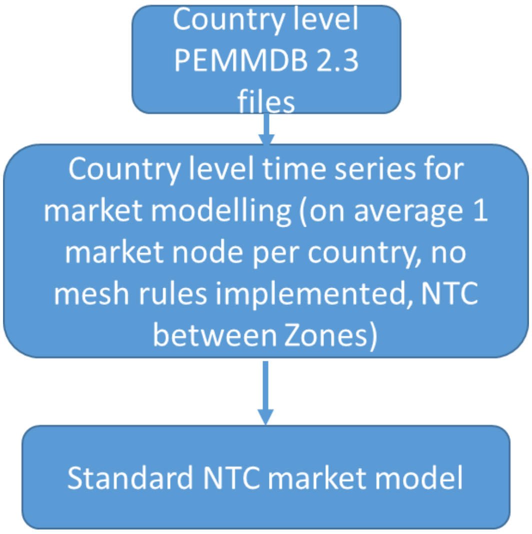


Figure 2 IoSN 2040 Input Data Flow Diagram

Figure 2

4. SOFTWARE TOOLS INVOLVED

4.1 Pre-qualification test for Zonal IoSN

In order to identify the software tools capable to participate in the IoSN process, specific pre-qualification test were performed during TYNDP 2020 process.

The key requirements for any team to participate 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.

The test sample model can be visually represented as in Figure 3:

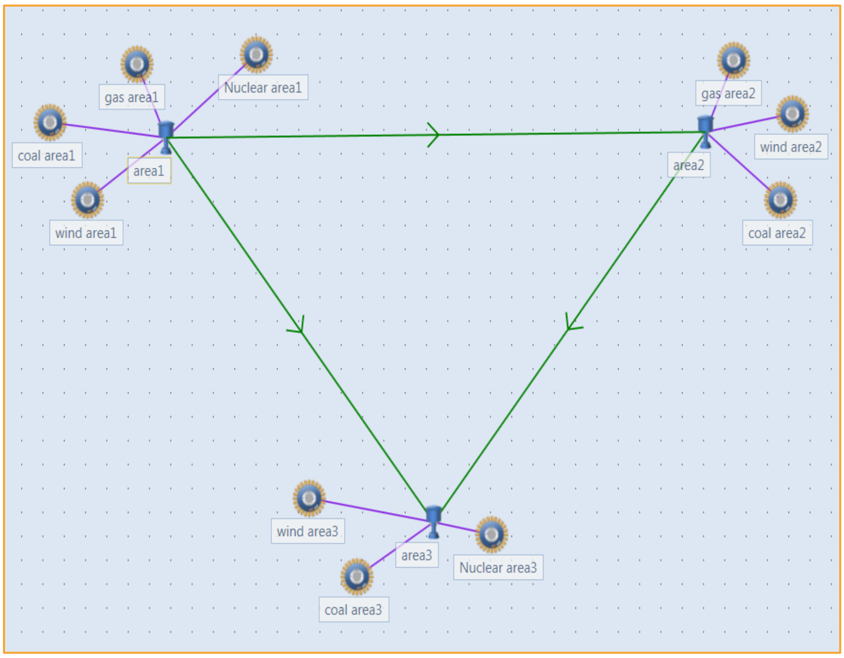


Figure 3 Zonal Model Test Sample

As visible in Figure 3, the test sample consists of 3 Zones with different generation mixes. The first Zone (area) includes wind, coal, gas, nuclear generation, while the second Zone (area) is represented by gas, wind and coal generation. The third Zone encloses nuclear, coal and wind generation.

In more detail, the generation parameters are defined in Table 1.

Table 1 Generation parameters of the Zonal Test Sample

Zone (area) 1

cluster	Hard Coal	Gas	Nuclear
Number of units	1	2	4
nominal capacity [MW]	500	500	500
marginal-cost [€]	55	50	14

Zone (area) 2

cluster	Hard Coal	Gas
Number of units	2	4
nominal capacity [MW]	500	500
marginal-cost [€]	55	50

Zone (area) 3

cluster	Hard Coal	Gas	Nuclear
Number of units	4	4	4
nominal capacity [MW]	500	500	500
marginal-cost [€]	55	50	14

The parameters of the connections between the Zones are described in Table 2.

Table 2 Parameters of the Zone connections for the Zonal test sample

	3 AC lines between the 3 areas			**PST between area 1 and area 2**		
TEST 1	**Lines**	**Capacity [MW]**	**Reactance [pu]**			
	area 1 -area 2	500	0,05	**NO PST**		
	area 2 -area 3	500	0,05			
	area 1 - area 3	500	0,1			
TEST 2	**Lines**	**Capacity [MW]**	**Reactance [pu]**			
	area 1 -area 2	500	0,05	**PST Phase-shifting power**		500 MW
	area 2 -area 3	500	0,05			
	area 1 - area 3	500	0,1			

	Lines	Capacity [MW]	Reactance [pu]			
TEST 2	area 1 -area 2	450	0,05	**PST Phase-shifting power**		500 MW
	area 2 -area 3	450	0,05			
	area 1 - area 3	450	0,1			

4.2 Software Tools that passed the pre-qualification

According to the pre-qualification results performed for TYNDP 2020, Antares software tool has been qualified to be involved in the Zonal IoSN process and was again used for TNDP 2022.

5. STEP-BY-STEP METHODOLOGY DESCRIPTION

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

5.1 Description of the Preparatory phase – 2030 Zonal Study

The Preparatory phase may be visualized as the block diagram in Figure 4.

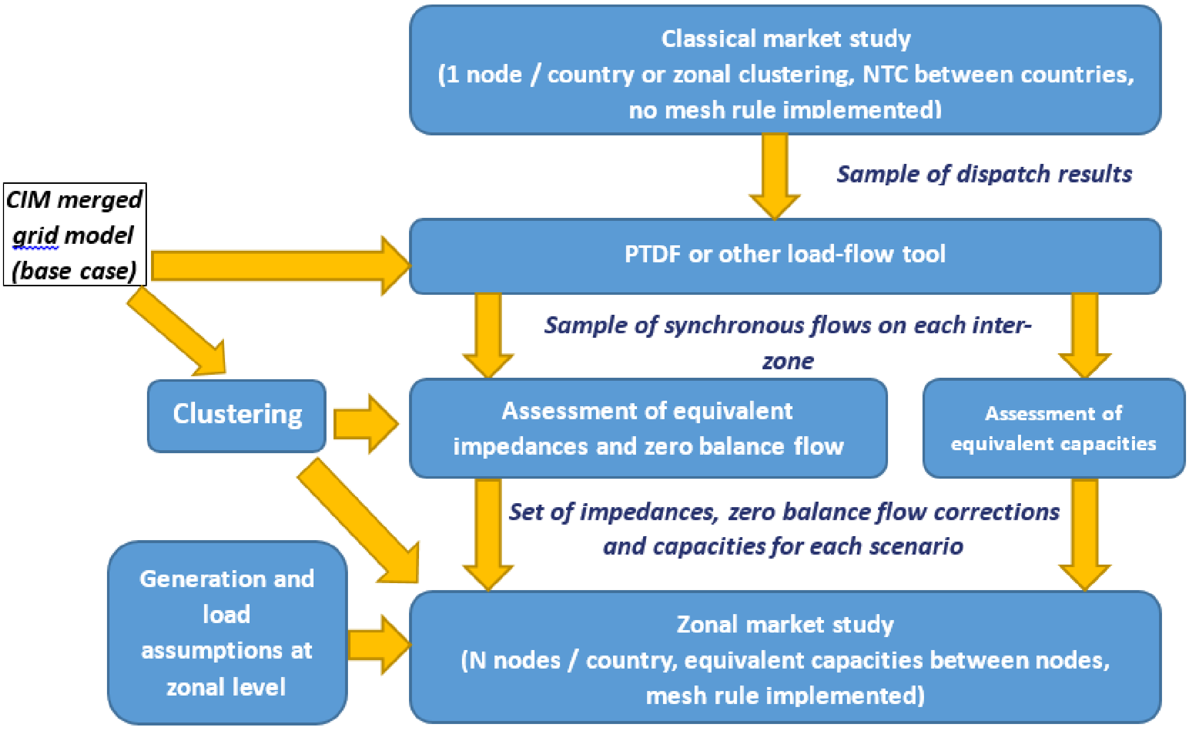


Figure 4. Zonal IoSN prepratory phase diagram

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

As visible in Figure 4, the preparatory phase starts with a Classical market study based on a scenario of TYNDP 2022, which is done based on a prepared dataset in PEMMDB 2.3 format built as part of the Scenario Building process.

The composition of such dataset is explained more in detail in Chapter 0 of this document.

<u>CIM merged grid model (base case)</u>

The grid model to be used as base case for IoSN 2030 of TYNDP 2022 is built from the grid model of TYNDP 2020, which came with 2027 MAF NTCs used as a starting point. Several projects have then to be disconnected in order to reach the grid corresponding to the reference base case NTCs for the scenario NT2030 (MAF 2025 NTCs), which is used for IoSN 2030. The grid model is built in CIM (CGMES) format.

Clustering

The clustering has been updated during TYNDP 2022 in the beginning of the process (Before the IoSN started). A detailed 6-month study has been performed focused on the zonal clustering improvement and has successfully achieved the results that were expected. Around 13 iterations have been made in order to identify the best trade-off considering several criteria. The proposed achieved clustering represents a significant improvement compared to the clustering used within TYNDP 2020.

The clustering used for TYNDP 2020 still left room for improvement in some areas, even for the interconnections. A first step was done to improve it by splitting BE in 3 zones. The results were still not satisfactory because the problem has to be solved in a bigger area than BE. If and how a country is clustered does not affect only that country but can have a big impact all around.

CRITERIAS USED TO IMPROVE THE CLUSTERING

As the perfect clustering does not exist, a compromise has to be found between several criteria:

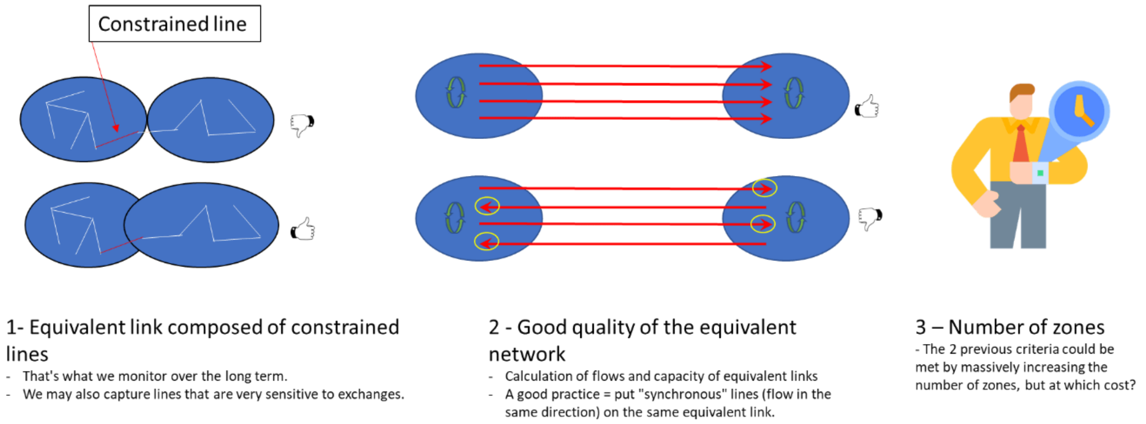


Figure 5 : Compromise needed between different criteria to reach an adapted clustering.

The objective of the first criteria is to put on interzones the most critical lines in order to be able to monitor them in the model. In fact, with an equivalent grid model, the only lines which can be monitored are the equivalent ones. By putting the critical lines on interzones, the dispatch can be adapted by the market tool in order to avoid any overload on the interzones.

The second one is linked to the choice of lines to out on the same interzone. In order to ensure a good quality, the best way is to put on the same interzones links which have the same behaviour. For instance, if in several hours of the studied climate years, some lines have direct flows while the others have indirect flows, the equivalent flow would be very close to zero because it would be the sum of all the flow of the links. The equivalent capacity calculated would also be close to 0 MW which is not realistic. Plus, the optimizer would not be able to find one single value for the equivalent impedance which would reflect objectively the behaviour of the equivalent link due to the instability of the hourly values.

The third criteria is the number of total zones. In fact, the 2 first criteria could be achieved simultaneously by massively increasing the number of zones. That solution would not be very realistic because the total number of zones has to be limited in order to be able to run the calculations (regarding computation time), to ensure a good definition of zonal hypothesis (regarding granularity of the dispatch). In addition, the perfect zonal model without any error or trade off would be a model in which every grid node represents a separate zone. Considering that a nodal market model seems not to be very realistic or affordable, it is mandatory to split biggest countries, which can significantly affect the quality of the European model, into several zones.

In addition, some other criteria have to be considered when it is possible to obtain the best clustering possible. For example, inside a zone, the grid has to be connected. To ensure a good grid reduction quality, it is not acceptable to have 2 isolated parts of grid inside a same zone. Also, the size of zones has to remain proportional if possible. A wide zone connected to much smaller ones would massively affect their behavior and their grid quality. Finally, the consistency of the zones with PECD ones could ease the process of splitting the country hypothesis into zonal ones.

IDENTIFICATION OF CONSTRAINED LINES

To catch the first criteria, it is necessary to identify the constrained lines. For that, flow calculations have been run using the same grid model than in IoSN of TYNDP 2020. It was based on the TYNDP 2018 grid model (the TYNDP 2020 was not final at the beginning of the study on zonal clustering) but with the same reference grid of 2025. The most important thing was to keep the reference grid of 2025 even if the grid model came from another TYNDP.

By definition, a constrained line is an overloaded one. Flow calculations have been run for all the 225 kV and 400 kV lines on 3 climate years (1982, 1984 and 2007). On every hour, the overloaded lines are identified and the severity of the congestion in MW, which is the maximum value of the flow. Some lines may be frequently constrained but with a low severity while some others are rarely overloaded but with a higher severity. Using only the frequency as single criteria would not be enough to capture the most critical lines, neither would the severity. Hence, to combine the two indicators, a new criteria is used: the annual overload energy for each line which represents the sum in MWh of the hourly overload in the whole year. The bigger the value, the more critical the line is. An example is provided below:

Table 3 : Examples of constraints on lines

	Lines				
	A	B	C	Criteria used to identify the most critical line	Most critical lines
Frequency of constraints (%/year)	5	40	15	x	2, 3 then 1
Highest overload value = Severity (MW)	2000	100	3000	x	3, 1 then 2
Total annual overload energy (TWh/year)	20	10	1	x	1, 2 then 3

CLUSTERING IMPROVEMENT METHODOLOGY AND QUALITY INDICATORS EVOLVEMENT

The different steps of improving the clustering are:

- Identification of the gaps of the original clustering
- Calculation of flows and identification of the bottlenecks and critical branches to capture (put on interzones) when it is possible
- Adaptation of the clustering by iterations of one or several adjustments
- Testing of the new proposal, drawing the results on a map and decision to keep or reject the tested modifications based on the evolvement of the indicators.

Those indicators are:

- RMSE (Root Mean Square Error): For each iteration, the RMSE obtained for the tested clustering is compared to the previous one in order to see if it has improved. In that case, the changes tested are kept and the process goes on with others changes. Several iterations are made with modifications not country per country but with several changes in codependent countries. The grid reduction is done using an optimizer. The only way to improve its results is to modify adequately the clustering which is put as an input. Most of the iterations was made based on their impact on the grid reduction quality obtained after the optimization.

