Report on the Locational Marginal Prices Study of the Bidding Zone Review Process in Baltics

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Contents

Introduction

The wholesale electricity market in Europe is designed using a zonal system, as is put down in the Regulation (EU) 2019/943 on the internal market for electricity ("Electricity Regulation"). Under this system, zones are formed in which unrestricted trade amongst market participants is made possible, called Bidding Zones (BZ). According to article 14 of the Electricity Regulation, BZ borders shall be based on long-term, structural congestions in the transmission network. To ensure an optimal configuration of BZs which maximizes economic efficiency while maintaining security of supply, a Bidding Zone Review ("BZR") shall be carried out.

As result of the implementation of the Electricity Regulation in July 2019, all EU Transmission system operators (TSOs) were obliged to submit a proposal for the methodology and assumptions that are to be used in the BZR process and for the alternative BZ configurations to be considered, to the relevant regulatory authorities (NRAs) for approval. As NRAs did not reach an agreement to approve the proposal, the decision on the methodology and assumptions as well as for the alternative bidding zone configurations to be considered in the BZR process was transferred to ACER on 13th July 2020.

Eventually, ACER has both amended and adopted this methodology and assumptions that are to be used in the BZR process for alternative bidding zone configurations in its 24th November 2020 decision 29/2020 (Annex 1 of this decision is herein after referred to as "Methodology"). This Methodology determines how TSOs will assess alternative BZ configurations, which includes an LMP (Locational marginal pricing) analysis (article 11) and technical specifications and timeline of the data request for LMP analysis (Annex 2).

On December 22nd, 2020 Baltic TSOs sent a letter to the ACER regarding implementation of bidding zone review methodology and conduct LMP analysis in the Baltic states by requesting a postponement and providing implementation suggestions for the LMP analysis in the Baltics. In a response letter in March 18, 2021 ACER stressed the need for the Baltic TSOs to deliver the results of the LMP analysis as required under Annex 2 of the ACER Decision as soon as the results of the dynamic studies becomes available.

In a second step based on results from the LMP analysis ACER will decide alternative bidding zone configurations to be considered in the BZR process.

As a result, the LMP analysis for the Baltic region officially started in Q3 2022, after dynamic studies become available. Until then the Baltic TSOs developed the necessary tools and methodologies for the LMP analysis. With this report Baltic TSOs would like to transparently report in a comprehensive way, the assumptions, limitations, simplifications, and results of this Baltic LMP simulation. This report concerns the project in Baltic region and sections from Continental Europe LMP analysis as common parts from methodologies adopted to Baltic LMP analysis.

The nodal simulation was performed in the Plexos market modelling tool. In total, simulation model for the Baltic region includes 55 generators, 79 lines, 51 nodes and 76 critical network elements and contingencies. As Baltic's electricity grid has interconnectors with Nordic and Central Europe (CE) (Poland) markets the Baltics LMP model also includes additional lines, generators, and nodes from these countries. This will create more realistic and reliable LMP model and results for the Baltics.

Data delivery

In the result of simulations, Baltic TSOs has provided LMP results to the ACER pursuant to the article 1 of Annex 2 of the ACER Decision on the BZR methodology. In addition to the results from the nodal simulations, 6 snapshots of the grid model in PSSe format were delivered to ACER from Baltic TSOs.

Outline of the report

The report consists of three main parts, which includes:

- Chapter 1 with explanation of the market and grid assumptions of the LMP calculations in BZRR Baltics
- Chapter 2 with explanation of the applied simulation chain of the LMP calculations in BZRR Baltics
- Chapter 3 with results of the LMP calculations in BZRR Baltics

The report is supplemented with 2 annexes:

- Annex 1: Methodology and process from CE for selection of the Climate years
- Annex 2: Development projects in the Baltics