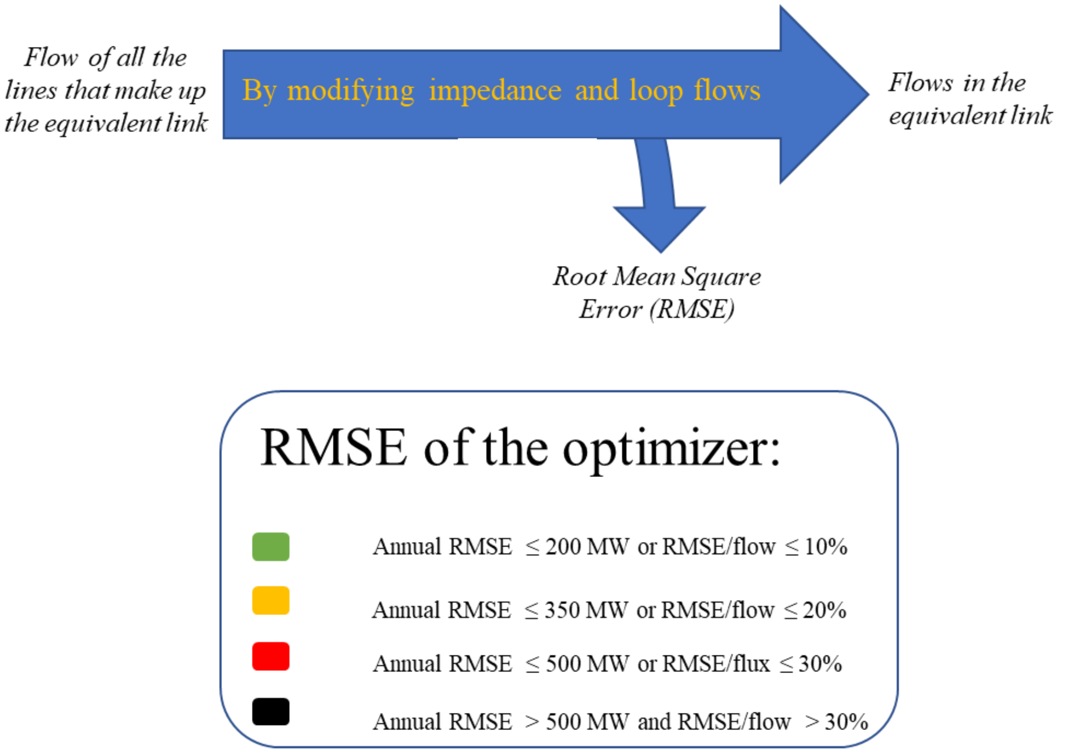


Figure 6 : Schematic view of the RMSE impact on the clustering

When the criteria "RMSE" has been finally stable, the process continues with other changes looking for an improvement of the second indicator which is:

- The quality of the equivalent capacities but also its evolvement compared to the TYNDP 2020 quality when the interzone existed before.

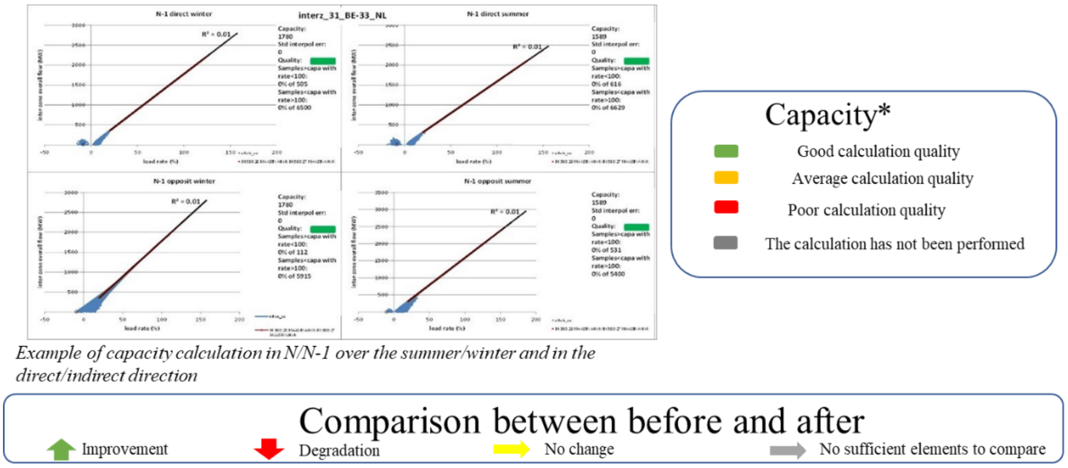


Figure 7: Example of capacity calculation in N/N-1 over the summer/winter and in the direct/indirect directions.

The priority was given to the "RMSE" indicator because the capacity are calculated by tools whose parameters can more easily be adapted. The quality does not only depend on the chosen clustering, but also on how the capacities themselves are calculated: for instance, are the 225 kV lines taken into account as critical outages? If no, they can be ignored to improve the capacity quality. Also, do TSOs have some topological actions to handle some critical situations? If yes, as it is not possible to directly model those, they are indirectly integrated by not taking the corresponding CBCO into account, and so on.

So the main criteria to adopt changes is their ability to improve the grid reduction with RMSE. Still, their impact on the capacities is analyzed and the best clustering would be the one which could also improve the equivalent capacities quality even if it is possible to post process them for improvement.

PROBLEMATIC CLUSTERING SITUATIONS

In the process of reclustering, in some situations, it is quite difficult to improve the result:

- A too dense network in some areas or
- A geographical boundary which by definition cannot be moved. In that case, the only possibility is to try to modify the clustering inside countries. On the interconnections, the only possible modification would be to separate the border into two or several more and that would mean creating a new zone at least in one of the countries. As the number of zones has also to be limited, that is not an acceptable solution in any case.
- An area with triple border. In that case, it is impossible to ensure a good reduction quality on all the borders.
- Constraints on a series of lines: When several lines are constrained, it is necessary to choose to capture the most critical one which will be on the interzone.
- A lack of information on the 110 kV grid: That can be problematic when on an interzone there are only 110 kV lines without enough description. The clustering has then to be readapted to avoid that kind of situations.

RESULTS OF THE RECLUSTERING

The table below gives the results of the clustering process for 3 steps:

- Beginning of the process (iteration 0) with the initial clustering: **IoSN TYNDP 2020 version**
- Intermediate step (iteration 11) after the adjustments based on the quality of grid reduction and before the adjustments for capacities: **Step before iteration for capacity**
- End of the process (iteration 13) after the adjustments for capacities: **Proposal for TYNDP 2022**

Only the countries with modification of their initial clustering are presented on the table below. For the other countries, there has been no update of the TYNDP 2020 clustering.

- ➢ Countries whose number of zones decrease
- ➢ Countries whose number of zones increase
- ➢ Countries with same number of zones but with border adjustements

Table 4 : Number of zones in the clustering

Countries with modifications	IoSN TYNDP 2020 version	Step before iteration for capacity	Proposal for TYNDP 2022
Portugal	2	3	2
Spain	11	11	10
France	14	16	16
Germany	7	11	11
Switzerland	2	4	2
Austria	3	4	4
Belgium	3	3	3
The Netherlands	1	5	5
Poland	5	5	5
Total	**92**	**106**	**102**

Number of zones per country in each clustering.

In the version of the proposal, the number of zones is compared with the version of the IoSN TYNDP 2020.

The arrows indicate the evolution of the number of zones compared to TYNDP 2022 IoSN clustering (increases, decreases or remain the same).

Compared to the intermediate stage, the final proposal includes:

- A decrease of zones in Switzerland, Spain and Portugal
- In Germany and the Netherlands an increase of the number of zones which is **considered necessary** in order to ensure a good quality in several other countries.

In the iterations for the capacities, if an increase of the zones in one country had an acceptable impact on the grid reduction but decreased significantly the capacity quality, the modification was rejected. On the other hand, if adding a zone was very interesting for the capacity but affected negatively the grid reduction, it was also rejected. Hence, a compromise had to be found between keeping the number of zones and having an average good quality for grid reduction but a much better quality of capacity compared to the situation with more zones. It was the case for Portugal (2 zones were finally kept and not 3 to be average on grid reduction and also on capacities). It was also the case for Spain (from 11 to 10) and for Switzerland (from 4 to 2).

o RESULTS ON GRID REDUCTION (RMSE)

After all these adjustments, the quality obtained on grid reduction and based on RMSE is given below, in comparison with the same results in TYNDP 2020:

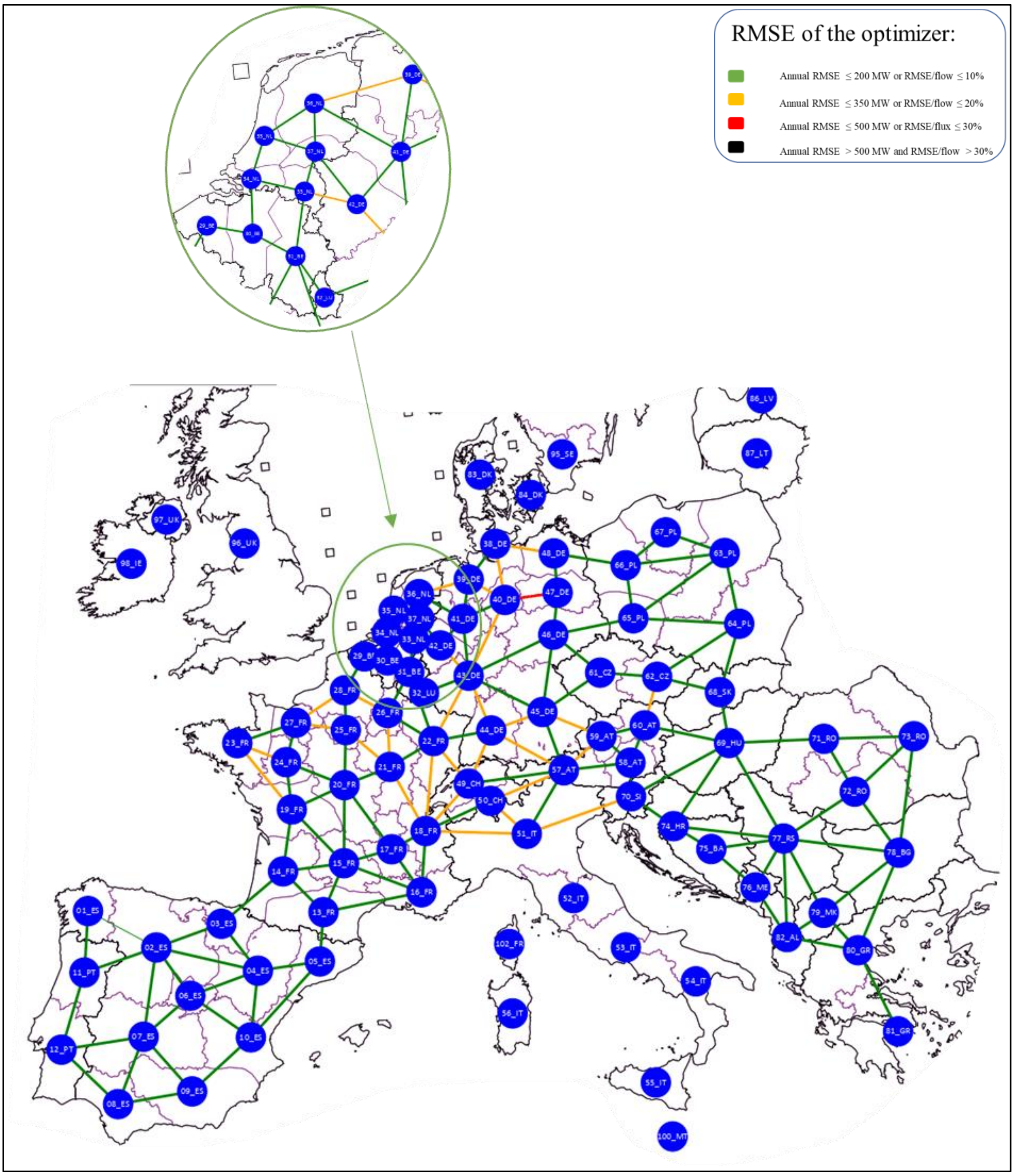


*Figure 8: RMSE of TYNDP **2022** IoSN Zonal Clustering (Proposal)*

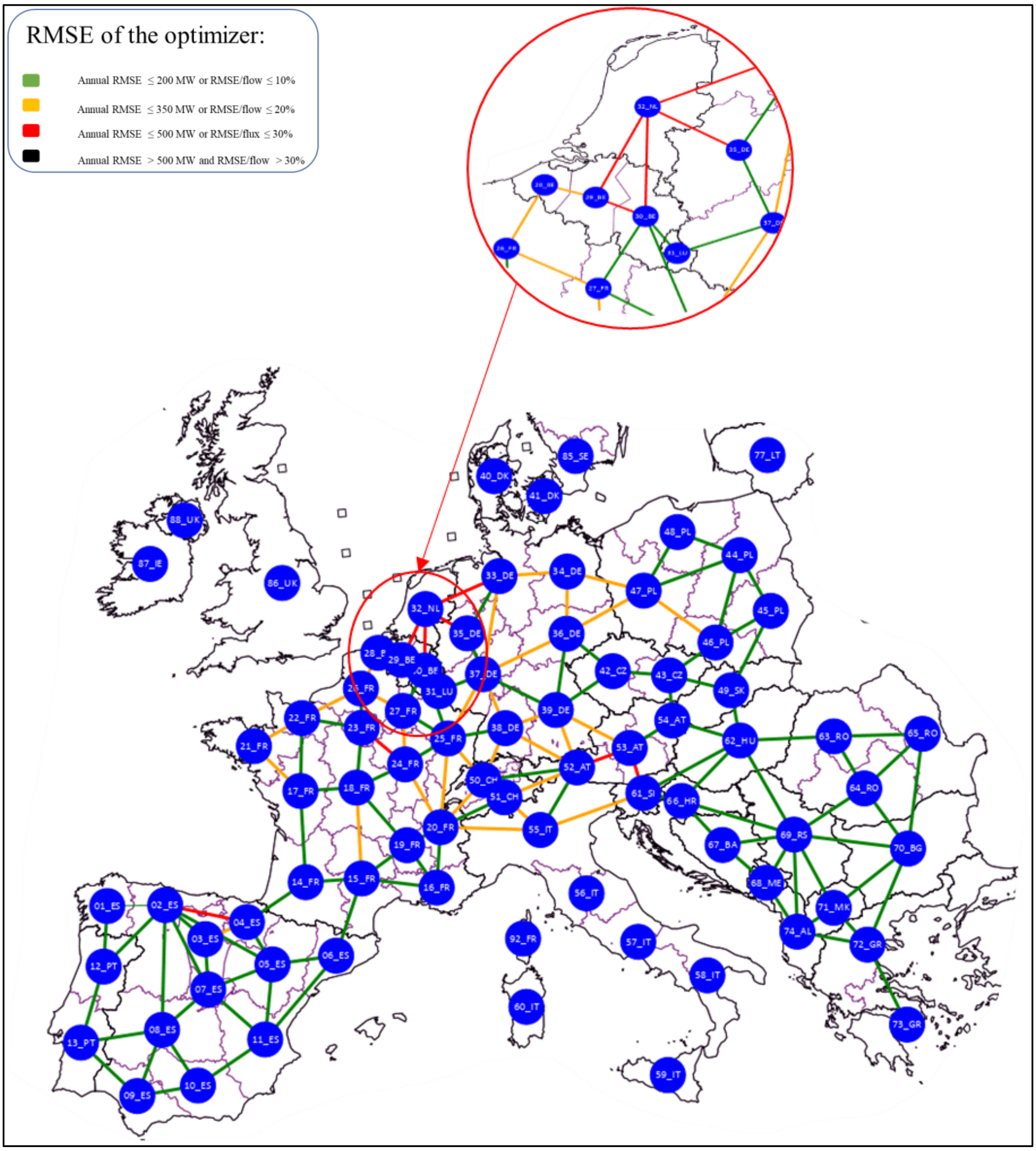


*Figure 9: RMSE of TYNDP **2020** IoSN Zonal Clustering*

The results show that compared to TYNDP 2020 clustering, it has been possible to highly improve the grid reduction quality (based on RMSE), especially on the interconnections. There is no more red RMSE (areas around Belgium, Germany, Netherlands and on the border Austria-Slovenia).

Inside countries, there also is a big general improvement (for example in Poland, Spain, Germany and France).

In some countries, only with some internal modifications of the interzones, it has been possible to enhance the clustering without increasing the number of zones.

A focus on the area of Netherland-Germany-Belgium shows that the number of zones has been obtained after several iterations by modifying the borders. The number of zones has been increased only when it was mandatory. This area is very specific because of the different size of countries inside it. Germany, a very wide country, is linked to smaller ones (Belgium and Netherlands). The behavior of each of these countries can significantly affect that of the others. In addition, in the Netherlands it was mandatory to separate the interzones with Germany North and South, and the ones with Belgium East and West in order to ensure a good quality. Finally, it was unavoidable to separate into a specific zone the Southwestern part of the Netherlands with offshore generation which is globally always exporting and does not behave in the same way than the rest of the country. All these points were the reasons for the splitting of the Netherlands into several zones otherwise it would not have been possible to improve the results in this area.

o Results on capacities

For the last iterations, the objective was to improve if possible the quality of equivalent capacities by keeping the quality obtained for the grid reduction.

For that, the quality of the capacity is analyzed and assessed for every country, as well as its evolution compared to the quality of TYNDP 2020 IoSN.

FINAL ADJUSTMENTS FOR TYNDP 2022

The clustering proposal explained previously has been used in IoSN TYNDP 2022 in the NT2030 zonal model. The first results have shown a decrease of the quality for the Austrian internal borders. Then, the Austrian zones have been kept but there have been few modifications on the interzone: some substations have been moved to another zone in order to take off the internal interzone between 58_AT and 59_AT.

The final clustering used in TYNDP 2022 is below (it has been completed with the other zones like MedTSO ones even if they are not influenced by the zonal clustering).

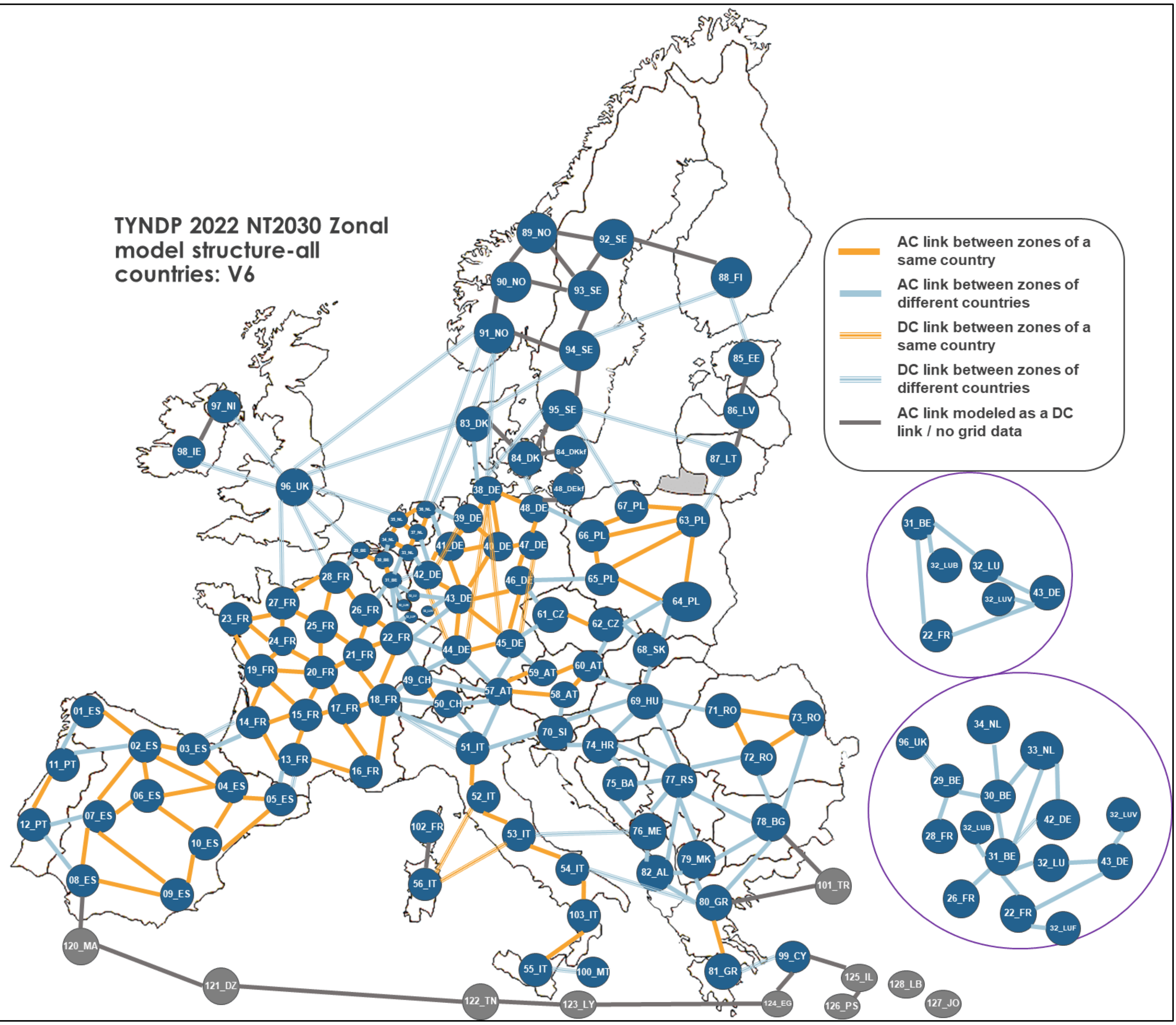


Figure 10. TYNDP 2022 Zonal clustering

The table below gives the number of zones per country:

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

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

Table 5. Number of zones per country

GENERATION AND LOAD ASSUMPTIONS AT ZONAL LEVEL

The objective of this part is to allocate generation and load at every zone, according to the clustering defined 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 proportionally to the ConformLoad in every subzone

$$DemandTimeseries(subzone) = (DemandTimeseries(zone) - NonConformLoad(zone)) * ConformLoad(subzone)/ConformLoad(zone) + NonConformLoad(subzone)$$

For dispatchable generation, the capacity allocation per zone can be based on the merged grid model, which normally matches with the PEMMDB data per country, and <u>per zone</u>. With the location provided in the PEMMDB files for each generation power plant, the generation per zone should be easily known. However, 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 would be very interesting to have a common approach based on a climate data base and the construction of transfer functions in every zone. For this exercise, a methodology of splitting has to be defined and scripts developed in order to massively establish them. However, if case that is not possible or does not fit within the IoSN timeline, the alternative to infer the zonal times series from the country level time series by scale factor.

<u>For DSR:</u>

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.

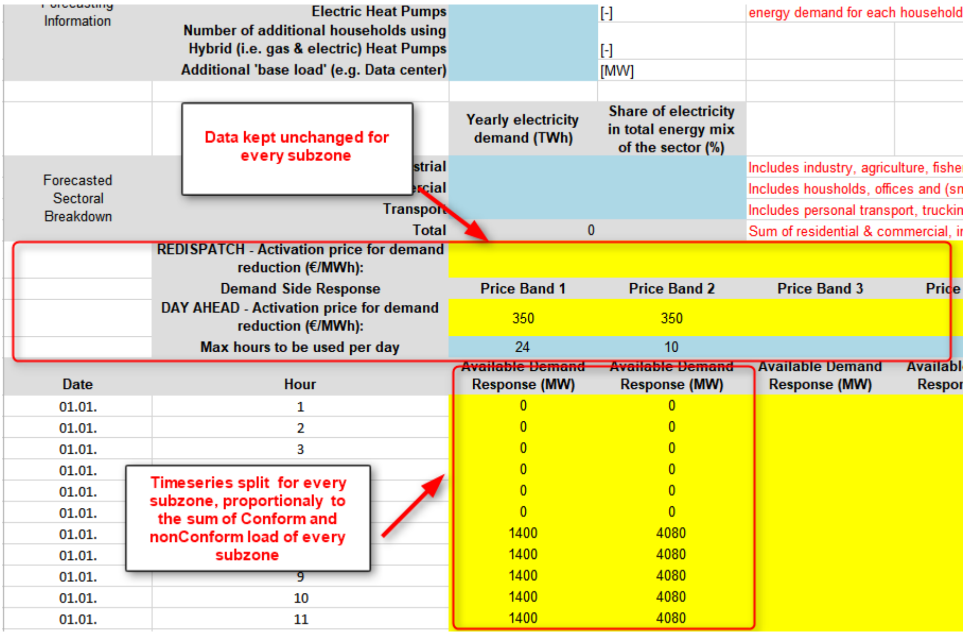


Figure 11 Demand and DSR Dataset Structure

For Battery:

Installed market participating Battery storage capacities (output, MW)

Installed market participating Battery storage capacities (storage, MWh)

These data will be split proportionally to the whole load (conform load + non conform load) of every subzone.

For 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.

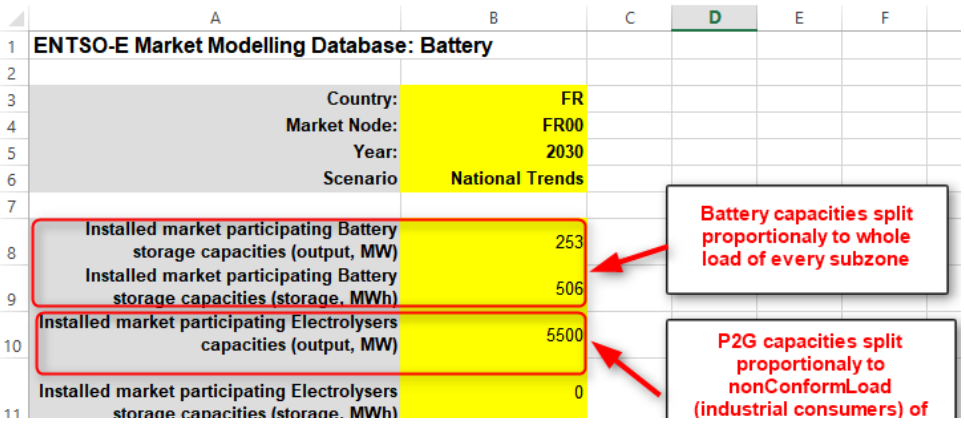
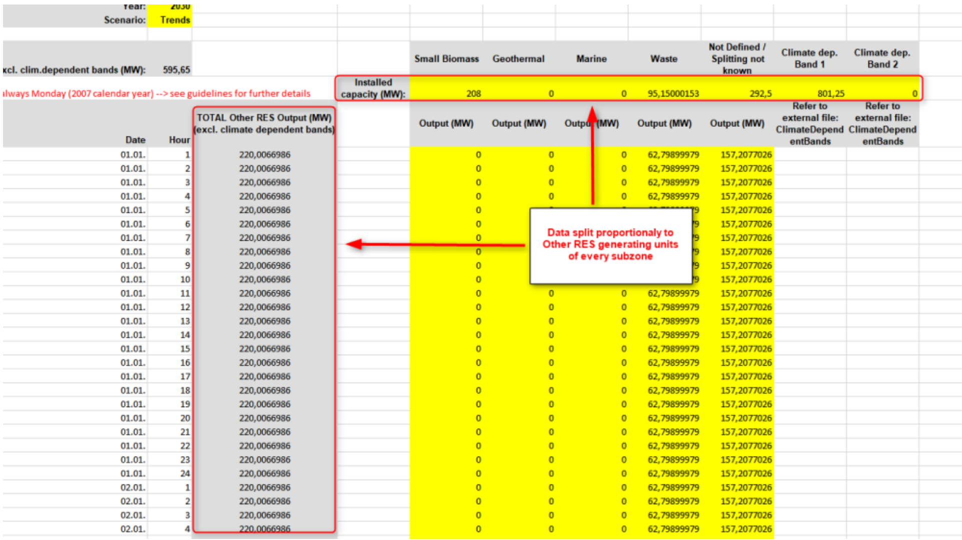


Figure 12 Battery and P2G data structure

For Other RES splitting¶



Year:	2030									
Scenario:	Trends									
xcl. clim.dependent bands (MW):	595,65			Small Biomass	Geothermal	Marine	Waste	Not Defined / Splitting not known	Climate dep. Band 1	Climate dep. Band 2
lways Monday (2007 calendar year) --> see guidelines for further details			Installed capacity (MW):	208	0	0	95,15000153	292,5	801,25	0
Date	Hour	TOTAL Other RES Output (MW) (excl. climate dependent bands)		Output (MW)	Output (MW)	Output (MW)	Output (MW)	Output (MW)	Refer to external file: ClimateDependentBands	Refer to external file: ClimateDependentBands
01.01.	1	220,0066986		0	0	0	62,79899979	157,2077026		
01.01.	2	220,0066986		0	0	0	62,79899979	157,2077026		
01.01.	3	220,0066986		0	0	0	62,79899979	157,2077026		
01.01.	4	220,0066986		0	0	0	62,79899979	157,2077026		
01.01.	5	220,0066986		0	[illegible]	[illegible]	[illegible]	157,2077026		
01.01.	6	220,0066986		0	[illegible]	[illegible]	[illegible]	157,2077026		
01.01.	7	220,0066986		0	[illegible]	[illegible]	[illegible]	157,2077026		
01.01.	8	220,0066986		0	[illegible]	[illegible]	[illegible]	157,2077026		
01.01.	9	220,0066986		0	[illegible]	[illegible]	[illegible]	157,2077026		
01.01.	10	220,0066986		0	[illegible]	[illegible]	[illegible]	157,2077026		
01.01.	11	220,0066986		0	0	0	62,79899979	157,2077026		
01.01.	12	220,0066986		0	0	0	62,79899979	157,2077026		
01.01.	13	220,0066986		0	0	0	62,79899979	157,2077026		
01.01.	14	220,0066986		0	0	0	62,79899979	157,2077026		
01.01.	15	220,0066986		0	0	0	62,79899979	157,2077026		
01.01.	16	220,0066986		0	0	0	62,79899979	157,2077026		
01.01.	17	220,0066986		0	0	0	62,79899979	157,2077026		
01.01.	18	220,0066986		0	0	0	62,79899979	157,2077026		
01.01.	19	220,0066986		0	0	0	62,79899979	157,2077026		
01.01.	20	220,0066986		0	0	0	62,79899979	157,2077026		
01.01.	21	220,0066986		0	0	0	62,79899979	157,2077026		
01.01.	22	220,0066986		0	0	0	62,79899979	157,2077026		
01.01.	23	220,0066986		0	0	0	62,79899979	157,2077026		
01.01.	24	220,0066986		0	0	0	62,79899979	157,2077026		
02.01.	1	220,0066986		0	0	0	62,79899979	157,2077026		
02.01.	2	220,0066986		0	0	0	62,79899979	157,2077026		
02.01.	3	220,0066986		0	0	0	62,79899979	157,2077026		
02.01.	4	220,0066986		0	0	0	62,79899979	157,2077026		