1. Explanation of the market and grid assumptions of the LMP calculations in BZRR Baltics

1.1. Market assumptions

1.1.1. Climate Years used in LMP analysis

According to the requirements from the ACERs decision on methodology and assumptions used in the bidding zone review process, TSOs shall jointly select three reference climate years to assess BZ configurations and these three years shall be selected among the thirty most recent available climate years. As reference climate years shall be consistently used across all BZR Regions and BZ configurations, Baltic TSOs have used the same climate years in the Baltic LMP analysis as the continental Europe and Nordic region. Instead of representative weeks, Baltic TSOs performed full year market simulations for 1989, 1995 and 2009 climate years. In Annex 1 full description on how climate years by Central Europe TSOs were selected can be found.

Similarly, to the Nordic region, in the Baltic region hydro inflows and temperatures are important factors for the power system. Largest hydro power generation stations are in Latvia and are accounting on average for 40% of all generated electricity in Latvia. However, in last years also wind and solar generation is becoming more relevant the Baltic region and it's expected that installed capacity will increase by around 40% since year 2018. In the Baltics simulated climate years depict different situation in solar and wind profiles. Climate year 1989 on average has 10% more solar and wind input than normal, while year 1995 has around 15% more. Year 2009 shows different picture with more than 20% less wind and solar input from normal. Even through two from three climate years show similar situation, the year 2009 gives more diverse picture with fairly representation of wind and solar input.

1.1.2. Weeks selected for LMP snapshot delivery

As required by the methodology, LMP analysis for the Baltic region was performed for all Market time units (MTUs) of the target year for all three climate years. However, in addition to the LMP results, the TSOs are also delivering snapshots requested by the ACER for performing flow decomposition analysis/ assessing loop flow indicators in the first step of ACERs procedure for identifying alternative Bidding Zone configurations. To select snapshots, Baltic TSOs has taken two hours per each climate year - one from winter and one from summer season. Table 1 summarizes selected weeks and hours selected for the snapshot delivery.

Table 1. Selected weeks for snapshot delivery

Climate years	Market modelling	Network modelling
1989	All year	1989 max load hour 12:00 03.01.2025 1989 min load hour 03:00 27.05.2025
1995	All year	1995 max load hour 11:00 05.01.2025 1995 min load hour 03:00 03.06.2025
2009	All year	2009 max load hour 11:00 31.01.2025 2009 min load hour 03:00 27.05.2025

More information about the selection of snapshots can be found can be found in section 2.3.

1.1.3. Scenarios used for generation and demand

As required by ACERs Decision on the Methodology and assumptions to be considered by TSOs in the LMP analysis, the target year of the analysis shall be three years later than the year when the configurations for given BZR Region are approved. As alternative bidding zone configurations to be studied in the BZR process will be defined in the first part of year 2023, the generation and demand scenarios used for LMP analysis shall be created for the target year 2025. Due to planned Baltic synchronization with Continental Europe by the end of year 2025, Baltic TSOs originally planned to use year 2026 as target year for Baltic's LMP analysis to capture the system characteristics after the synchronization. However due to changes in the geopolitical situation discussions are held to possibly bring the synchronization forward. Therefore, all projects related to Baltic synchronization in this analysis are considered before designated cut-off date (i.e. June 30 of 2025) and year 2025 will be used as target year for Baltic's LMP analysis with the assumption that the Baltics are synchronized with Continental Europe.

The basis for the Baltic modelling has been the European Resource Adequacy Assessment (ERAA) 2021 model, which uses inputs from Pan-European Market Modelling Data Base (PEMMDB) version 3.4. The ERAA 2021 simulation model - National trends - 2025 scenario. Consumption patterns were updated from ERAA 2022 to reflect the latest significant consumption changes in the Baltic system.