Figure 13 Other RES Data Structure

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

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

For Other Non RES splitting

Extract from PEMMDB 2.3 (sheet Other Non-RES) the following data:

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 em. 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)

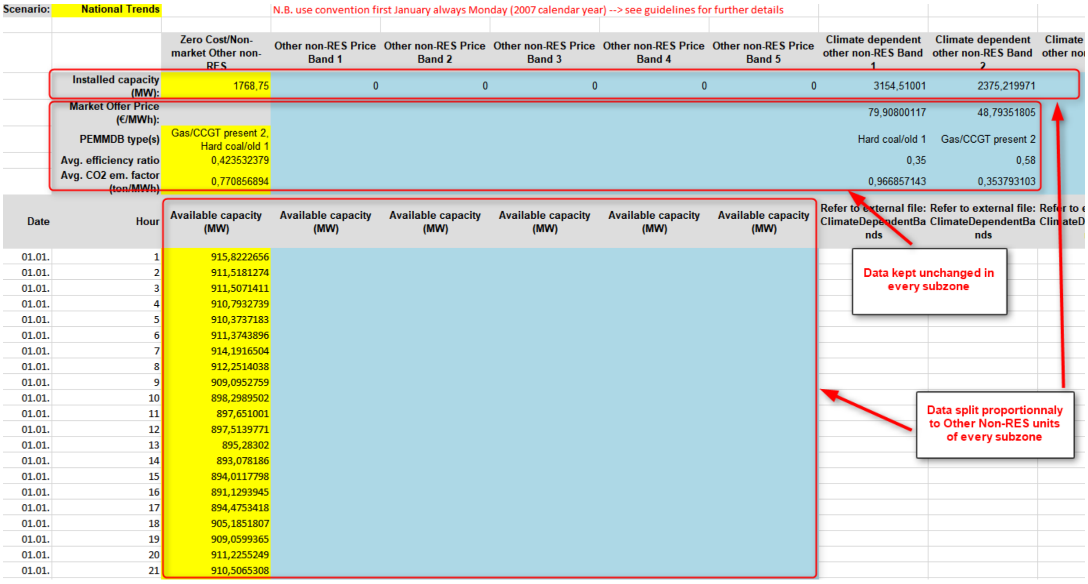


Figure 14 Other Non-RES Data Structure

5.2 Description of the Preparatory phase – 2040 Classic Study

IoSN 2040 uses a classical market study based on National Trends scenario of TYNDP 2022. Preparatory phase for 2040 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). The model is based on the prepared dataset in PEMMDB 2.3 format received as part of the Scenario Building process.

The composition of such dataset is explained more in detail in chapter 0 of this document.

5.3 Step-by-Step description of the Implementation phase

Implementation phase for 2030 time horizon

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

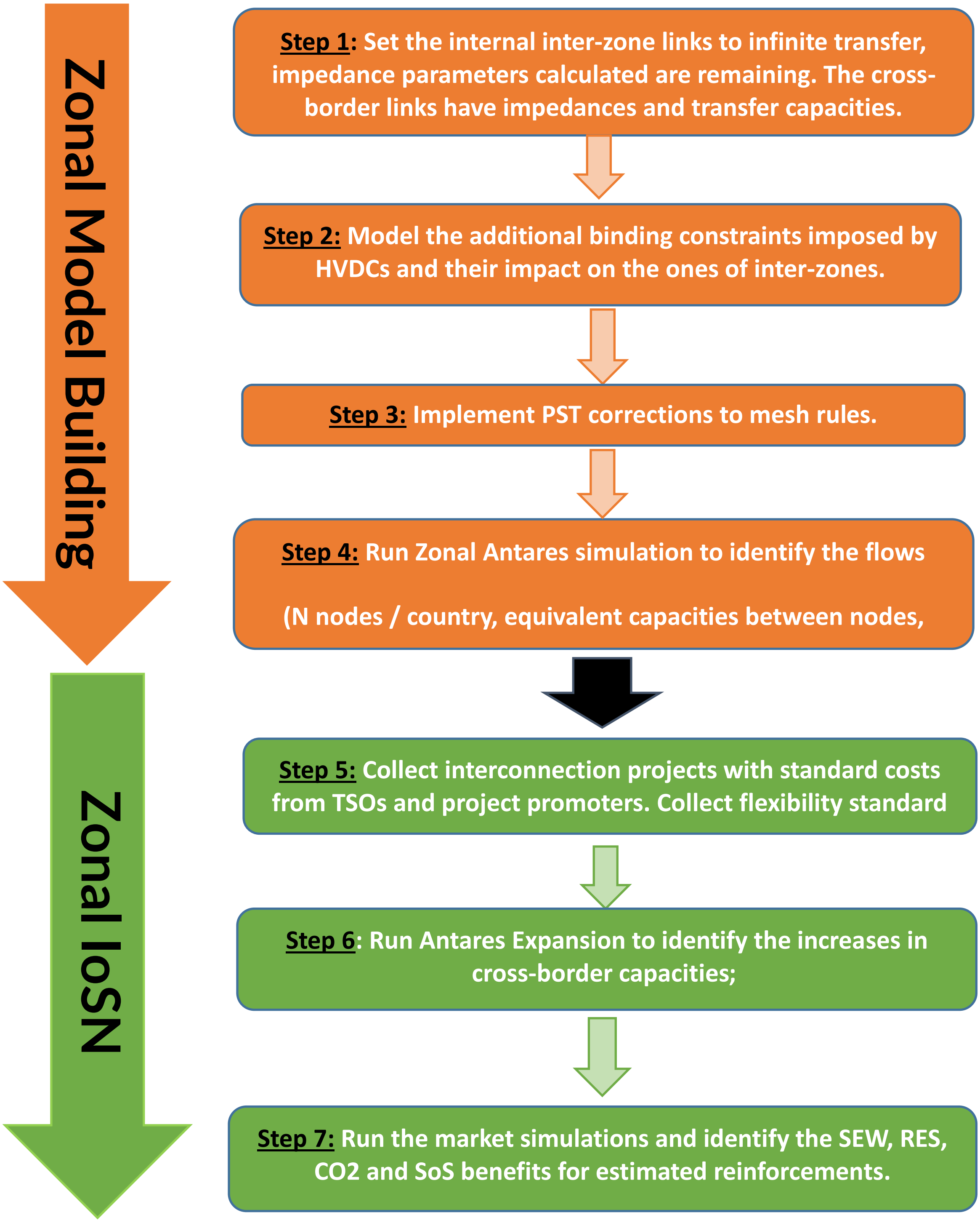


Figure 15 Step-by-Step IoSN Implementation phase process diagram

The steps are explained more in detail further in this chapter.

Step 1: Set the internal inter-zone links to infinite transfer capacity, impedance parameters are remaining. The cross-border links have impedances and transfer capacities.

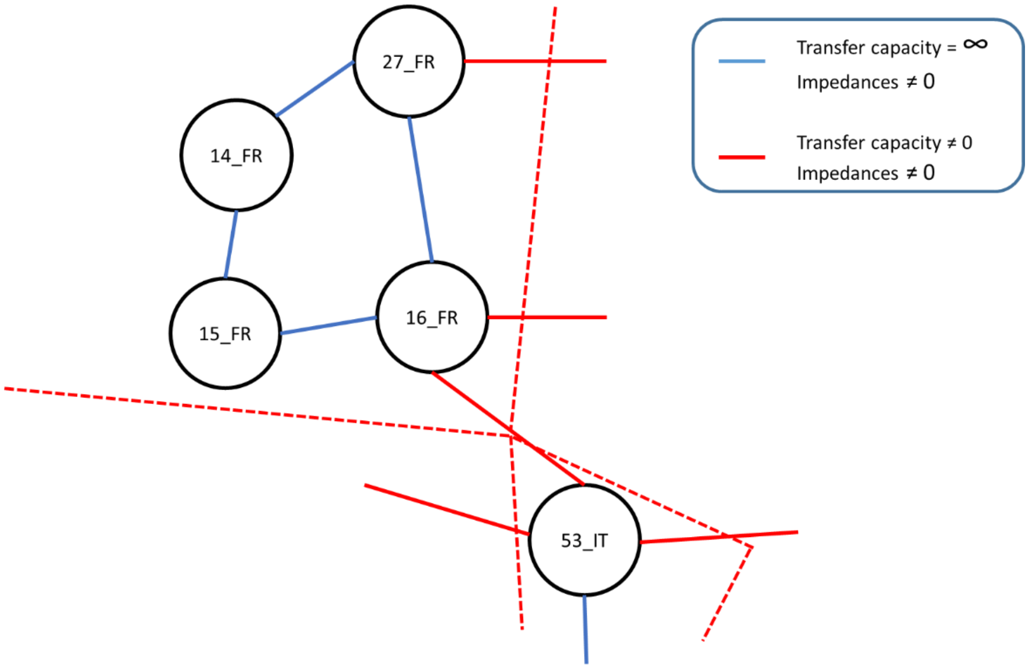


Figure 16 Starting assumptions for the Zone connections

The assumptions according to the Step 1 of the implementation phase are illustrated in 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.

Step 2: Additional binding constraints are imposed by HVDCs;

HVDC links have to be added separately into the model. There is no mesh rule on them, but they may require binding constraints too in some cases:

- To simulate an AC emulation for an HVDC,
- To specify a different direction of flow for several HVDCs 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).
- Plus, due to specific behaviour of HVDC links in the system, separate constraints have to be added to account for these system elements. For example, HVDCs have an impact on loop flows. If the impact is non-negligible and can strongly modify the flows, it may be interesting to implement it.

The impact on an interzone can be modelled this way:

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

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

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

Table 6. Impact in MW on each cross-border inter-zone for 100MW on the HVDC (impacts above 5% only) – scenario ST2040 of TYNDP 2018

Following this, instead of setting the capacities of A-B like this :

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

we have to write a new binding constraint which is:

$$\mathbf{- capa\_opposit_{A\text{-}B} - F0_{A\text{-}B} \leq Flow_{A\text{-}B} + k_{HVDC1 \rightarrow A\text{-}B} \, x \, Flow_{HVDC1} + k_{HVDC2 \rightarrow A\text{-}B} \, x \, Flow_{HVDC2} + \dots \leq capa\_direct_{A\text{-}B} - F0_{A\text{-}B}}$$

In addition, the HVDCs inside Germany have to be used in a classical way to calculate the flows. It is suggested to simulate them with AC emulation, as for the one 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 in this map:

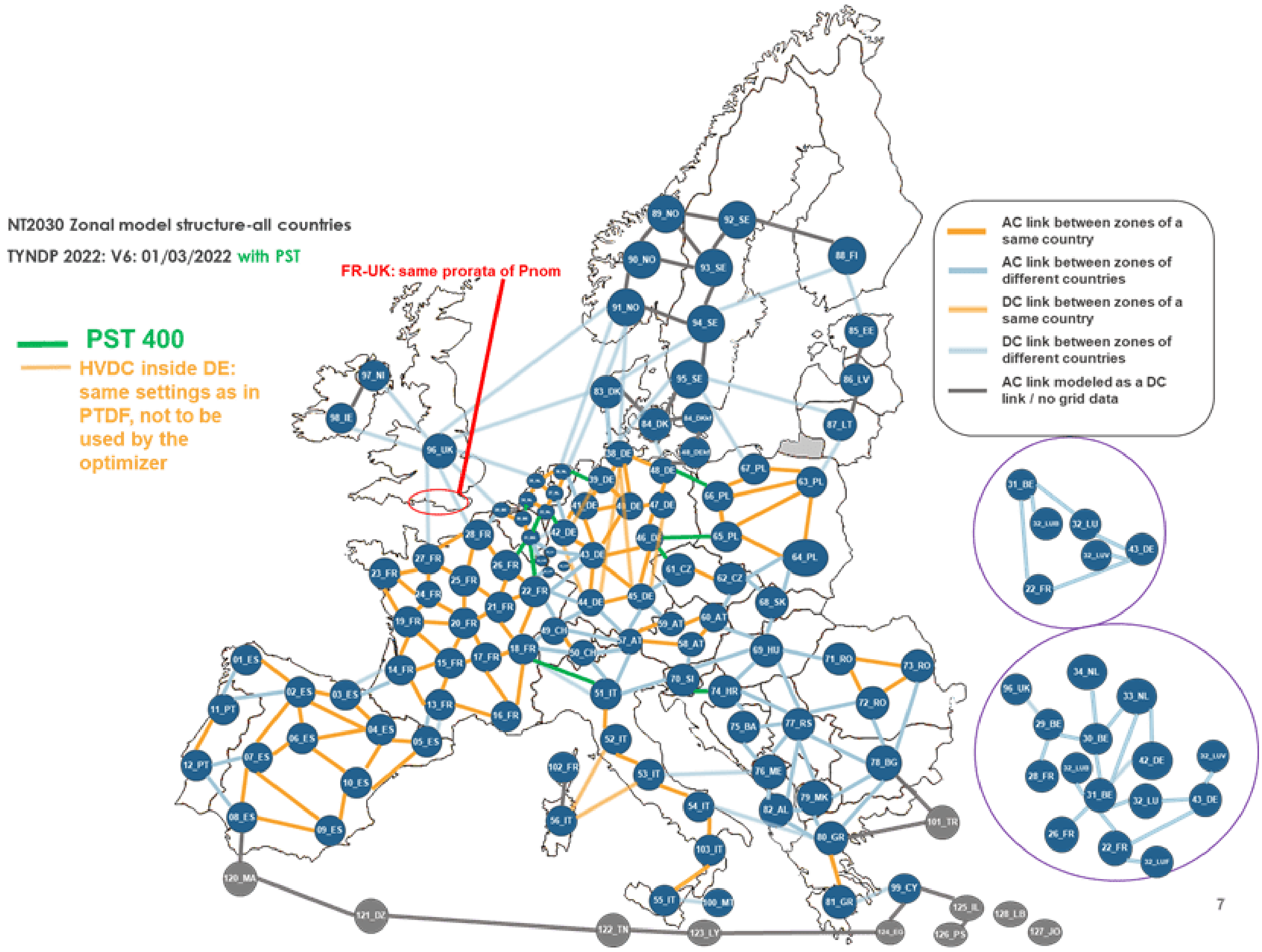


Figure 17 Location of the HVDCs and PSTs specifically modelled within Zonal Model 2030 NT

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

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

$$\mathbf{X_1.F_1 + X_2.F_2 + \ldots + X_n.F_n = 0}$$

becomes,

$$\mathbf{\varepsilon' \leq X_1.F_1 + X_2.F_2 + \ldots + X_n.F_n \leq \varepsilon,}$$

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

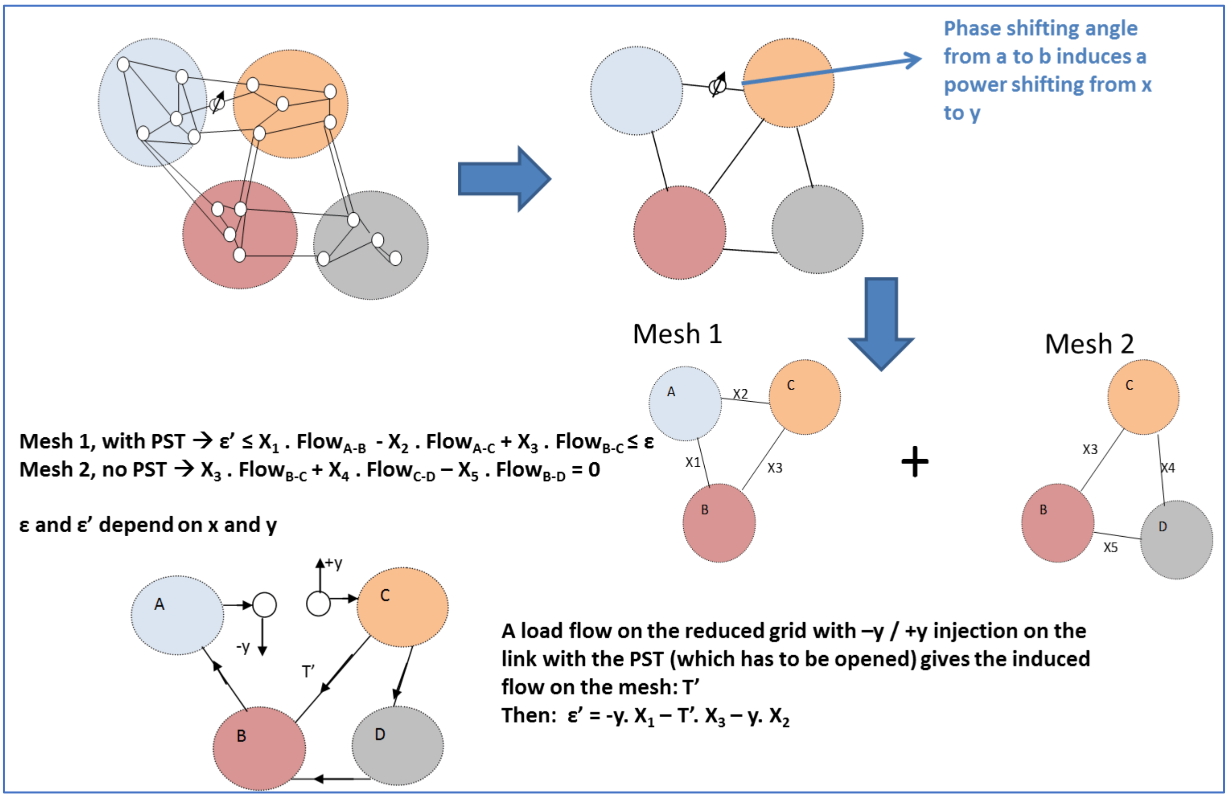


Figure 18 Modelling of PSTs using Kirchhoff mesh rule in Zonal Model 2030 NT

In case PSTs are meant to be used only when outages occur (curative actions only), they do not 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: 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.

Step 5: Collect interconnection projects with standard costs from TSOs and project promoters.

The collection process is described in chapter 7 of this document.

The list of investment candidates is available as an Appendix.

Step 6: Implement the candidate project parameters (standard costs) into Expansion.

The candidate projects have been implemented in the Antares Xpansion[1] module 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 with the following formula :

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

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

Step 7: Run the Antares Expansion to identify the increases in the cross-border capacity;

The "Capacity Expansion" problem consists of finding 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. It 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. IoSN 2030 studies with this method only cross-border interzone investments; no retirements or generation investments or divestments.

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

[1] *More information on the User Guide of Antares Xpansion webpage.*

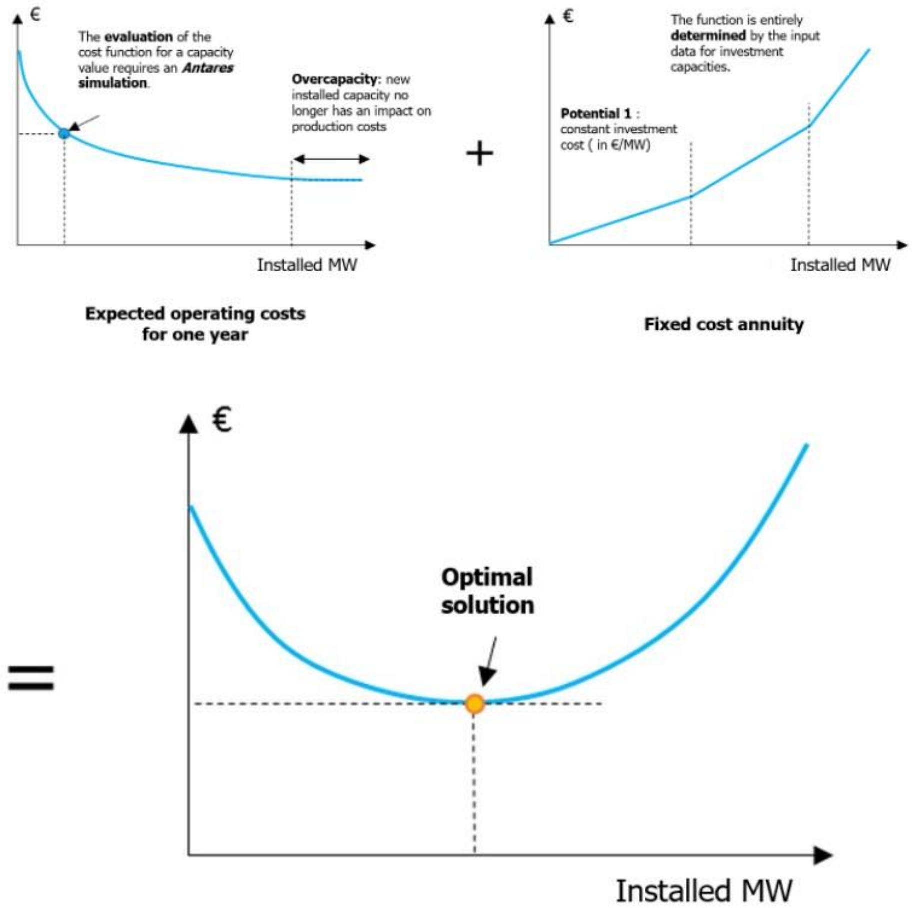


Figure 19 Expansion optimization principle

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 realised 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.

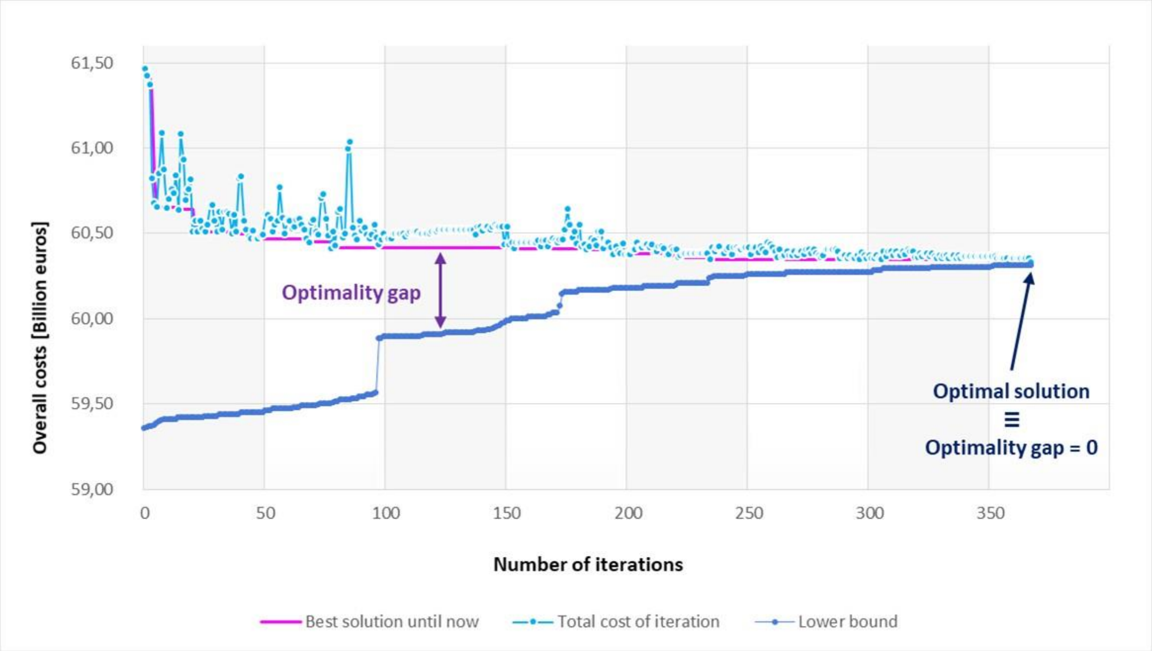


Figure 20 Example of evolution of optimality gap over Antares Xpansion iterations

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, we need to:

- Specify the Xpansion settings: type of simulation, optimaliy gap, additional constraints file name, Monte Carlo year weights file name.

- Create line candidates for each interconnection candidates and specify their expansion properties:
  - the related cross-border interline
  - its already installed capacity
  - the project capacity
  - the project annualized costs
- Create the Xpansion additional constraints file specifying if projects are linked together and must be simultaneaously invested in.

- 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.

Implementation phase for 2040 time horizon

In general, the implementation phase for the NTC IoSN process can be described in 5 consecutive steps as visible in Figure 21:

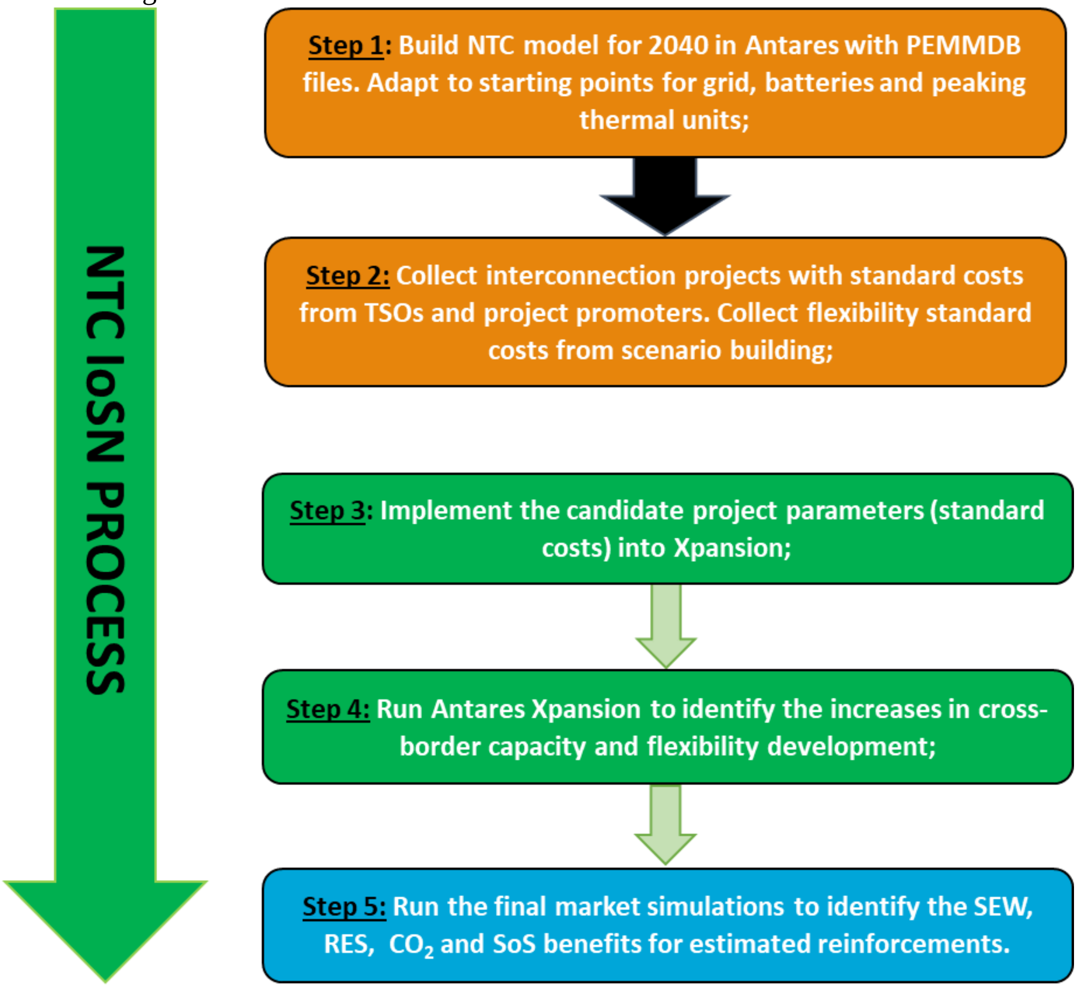


Figure 21 : Step-by-Step NTC IoSN implementation phase process diagram

The steps are explained more in detail further in this chapter.

Step 1 : Build NTC model for 2040 in Antares with PEMMDB files. Adapt to starting points for grid, batteries and peaking thermal units;

IoSN 2040 is based on NT 2040 scenario with a 2025 starting grid with the exception of countries split in different bidding zones (detailed hereafter). The model is built with PEMMDB 2.3 data for this scenario except for batteries and peaking thermal units (OCGT and light oil).

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

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)

IoSN 2040 studies the interactions between cross-border grid investments, storage investments and peaking investments. Starting point for storage was set to NT 2030 levels for batteries, meaning that all batteries commissioned between NT 2030 and NT 2040 scenarios were taken out of the IoSN.

Peaking flexibility – particular case of thermal peaking units (NT 2030 starting point)

Like for storage, peaking starting point is set to NT 2030 levels. However, between NT 2030 and NT 2040, thermal peaking units are usually decommissioned rather than new ones being commissioned. IoSN studies only optimal investments to reach climate goals and not decommissioning, therefore, starting point for peaking units was chosen as follows :

- If peaking thermal units are decommissioned between NT 2030 and NT 2040 which means that peaking thermal unit capacities are lower in 2040 than 2030, then starting point is NT 2040 case.

- If peaking thermal units are commissioned between NT 2030 and NT 2040, the investments are studied in the IoSN. Therefore, the starting point is NT 2030 and peaking capacity is proposed to the optimizer.

In other words, the lowest installed capacity for thermal generation case is always the starting case.

Ex. In PL00, IoSN 2040 OCGT new are reduced from 3 600 MW to 0 MW and peaking capacity is proposed to the optimiser (see step 4).

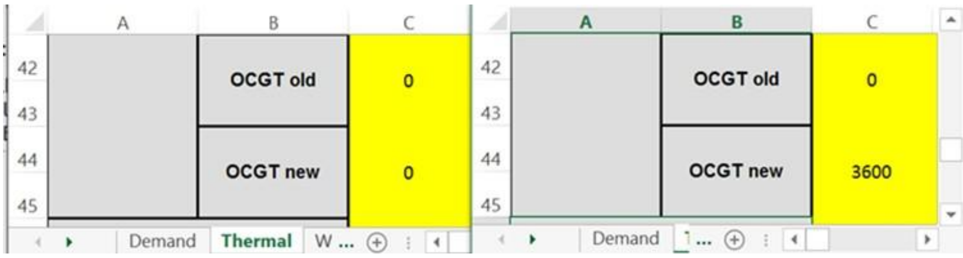


Figure 22 NT 2030 PEMMDB "Thermal" tab for PL00 (left) and NT 2040 PEMMDB "Thermal" tab for NL00 (right).

Step 2 : Collect interconnection projects with standard costs from TSOs and project promoters. Collect flexibility trajectories with standard costs from scenario building;

The collection process is described in chapter 7 of this document.