The PEMMDB is containing data collected from TSOs on generation capacities, interconnection capacities, generation planned outages and many other characteristics. However, some adjustments and improvements has been made to reflect the target year in the best possible way such as:

- As Baltic states are planning to synchronize with Continental Europe Network, all power lines with third countries will be disconnected.
- In Baltics there are no commercial flows with 3rd countries, therefore there is no change regarding market flows after Baltics synchronization with Continental Europe Network.
- Power system will be upgraded with additional battery energy storage systems for balancing.
- Wind and solar installed capacity forecasts have been updated in line with the most recent Baltic TSO-forecasts by the time of start of the analysis.
- Each Baltic bidding zone was split into nodal configuration for each 330 kV (or above) substation as a separate node.
- Generation units have been distributed to their respective nodes with respect to physical location and connection points.
- Demand profiles for the Baltic countries have also been distributed into nodes with respect to physical locations and connection points.

1.1.4. Market model build

Baltic LMP nodal market model was built on ERAA 2021 dataset. To have reasonable calculation times pan-European model was scaled down to Baltic countries with neighboring countries (including Norway). Neighboring countries were modeled as aggregated zonal areas and only Baltic countries split into nodal configuration. More detailed description about nodal grid configuration setup is provided in the following sections.

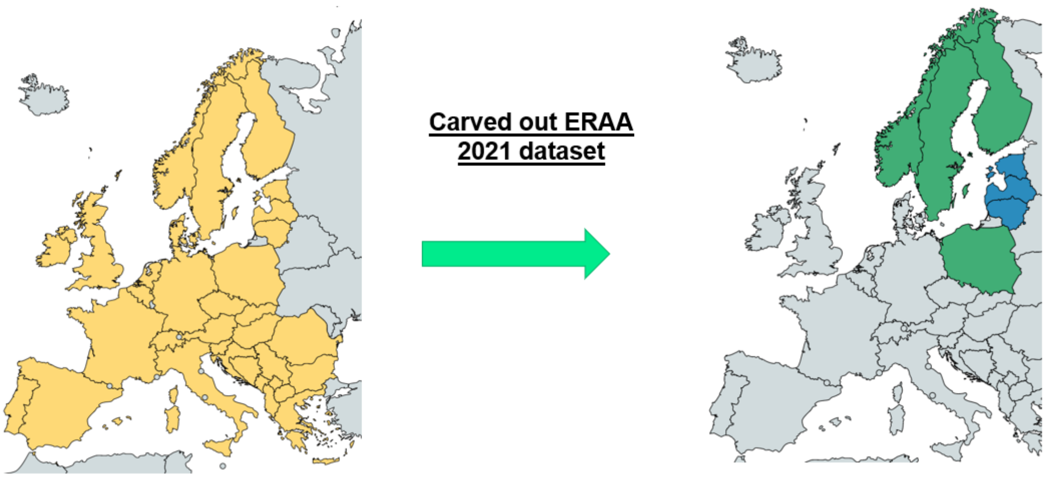

Figure 1. Model used for simulations

1.1.5. RES modelling

For the scope of the LMP simulations, RES units are modelled as variable generation with available capacity according to hourly time series derived from Pan-European Climatic database (PECD) data sets for the selected climate weeks. The short-run marginal cost of wind and solar power plants shall be 0 €/MWh by default and other Renewable energy sources (RES) units also bid at 0 €/MWh. These values were chosen to reflect price sensitivity for RES installations as they would be commissioned on market basis.

1.1.6. Short term marginal costs

The prices used in the LMP analysis are:

- CO_2: 93.75 €/ton
- Gas: 47.06 €/MWh thermal
- Coal: 8.28 €/MWh thermal

The fuel costs in our analysis are inherited from ERAA 2022 and is mainly following the assumptions of RePower EU scenario with some components from fit-for-55 scenario and some from national estimations. For the purpose of simulation LMP Short run marginal costs (SRMC) are calculated using the following formula:

SRMC = Fuel Price x Marginal Heat Rate + VOM Charge + Emissions Incremental Cost

A summary of fuel prices taken from Scenario Building 2022 can be found in the following table.

Table 2. Short Run Marginal Costs

Fuel	Price (€/GJ)
Closed Loop Pumping	Water value determined by the model
Open Loop Pumping	Water value determined by the model
Reservoir	Water value determined by the model
Run of River and Pondage	Water value determined by the model
Gas	13.07
Hard coal	2.30
Heavy oil	10.56
Light oil	12.87
Lignite G1	1.4
Lignite G2	1.8
Lignite G3	2.37
Lignite G4	3.1
Nuclear	0.47
Oil shale	1.56

Biofuels are used as secondary fuels. Biofuel prices were provided per unit in PEMMDB either custom for the unit or if the TSO has not provided a price, the primary fuel price was taken.

The prices are then randomized as requested by the methodology, in a range of ±1€/MWh hourly around the original value.

Heat rates are defined per unit, therefore units with the same fuel price can result in having a different SRMC.

1.1.7. Demand side response (DSR)

Article 4 of the BZR methodology requires modelling explicit and implicit demand side response. The main differences between explicit and implicit DSR were identified in CE LMP analysis report and are summarized in table below.

Aspect	Explicit DSR	Implicit DSR
Definition	*It is committed, dispatchable flexibility that can be traded on the different energy markets (wholesale, balancing, system support and reserves markets). This form of Demand-Side Flexibility is often referred to as "incentive driven" demand-side flexibility.*	It is the consumer's *reaction to price signals. Where consumers have the possibility, they can adapt their behavior (through automation or personal choices) to save on energy expenses. This type of Demand-Side Flexibility is often referred to as "price-based" demand-side flexibility.*
Participation to market segments	*It can potentially participate to all market segments/mechanisms (balancing, ancillary services, etc.)*	*A priory, it does not participate in other market segments or mechanisms (balancing, ancillary services, etc.)*
Visibility/identification of offers	*Individual offers can be often identified.*	• *It may be 'visible' in the wholesale (day-ahead or intraday markets), it may be partly 'hidden', e.g. in the portfolio of vertically integrated companies.* • *Individual offers difficult to identify*
Activation prices	*In theory, activation at any price. In practice, based on TSOs' information, only identifiable at 'relatively' high prices (e.g. 150 euros/MWh or well above)*	*At any price*

For the scope of the LMP analysis, Baltic TSOs predefined Explicit DSR values and prices at which DSR is activated. In table below Baltic TSOs summarized explicit DSR capacities and price levels. Each price band in the table shows an additional capacity that is activated if the market price reaches the offered price.

Table 3. Explicit DSR values and prices

Zone	Price (EUR/MWh)	Capacity (MW)
Estonia	100	60
Latvia	183	0,3

	150	
	200	1,5
Lithuania	100	10

For simulation of implicit DSR similar 2 step approach as for CE & Ireland was used:

1. In a first step, demand elasticity values have been applied and a simplified zonal yearly simulation has been run (activating Plexos Cournot competition model). The scope of this step is to derive demand slope and intercept to be adopted in the final simulations.
2. In the second step, computed hourly demand slope and intercept parameters are assigned to each (existing) Bidding zone and adopted in the final LMP simulations.

Demand elasticity values are the main input for assessing implicit DSR parameters. For Baltic LMP simulation ACERs default elasticity value of -0.2 has been adopted.

1.1.8. Reserve modelling

Article 11.5(d) of the BZR Methodology prescribes that in LMP simulation "reserves and balancing requirements, as described in Article 4.3; these constrains shall be consistent with the ones adopted for the day-ahead market dispatch according to Article 7.4".

Article 4.3 states: "Reserve requirements: Reserve requirements shall be set separately for FCR, FRR and RR.

a) For each target year, the dimensioning of FCR, FRR and RR, and the related contribution of each TSO, shall reflect reserve needs to cover imbalances in line with Articles 153, 157 and 160 of SO regulation.
b) The assignment of these balancing reserves to generation, demand and storage shall reflect expected operational practices for the target year."