Steps 3 : Implement the candidate project parameters (standard costs) into Expansion;

The candidate projects have been implemented in the Antares Xpansion module 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 with the following formula:

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

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

Storage and peaking assumptions are based on scenario building assumptions[2] found below :

Flexibility	CAPEX (k€/MW)	OPEX (k€/y/MW)	Discount rate	Lifetime (years)
Storage	430	14,1	6%	25
Peaking	424	7,6	6%	25

Table 7. Storage and peaking assumptions

Steps 4 : Run Antares Expansion to identify the increases in cross-border capacity and flexibility development;

The “Capacity Expansion” problem consists of finding 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. It 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. IoSN 2030 studies with this method only cross-border interzone investments; no retirements or generation investments or divestments.

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

[2] *Assumptions form scenario building, see Scenario Report.*

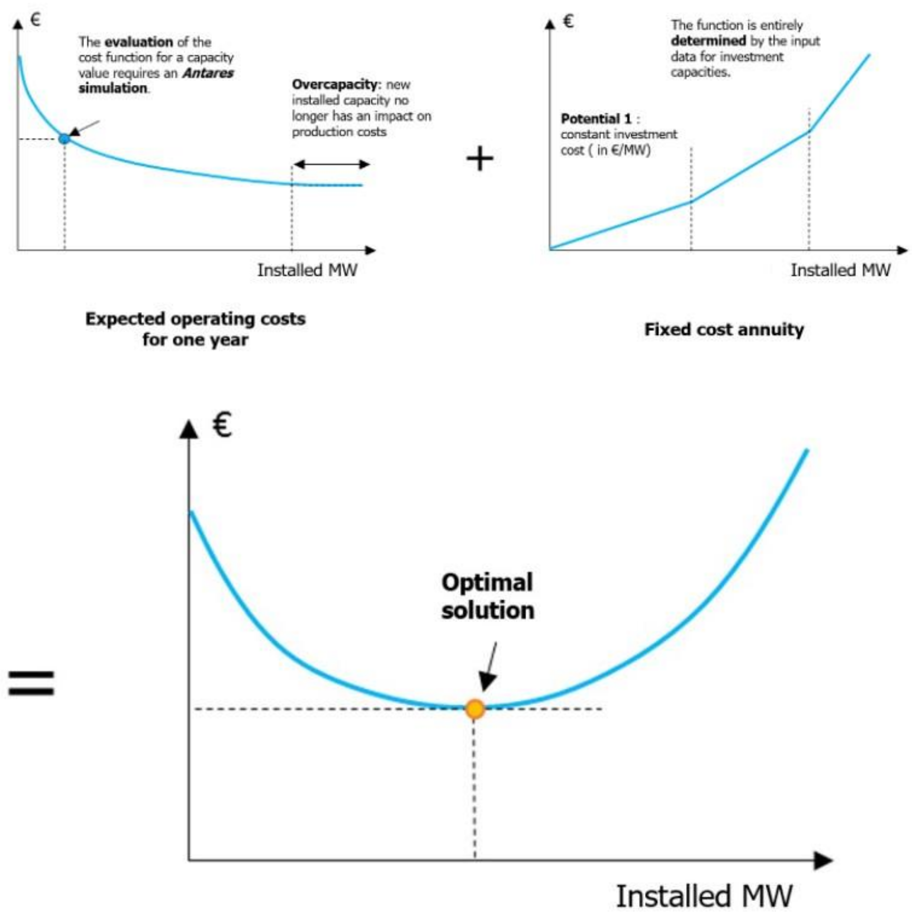


Figure 23 Expansion optimization principle

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 realised 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 a next iteration.

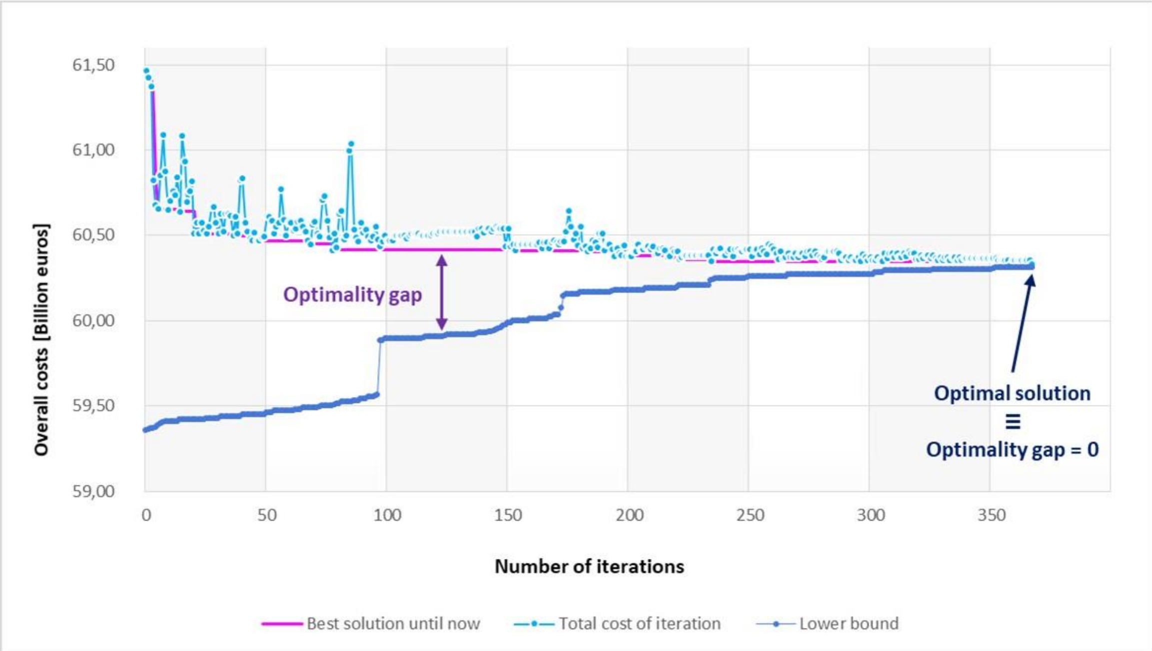


Figure 24 Example of evolution of optimality gap over Antares Xpansion iterations

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 and peaking candidates for each country and specify their expansion properties:
  5. the country
  6. the maximum capacity
  7. the annualized costs

- Create the Xpansion additional constraints file specifying if projects are linked together and must be simultaneaously invested in.

- Specify the weights of each Monte Carlo year in a specific file.

The optimization problem is more complex when additional investment candidates, binding constraints bonding candidates and Monte Carlo years are added.

Steps 5 : Run the NTC starting point and final simulations and identify the RES, Security of Supply, 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 CO_2 (in million tons) and avoided curtailment (in TWh). In IoSN 2040 of TYNDP 2022, benefits to security of supply needs are also studied. It is important to note that this is not a thorough security of supply study which should be performed on a much higher number of stress situations for the system.

6. REQUIREMENTS FOR THE MODELS

6.1 Scenario Models

Market Models

The planned Scenarios to be used for the Identification of the System Needs phase are:

- 2040 NT
- 2030 NT

Network Models

There is clear requirement to prepare 1 network model which should be used for the Zonal IoSN process:

- IoSN NT 2030: 2025 network model from TYNDP 2020

Network model update (TYNDP 2022 CBA reference to 2025 MAF)

Because of the complexity of a zonal Modelling and also because IoSN is the first step of TYNDP, a previous model has to be used. That model is consistent with the reference grid defined for the TYNDP (for example: 2025 MAF NTCs for TYNDP2020). After some other update, the grid model is used to establish a zonal model for the base case of the study.

Climatic conditions under investigation

For the Identification of the System Needs study, the technical team took the decision to use similar approach for the definition of the climatic years for the study as the one used 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.

6.2 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[3] 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;

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

- **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:

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

Bidding Zones are then grouped into relevant macro regions according to the procedure adopted in the TYNDP (Figure 25). 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					

Table 8. Macro Regions from TYNDP

6.3 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 25 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 25. Overview of the approach for the definition of representative years/weeks

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.

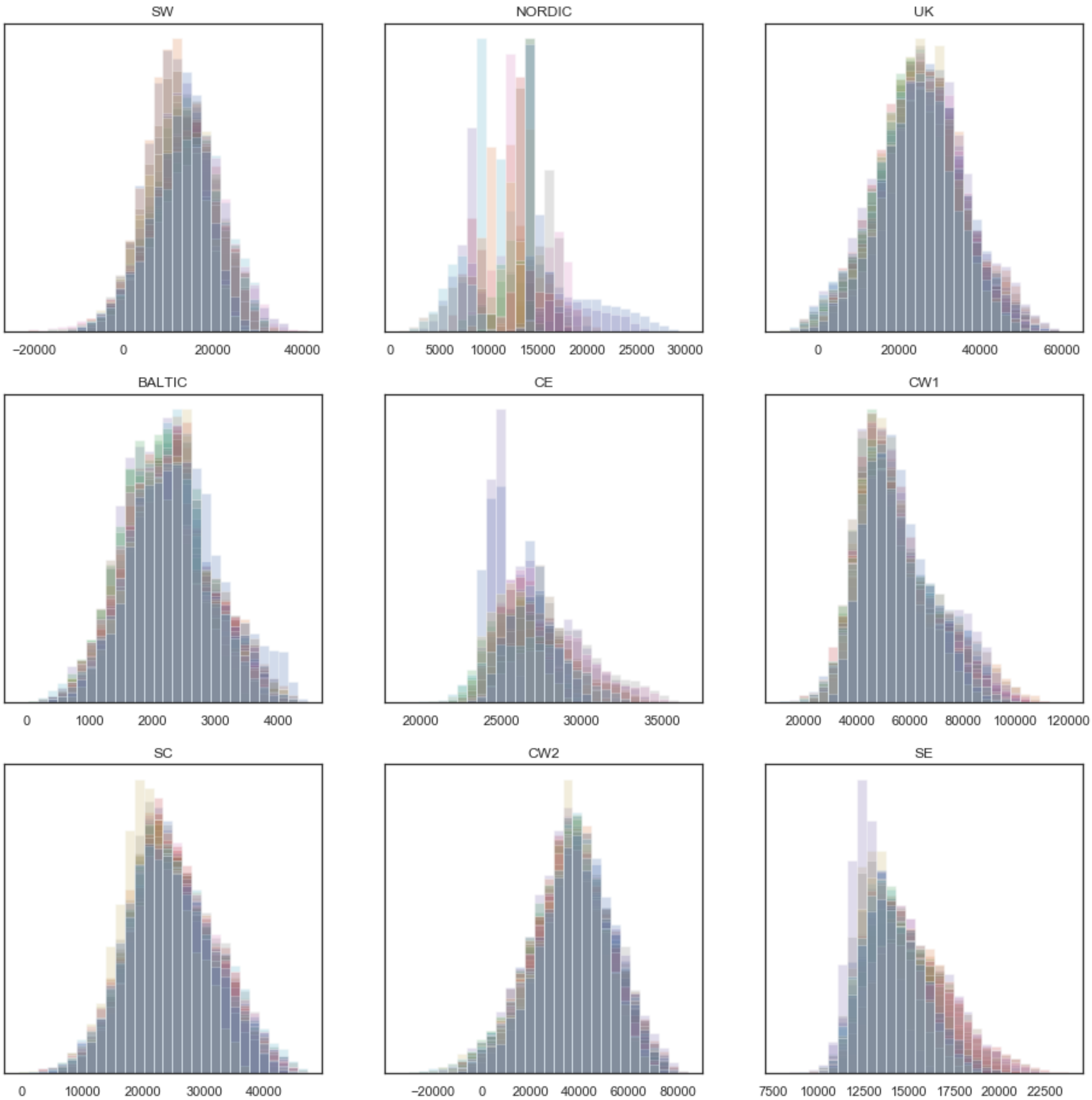


Figure26: Distributions of residual load per region and year (each year is one color; x-axis: residual load in MW, y-axis: occurrences)

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:

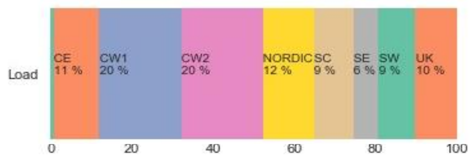


Figure 27: Weighting factors

Selection of candidate combination

The selection of the candidate combination done in a two-step process, as shown in Figure 28.

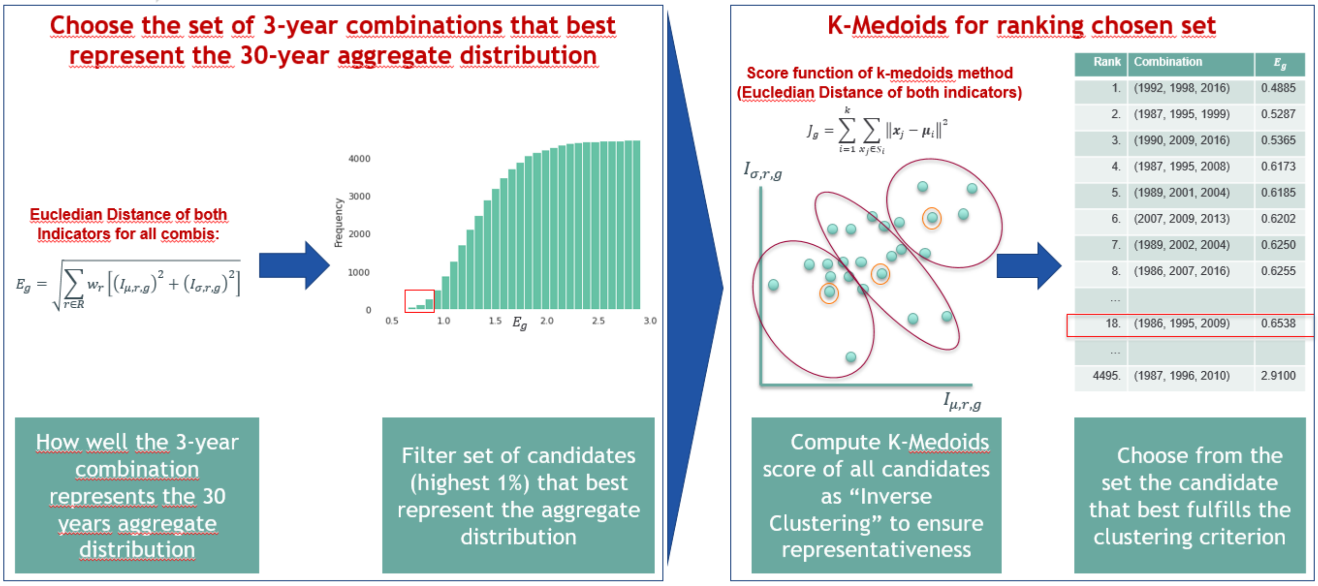


Figure 28: Two step-process for the selection of the representative candidate

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 assessed. 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”).

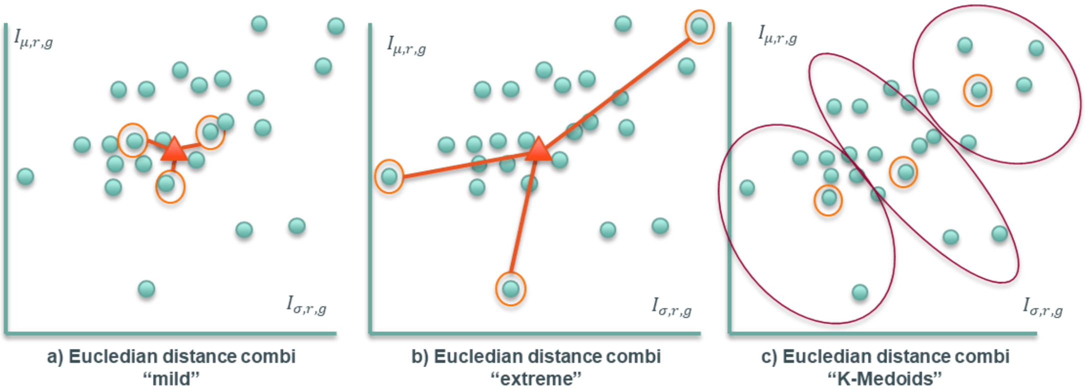


Figure 29. Examples on the selection of representative candidates

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 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:

Season	Number of the weeks
Winter	1-9; 49-52
Spring	10-22
Summer	23-35
Autumn	36-48

Table 9 – Selected week candidates per season

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.

7. SELECTION OF IOSN INVESTMENT CANDIDATES

Flexibility standard costs have been set as part of TYNDP 2022 scenarios, in accordance with the TYNDP 2022 Scenarios Building Guideline. (https://2022.entsos-tyndp-scenarios.eu/wp-content/uploads/2022/04/TYNDP_2022_Scenario_Building_Guidelines_Version_April_2022.pdf)

Collection data was done in early stage in order to cover all the borders, all the cases and also allow the possibility to iterate with Project Promoters.

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 crossborder potential capacity increases is 500 MW.
Hybrid projects (crossborder potential capacity increases) are not in the scope of IoSN (see Appendix 2 List of investment candidates).

APPENDIX 1. STARTING GRID OF THE STUDY

The following table lists all projects expected to be commissioned around 2025 and considered in the starting grid on top of the existing grid in late 2021.

TYNDP ID	Project name	Border	NTC (A->B) 2025	NTC (B->A) 2025
4	Interconnection Portugal-Spain	ES00-PT00	1900	1000
13	Baza project	internalES00	0	600
16	Biscay Gulf	ES00-FR00	2200	2200
21	Italy-France	FR00-ITN1	1200	1000
23	FR-BE I: Avelin/Mastaing-Avelgem-Horta HTLS	BE00-FR00	1000	1000
26	Reschenpass Interconnector Project	AT00-ITN1	300	300
33	Central Northern Italy	ITcn-ITN1	400	400
33	Central Northern Italy	ITCN-ITCS	0	0
48	New SK-HU intercon. - phase 1	HU00-SK00	800	1300
62	Estonia-Latvia 3rd IC	EE00-LV00	1100	1100
75	Modular Offshore Grid (MOG)	InternalBE	0	0
77	Anglo-Scottish -1	internalUK00	0	0
78	South West Cluster	internalUK00	0	0
81	North South Interconnector	IE00-UKNI	1120	1120
85	Integration of RES in Alentejo	internalPT00	0	0
94	GerPol Improvements	DE00-PL00	500	1500
103	Reinforcements Ring NL phase I	DE00-NL00	600	600
123	LitPol Link Stage 2	LT00-PL00	500	500
134	N-S Western DE_section South	internalDE00	0	0
135	N-S Western DE_parallel lines	internalDE00	0	0
138	Black Sea Corridor	BG00-RO00	600	600
142	CSE4	BG00-GR00	930	600
167	Viking DKW-GB	DKW1-UK00	1400	1400
172	ElecLink	FR00-UK00	1000	1000
173	FR-BE II: PSTs Aubange-Moulaine	BE00-FR00	500	500
183	"DKW-DE, Westcoast"	DE00-DKW1	1000	1000
186	east of Austria	internalAT00	2000	2000
191	OWP TenneT Northsea Part 2	internalDE00	0	0
197	N-S Finland P1 stage 2	internalFI00	1000	1000
200	CZ Northwest-South corridor	CZ00-DE00	500	500

203	Morella-La Plana (previosly Aragón-Castellon)	internalES	600	1100
208	N-S Western DE_section North_1	internalDE	0	0
209	Reinforcement Northeastern DE	internalDE	0	0
219	EuroAsia Interconnector- stage 1 of investment 1410 (GR03-GR)	GR03-GR00	1000	1000
228	Muhlbach - Eichstetten	DE00-FR00	300	300
230	GerPol Power Bridge I	DE00-PL00	1500	500
236	Internal Belgian Backbone West: HTLS upgrade Horta-Mercator	InternalBE	0	0
245	Upgrade Meeden - Diele	DE00-NL00	300	300
251	Audorf-Dollern	DKW1-DE00	1000	700
254	Ultranet	internalDE00	0	0
255	Connection Navarra-Basque Country	InternalES	1100	600
258	Westcoast line	InternalDE	500	500
262	Belgium-Netherlands: Zandvliet-Rilland	BE00-NL00	1000	1000
269	Uprate the western 220kV Sevilla Ring	ES00-PT00	0	500
297	BRABO II + III	BE00-NL00	0	1000
312	St. Peter - Tauern (AT internal)	AT00-DE00	2000	2000
313	Isar/Altheim/Ottenhofen (DE) - St.Peter (AT)	AT00-DE00	2000	2000
320	Slovenia-Hungary/Croatia interconnection	HU00-SI00	1200	1200
336	Prati (IT) – Steinach (AT)	AT00-ITN1	90	90
337	Conneforde-Merzen	internalDE00	0	0
348	NoordWest380 NL	DE00-NL00	150	150
378	Transformer Gatica	internalES00	0	0
379	Uprate Gatica lines	internalES00	0	0
1055	Interconnection of Crete to the Mainland System of Greece	GR03-GR00	800	800

APPENDIX 2. INVESTMENT CANDIDATES (CAPACITY INCREASES) – CAPACITIES AND COST ASSUMPTIONS

The following capacity increases were proposed to the optimiser.

The capacity increases listed in this appendix include projects in the TYNDP 2022 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	Node from	Node to	Direct capacity increase (in MW)	Indirect capacity increase (in MW)	CAPEX (MEuro)	OPEX (Meuro/year)	Internal reinforcement CAPEX node from	Internal reinforcement CAPEX node to	Real or conceptual
AL00-GR00	AL00	GR00	500	500	60	0.72	31	25	Conceptual
AL00-GR00	AL00	GR00	500	500	60	0.72	0	20	Conceptual
AL00-ME00	AL00	ME00	500	500	5.05	0.0606	4.35	0	Conceptual
AL00-ME00	AL00	ME00	500	500	6.15	0.0738	4.35	0	Conceptual
AL00-MK00	AL00	MK00	500	500	23.2	1.86	24.5	0	Conceptual
AL00-MK00	AL00	MK00	500	500	36.6	2.93	30.1	11	Conceptual
AL00-MK00	AL00	MK00	500	500	81.4	4.28	(included in CAPEX)	(included in CAPEX)	Real
AL00-RS00	AL00	RS00	500	500	24.5	0.294	0	0	Conceptual
AL00-RS00	AL00	RS00	500	500	49.8	0.5976	43	0	Conceptual
AT00-CH00	AT00	CH00	1000	1000	383	4.656	99	100	Conceptual
AT00-CH00	AT00	CH00	1000	1000	247	3.768	124	100	Conceptual
AT00-CH00	AT00	CH00	100	200	35.3	0.3	0	0	Real
AT00-CZ00	AT00	CZ00	500	500	98	1.216	50	4	Conceptual

AT00-CZ00	AT00	CZ00	500	500	41	1.24	110	4	Conceptual
AT00-CZ00	AT00	CZ00	500	500	196	3.328	210	10	Conceptual
AT00-DE00	AT00	DE00	2000	2000	4775	46.2	1000	0	Conceptual
AT00-DE00	AT00	DE00	2000	2000	5100	48.8	1000	0	Conceptual
AT00-DE00	AT00	DE00	600	600	174	1.3904	45	0	Real
AT00-DE00	AT00	DE00	1500	1500	197	2	0	0	Real
AT00-DE00	AT00	DE00	1000	1000	235.6	1.9	0	0	Real
AT00-HU00	AT00	HU00	1000	1000	111	4.928	309	196	Conceptual
AT00-HU00	AT00	HU00	1000	1000	246	9.72	726	243	Conceptual
AT00-ITN1	AT00	ITN1	500	500	500	4	0	0	Conceptual
AT00-ITN1	AT00	ITN1	500	500	750	6	0	0	Conceptual
AT00-ITN1	AT00	ITN1	500	500	175	0.9	0	0	Real
AT00-SI00	AT00	SI00	500	500	39.1	3.5152	385.3	15	Conceptual
AT00-SI00	AT00	SI00	500	500	56.7	3.784	385.3	31	Conceptual
AT00-SI00	AT00	SI00	500	500	70.93	4.52544	463.75	31	Conceptual
AT00-SI00	AT00	SI00	500	500	210	0.5	175	0	Real
BA00-HR00	BA00	HR00	500	500	161	8.05	1	0	Conceptual
BA00-HR00	BA00	HR00	500	500	115	5.75	2	0	Conceptual
BA00-HR00	BA00	HR00	500	500	83	0.1	49.1	0	Conceptual
BA00-HR00	BA00	HR00	998	302	160.014	0.34086	0	107.014	Real
BA00-ME00	BA00	ME00	500	500	9.43	0.188	3.43	6	Conceptual
BA00-ME00	BA00	ME00	500	500	12	0.24	6	6	Conceptual
BA00-RS00	BA00	RS00	500	500	21.5	0.3	0	17.1	Conceptual
BA00-RS00	BA00	RS00	500	500	29	0.3	0	10.5	Conceptual
BA00-RS00	BA00	RS00	1130	710	19.6	0.24	(included in CAPEX)	(included in CAPEX)	Real
BA00-RS00	BA00	RS00	1180	490	13	0.65	0	34	Real
BE00-DE00	BE00	DE00	1000	1000	1000	5.6	150	0	Conceptual
BE00-DE00	BE00	DE00	1000	1000	1200	6.4	150	0	Conceptual

BE00-DE00	BE00	DE00	1000	1000	600	4.8	0	244	Real
BE00-FR00	BE00	FR00	1000	1000	236	3.54	106	13	Conceptual
BE00-FR00	BE00	FR00	1000	1000	450	1.31	24	48	Conceptual
BE00-FR00	BE00	FR00	1000	1000	90	0.1	(included in CAPEX)	(included in CAPEX)	Real
BE00-LUG1	BE00	LUG1	500	500	210	0.6	(included in CAPEX)	(included in CAPEX)	Real
BE00-NL00	BE00	NL00	1000	1000	319	3.2	500	71	Conceptual
BE00-NL00	BE00	NL00	1000	1000	570	5.7	500	0	Conceptual
BE00-NL00	BE00	NL00	1000	1000	1090	5.5	0	0	Real
BE00-NL00	BE00	NL00	1000	1000	50	0.1	0	(included in CAPEX)	Real
BE00-UK00	BE00	UK00	2000	2000	1625	20	667	0	Conceptual
BE00-UK00	BE00	UK00	1400	1400	600	8	0	0	Real
BE00-UK00	BE00	UK00	1400	1400	746	28	(included in CAPEX)	750	Real
BG00-GR00	BG00	GR00	500	500	80	1.1	77	64	Conceptual
BG00-GR00	BG00	GR00	500	500	95	1.24	80	50	Conceptual
BG00-MK00	BG00	MK00	500	500	59.5	2.76	21.3	30	Conceptual
BG00-MK00	BG00	MK00	500	500	97	2.71	24	60	Conceptual
BG00-RO00	BG00	RO00	500	500	175	1.105	46	(included in CAPEX)	Conceptual
BG00-RO00	BG00	RO00	500	500	119	1.095	100	(included in CAPEX)	Conceptual
BG00-RS00	BG00	RS00	500	500	67	0.65	30	0	Conceptual
BG00-RS00	BG00	RS00	500	500	56	0.83	0	22	Conceptual
BG00-RS00	BG00	RS00	490	270	56	0.5	0	0	Real
BG00-TR00	BG00	TR00	500	500	78.5	2.25	15	17	Conceptual
BG00-TR00	BG00	TR00	500	500	51.9	2.32	147	23.8	Conceptual

BG00-TR00	BG00	TR00	1100	700	60	1.2	(included in CAPEX)	(included in CAPEX)	Real
CH00-DE00	CH00	DE00	1000	1000	1500	12	200	0	Conceptual
CH00-DE00	CH00	DE00	1000	1000	1900	15.2	0	0	Conceptual
CH00-DE00	CH00	DE00	100	600	58	0.3	0	0	Real
CH00-DE00	CH00	DE00	600	250	100.1	0.8	0	0	Real
CH00-DE00	CH00	DE00	1000	1000	1500	12	0	0	Real
CH00-DE00	CH00	DE00	0	700	92.92	0.46	(included in CAPEX)	(included in CAPEX)	Real
CH00-DE00	CH00	DE00	0	200	290.22	1.45	(included in CAPEX)	(included in CAPEX)	Real
CH00-DE00	CH00	DE00	500	0	48.75	0.24	(included in CAPEX)	(included in CAPEX)	Real
CH00-FR00	CH00	FR00	1000	1000	550	1.465	0	0	Conceptual
CH00-FR00	CH00	FR00	1000	1000	750	1.775	66.667	133.333	Conceptual
CH00-FR00	CH00	FR00	500	500	60	0.6	0	0	Real
CH00-FR00	CH00	FR00	100	1000	35	0.18	(included in CAPEX)	(included in CAPEX)	Real
CH00-ITN1	CH00	ITN1	1000	1000	1226	2.9	0	0	Conceptual
CH00-ITN1	CH00	ITN1	1000	1000	1753.5	5.5375	0	0	Conceptual
CH00-ITN1	CH00	ITN1	1000	1000	2125	6.7	0	0	Conceptual
CH00-ITN1	CH00	ITN1	1000	1000	660	2	0	2.3	Real
CH00-ITN1	CH00	ITN1	200	200	90	0.1	0	2.3	Real
CY00-GR03	CY00	GR03	1000	1000	790	7.9	0	0	Real
CY00-IL00	CY00	IL00	1000	1000	1575	15.6	0	0	Real
CZ00-DE00	CZ00	DE00	500	500	1643	0.344	0	1600	Conceptual
CZ00-DE00	CZ00	DE00	500	500	1550	12.4	0	0	Conceptual
CZ00-DE00	CZ00	DE00	500	500	315.27	0.02	0	0	Real

CZ00-DE00	CZ00	DE00	0	500	42.12	0.01	(included in CAPEX)	(included in CAPEX)	Real
CZ00-PL00	CZ00	PL00	500	500	74	0.8	0	121	Conceptual
CZ00-PL00	CZ00	PL00	500	500	69	1.5	4	179	Conceptual
CZ00-PL00	CZ00	PL00	500	500	0	0.0	4	400	Conceptual
CZ00-SK00	CZ00	SK00	500	500	54.2	1.85	4	173	Conceptual
CZ00-SK00	CZ00	SK00	500	500	98.16	2.14	10	159	Conceptual
CZ00-SK00	CZ00	SK00	500	500	86.3	0.62	0	0	Real
DE00-DKE1	DE00	DKE1	500	500	383.3	9	0	(included in CAPEX)	Conceptual
DE00-DKE1	DE00	DKE1	500	500	384.3	9	0	(included in CAPEX)	Conceptual
DE00-DKW1	DE00	DKW1	2000	2000	4800	38	0	0	Conceptual
DE00-FR00	DE00	FR00	1000	1000	1465	2.085	0	50	Conceptual
DE00-FR00	DE00	FR00	1000	1000	1508.75	2.085	0	100	Conceptual
DE00-FR00	DE00	FR00	1500	1500	104	0.752	(included in CAPEX)	(included in CAPEX)	Real
DE00-LUG1	DE00	LUG1	1000	1000	165.5	1.33	0	0	Real
DE00-LUG1	DE00	LUG1	400	400	64.75	0.518	0	0	Real
DE00-NL00	DE00	NL00	1000	1000	200	1.6	1500	375	Conceptual
DE00-NL00	DE00	NL00	1000	1000	250	2	1500	375	Conceptual
DE00-NL00	DE00	NL00	1000	1000	200	1.6	0	0	Real
DE00-NOS0	DE00	NOS0	1000	1000	1500	0	2000	500	Conceptual
DE00-NOS0	DE00	NOS0	1000	1000	1500	0.1	2000	500	Conceptual
DE00-PL00	DE00	PL00	500	500	422	6	0	1000	Conceptual
DE00-PL00	DE00	PL00	500	500	423	6	0	1000	Conceptual
DE00-PL00	DE00	PL00	500	500	424	6	0	1000	Conceptual
DE00-PL00	DE00	PL00	500	500	425	6	0	1000	Conceptual
DE00-SE04	DE00	SE04	500	500	428.6	1	0	50	Conceptual

DE00-SE04	DE00	SE04	500	500	429.6	1	0	50	Conceptual
DE00-SE04	DE00	SE04	500	500	430.6	1	0	50	Conceptual
DE00-SE04	DE00	SE04	700	700	660	1	0	0	Real
DE00-SE04	DE00	SE04	700	700	600	1	61	0	Real
DE00-UK00	DE00	UK00	1400	1400	1600	33	(included in CAPEX)	(included in CAPEX)	Real
DE00-UK00	DE00	UK00	1400	1400	1260	23	0	(included in CAPEX)	Real
DKE1-SE04	DKE1	SE04	500	500	150	0	(included in CAPEX)	(included in CAPEX)	Conceptual
DKE1-SE04	DKE1	SE04	500	500	150	0.1	(included in CAPEX)	(included in CAPEX)	Conceptual
DKW1-NL00	DKW1	NL00	1000	1000	2750	4	500	0	Conceptual
DKW1-NL00	DKW1	NL00	1000	1000	3350	4	500	0	Conceptual
DKW1-NOS0	DKW1	NOS0	1000	1000	850	0	(included in CAPEX)	300	Conceptual
DKW1-NOS0	DKW1	NOS0	1000	1000	850	0	(included in CAPEX)	(included in CAPEX)	Conceptual
DKW1-SE03	DKW1	SE03	500	500	471.4	1	(included in CAPEX)	(included in CAPEX)	Conceptual
DKW1-SE03	DKW1	SE03	500	500	471.4	1.1	(included in CAPEX)	(included in CAPEX)	Conceptual
DKW1-SE03	DKW1	SE03	700	700	317	1	(included in CAPEX)	(included in CAPEX)	Real
DKW1-UK00	DKW1	UK00	1400	1400	1151	28	(included in CAPEX)	(included in CAPEX)	Real
EE00-FI00	EE00	FI00	500	500	370	0	80	(included in CAPEX)	Conceptual

EE00-FI00	EE00	FI00	500	500	370	0.1	80	(included in CAPEX)	Conceptual
EE00-FI00	EE00	FI00	700	700	540	0.75	(included in CAPEX)	(included in CAPEX)	Real
EE00-LV00	EE00	LV00	500	500	120	4.2	90	(included in CAPEX)	Conceptual
EE00-LV00	EE00	LV00	500	500	130	4.4	90	(included in CAPEX)	Conceptual
EE00-LV00	EE00	LV00	0	700	69	0.35	(included in CAPEX)	(included in CAPEX)	Real
ES00-FR00	ES00	FR00	1500	1500	1825	10.6	0	75	Conceptual
ES00-FR00	ES00	FR00	1500	1500	2000	11.7	115	250	Conceptual
ES00-FR00	ES00	FR00	1500	1500	1089.5	3.26	80.59	0	Real
ES00-FR00	ES00	FR00	1500	1500	1192	5.33	8	270	Real
ES00-PT00	ES00	PT00	500	500	14	0.2	37	30	Conceptual
ES00-PT00	ES00	PT00	500	500	10	0.1	37	63	Conceptual
ES00-PT00	ES00	PT00	500	500	23	0.3	47	61	Conceptual
ES00-PT00	ES00	PT00	500	500	35.6	0.4	74	42	Conceptual
FI00-NON1	FI00	NON1	500	500	1000	0	(included in CAPEX)	(included in CAPEX)	Conceptual
FI00-NON1	FI00	NON1	500	500	500	0	(included in CAPEX)	(included in CAPEX)	Conceptual
FI00-SE01	FI00	SE01	500	500	250	0	(included in CAPEX)	(included in CAPEX)	Conceptual
FI00-SE01	FI00	SE01	500	500	250	0.1	(included in CAPEX)	(included in CAPEX)	Conceptual
FI00-SE01	FI00	SE01	900	800	297	0.3	(included in CAPEX)	(included in CAPEX)	Real

FI00-SE02	FI00	SE02	500	500	450	1	(included in CAPEX)	(included in CAPEX)	Conceptual
FI00-SE02	FI00	SE02	500	500	450	0.1	(included in CAPEX)	(included in CAPEX)	Conceptual
FI00-SE02	FI00	SE02	800	800	500	0.75	(included in CAPEX)	(included in CAPEX)	Real
FI00-SE02	FI00	SE02	800	800	270	0.3	(included in CAPEX)	(included in CAPEX)	Real
FI00-SE03	FI00	SE03	500	500	450	1	(included in CAPEX)	(included in CAPEX)	Conceptual
FI00-SE03	FI00	SE03	500	500	450	1.1	(included in CAPEX)	(included in CAPEX)	Conceptual
FR00-IE00	FR00	IE00	700	700	1450	8.67	150	150	Conceptual
FR00-IE00	FR00	IE00	700	700	1525	8.825	187.5	187.5	Conceptual
FR00-IE00	FR00	IE00	700	700	1000	8.4	(included in CAPEX)	(included in CAPEX)	Real
FR00-ITN1	FR00	ITN1	1000	1000	1400	1.86345	0	0	Conceptual
FR00-ITN1	FR00	ITN1	1000	1000	2500	3.02703	200	0	Conceptual
FR00-UK00	FR00	UK00	1400	1400	1000	8	300	300	Conceptual
FR00-UK00	FR00	UK00	1400	1400	1100	9	350	350	Conceptual
FR00-UK00	FR00	UK00	1400	1400	870	7.6	(included in CAPEX)	(included in CAPEX)	Real
FR00-UK00	FR00	UK00	2000	2000	1400	14	0	0	Real
FR00-UK00	FR00	UK00	1400	1400	885	23.8	0	0	Real
FR15-ITCO	FR15	ITCO	100	100	180	1.4	(included in CAPEX)	(included in CAPEX)	Real
GR00-ITS1	GR00	ITS1	500	500	250	0.25	(included in CAPEX)	(included in CAPEX)	Conceptual

GR00-ITS1	GR00	ITS1	500	500	1000	1	(included in CAPEX)	(included in CAPEX)	Conceptual
GR00-ITS1	GR00	ITS1	500	500	750	0.75	(included in CAPEX)	(included in CAPEX)	Conceptual
GR00-ITS1	GR00	ITS1	500	500	750	0.75	0	0	Real
GR00-MK00	GR00	MK00	500	500	18	0.66	30	0	Conceptual
GR00-MK00	GR00	MK00	500	500	28.75	0.94	70	20	Conceptual
GR00-MK00	GR00	MK00	500	500	5.625	0.215	0	0	Real
GR00-TR00	GR00	TR00	500	500	110.4	1.84	200	37.4	Conceptual
GR00-TR00	GR00	TR00	500	500	140.4	1.84	300	37.4	Conceptual
GR00-TR00	GR00	TR00	600	600	32.55	0.64	55	(included in CAPEX)	Real
HR00-HU00	HR00	HU00	500	500	90	2.28	36	102	Conceptual
HR00-HU00	HR00	HU00	500	500	150	3.47	1	196	Conceptual
HR00-RS00	HR00	RS00	500	500	52.8	0.1614	1	0	Conceptual
HR00-RS00	HR00	RS00	500	500	64.5	0.2478	1	17.1	Conceptual
HR00-RS00	HR00	RS00	600	600	19.04	0.0245	0	0	Real
HR00-SI00	HR00	SI00	1000	1000	69.5	3.475	1	1.5	Conceptual
HR00-SI00	HR00	SI00	1000	1000	97	4.85	26	16.5	Conceptual
HU00-RO00	HU00	RO00	500	500	60	5	254	140	Conceptual
HU00-RO00	HU00	RO00	500	500	2500	0	0	0	Conceptual
HU00-RO00	HU00	RO00	617	335	0	0	0	0	Real
HU00-RO00	HU00	RO00	1410	740	120	0.75	0	30	Real
HU00-RS00	HU00	RS00	500	500	37.9	3.4	240	40.7	Conceptual
HU00-RS00	HU00	RS00	500	500	2500	0	0	0	Conceptual
HU00-RS00	HU00	RS00	500	500	24.1	0.932	0	40.7	Real
HU00-SI00	HU00	SI00	500	500	0	1.02	102	0	Conceptual
HU00-SI00	HU00	SI00	500	500	140	2.9	42	18	Conceptual
HU00-SK00	HU00	SK00	500	500	50	0.85	35	227	Conceptual

HU00-SK00	HU00	SK00	500	500	80	1.82	0	106	Conceptual
IE00-UK00	IE00	UK00	504	504	426.8	13.42	(included in CAPEX)	(included in CAPEX)	Real
IE00-UK00	IE00	UK00	750	750	550	10	(included in CAPEX)	(included in CAPEX)	Real
ITCN-ITCO	ITCN	ITCO	400	400	720	5.6	0	0	Real
ITCS-ME00	ITCS	ME00	500	500	798	0	0	0	Conceptual
ITCS-ME00	ITCS	ME00	500	500	1000	0	0	0	Conceptual
ITCS-ME00	ITCS	ME00	600	600	362	0.7	0	0	Real
ITN1-SI00	ITN1	SI00	500	500	391	1.4	0	0	Conceptual
ITN1-SI00	ITN1	SI00	500	500	410	1.6	0	0	Conceptual
ITN1-SI00	ITN1	SI00	1000	1000	755	4	0	0	Real
ITN1-SI00	ITN1	SI00	125	125	16.61	0.3	(included in CAPEX)	(included in CAPEX)	Real
ITN1-SI00	ITN1	SI00	20	120	25.97	0.4	(included in CAPEX)	(included in CAPEX)	Real
ITSI-TN00	ITSI	TN00	600	600	600	2	0	0	Real
LT00-LV00	LT00	LV00	500	500	50	0.8	0	0	Conceptual
LT00-LV00	LT00	LV00	500	500	100	2.5	12	52	Conceptual
LT00-PL00	LT00	PL00	700	700	682.6	3	945.2	191.77	Real
LT00-SE04	LT00	SE04	500	500	900	10	(included in CAPEX)	100	Conceptual
LT00-SE04	LT00	SE04	500	500	1800	19.5	50	100	Conceptual
LT00-SE04	LT00	SE04	600	600	284	0.2	(included in CAPEX)	(included in CAPEX)	Real
LV00-SE03	LV00	SE03	500	500	512	8	287	(included in CAPEX)	Real
ME00-RS00	ME00	RS00	500	500	39	0.717	(included in CAPEX)	34	Conceptual

ME00-RS00	ME00	RS00	500	500	39	0.847	(included in CAPEX)	44.5	Conceptual
ME00-RS00	ME00	RS00	80	430	44.4	0.53	0	0	Real
ME00-RS00	ME00	RS00	160	410	18	0.65	0	34	Real
MK00-RS00	MK00	RS00	500	500	31.9	2.46	0	28.6	Conceptual
MK00-RS00	MK00	RS00	500	500	14.4	1.39	17.5	50.6	Conceptual
NL00-NOS0	NL00	NOS0	1000	1000	2100	4	500	0	Conceptual
NL00-NOS0	NL00	NOS0	1000	1000	2110	4	500	0	Conceptual
NL00-UK00	NL00	UK00	1000	1000	1135	4	375	0	Conceptual
NL00-UK00	NL00	UK00	1000	1000	1145	4	375	0	Conceptual
NL00-UK00	NL00	UK00	2000	2000	850	6	0	0	Real
NOS0-SE03	NOS0	SE03	500	500	250	0	(included in CAPEX)	(included in CAPEX)	Conceptual
NOS0-SE03	NOS0	SE03	500	500	250	0.1	(included in CAPEX)	(included in CAPEX)	Conceptual
NOS0-UK00	NOS0	UK00	1000	1000	1590	0	500	300	Conceptual
NOS0-UK00	NOS0	UK00	1400	1400	1700	10	0	0	Real
PL00-SE04	PL00	SE04	500	500	700	14	(included in CAPEX)	600	Conceptual
PL00-SE04	PL00	SE04	500	500	700	14	50	300	Conceptual
PL00-SK00	PL00	SK00	500	500	199	2	159	200	Conceptual
PL00-SK00	PL00	SK00	500	500	40	0.4	162	200	Conceptual
RO00-RS00	RO00	RS00	500	500	36.5	0.812	30	21	Conceptual
RO00-RS00	RO00	RS00	500	500	51	2.17	140	34	Conceptual
RO00-RS00	RO00	RS00	844	600	47	1.32	152	0	Real
RO00-RS00	RO00	RS00	680	720	4	0.84	0	80	Real
UK00-UKNI	UK00	UKNI	700	700	446	9.93	(included in CAPEX)	(included in CAPEX)	Real

APPENDIX 3. STARTING CAPACITIES FOR STORAGE (2040 STUDY)

For storage and peaking unit flexibilities the starting point is 2030 National Trends scenario capacities for battery storage and for peaking units.

Zone	IoSN 2040 starting total storage capacity (MW) (batteries & hydro)	IoSN 2040 starting point (MW) (thermal & DSR)
al00	0	0
at00	10202	2000
ba00	440	0
be00	1991	2485
bg00	1399	20
ch00	15658	0
cy00	41	50
cz00	2378	0
de00	14236	6832
dke1	0	647
dkw1	0	354
dz00	0	6280
ee00	0	260
eg00	0	574
es00	13050	1600
fi00	125	10049
fr00	5096	6116
fr15	0	286
gr00	2479	148
gr03	50	0
hr00	301	1
hu00	50	566

ie00	742	1670
il00	650	4200
is00	0	0
itca	1350	61
itcn	0	472
itcs	3347	1457
itn1	5017	4581
its1	850	507
itsa	1640	321
itsi	1380	719
lt00	950	50
lub1	0	0
luf1	0	0
lug1	0	9
luv1	1310	0
lv00	0	37
ly00	0	4849
ma00	824	615
md00	0	0
me00	0	0
mk00	333	0
mt00	0	0
nl00	5800	1329
nom1	4456	1424
non1	5273	1296
nos0	23492	3575
pl00	1539	0
ps00	0	0

pt00	3832	0
ro00	939	1051
rs00	814	0
se01	5	214
se02	25	377
se03	357	994
se04	156	265
si00	665	439
sk00	926	0
tn00	400	1680
tr00	1400	8000
ua01	0	0
ua02	0	0
uk00	19806	8844
ukni	300	921

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