For the Baltics the reserve modelling is considered for FRR reserve product as FCR and RR are currently not in use. The reserves are modelled considering their activation time and duration and qualified generation units, coherently to the PEMMDB data. As Plexos does not allow to consider reserve sharing across bidding zones, each reserve requirement shall be fulfilled with generation units located in the given bidding zone.

1.2. Grid Assumptions

1.2.1. Grid model

According to Article 4.2 (e) of the Bidding Zones Review Methodology, TSOs can model new network elements based on either of the following options:

- define multiple network models appropriately reflecting the gradual commissioning of new network elements throughout the target year; or
- where the definition of network models according to the first option is not possible, include, in all network models, all new network elements expected to be commissioned by the target year.

In line with BZR Methodology described above, as well as with the generation and demand scenarios, the grid model has been created based on the TYNDP 2020 national trends scenario reflecting all projects with commissioning date on 20 June 2025. The model includes the transmission grid of all three Baltic countries with all 330 kV lines and substations as well as interconnectors to neighboring regions without connections to 3rd countries.

For the target year 2025 it is assumed that Baltic power system will be operating synchronously with Central Europe. With respect to network development plans the following projects were included in the grid model with commissioning date on 30 June 2025:

Estonia:

- L300 Balti-Tartu line reconstruction
- L301 Tartu-Valmiera line reconstruction
- L353 Viru-Tsirguliina line reconstruction

Latvia:

- L301 Tartu-Valmiera line reconstruction
- L354 Valmiera- Tsirguliina line reconstruction
- 80MW Battery Energy Storage System (BESS) for frequency regulation

Lithuania:

- New 330kV line Vilnius-Neris
- LitPol Link extension stage I new 400/330kV autotransformer in Alytus
- New 330kV Mūša substation
- Klaipeda-Bitenai 330kV line reconstruction
- Bitenai-Jurbarkas 330kV line reconstruction
- New 330kV line Jurbakas-KHAE
- Construction of Darbenai switchyard (substation)
- Klaipeda-Grobina 330kV line reconstruction

With respect to network development plans Harmony Link new HVDC PL-LT was not included in the simulation for reference case scenarios. However, it was included in the sensitivity analysis. In Annex 2 Baltic TSOs summarized all developments projects from which the relevant ones were included in the LMP analysis.

1.2.2. Dynamic Line Rating (DLR)

In the Baltic region TSOs does not use Dynamic Line ratings, however the grid model used in the simulations have seasonal/ temperature dependent operational limits. For LMP analysis Baltic TSOs has applied two capacity limits for Critical network elements and contingencies (CNECs) based on thermal constrains at +20 degrees in the high temperature period (from May till September) and -10 degrees for low temperature period (from October till April).

Table 4. Line operational limits

Wire configuration setup	Voltage level (Un), kV	Line temperature, °C	Max amperage at ambient temperature, +20°C, A	Max amperage at ambient temperature, -10°C, A
2x300	330	70	1449	1835
2x300 (new wires)	330	70	1554	1968

2x330	330	70	1533	1941
2x400	330	70	1733	2194
2x400 (new wires)	330	70	1764	2234
2x500	330	70	2016	2553

1.2.3. Topological Remedial Actions (TRAs)

The calculations for the Baltics have been performed with the same grid topology for all MTUs. Contingencies (N-1) were applied to all 330 kV lines within Baltic system. This allows to have optimal system dispatch on different topological configurations and reflect remedial actions that lead to no cost within expected operational practices of TSOs.

Considering low gradient of Baltic nodal prices differentials, no remedial actions are necessary from the market flows perspective. No structural contingencies were identified except very small number of nodes in Latvia area.

1.2.4. Nodal allocation

Baltic nodal model was based on 330 kV substations network grid. The basis for nodal allocations were structured by Estonian, Latvian and Lithuanian TSOs planning analysis for 2025 target years. The distribution methods were applied harmoniously in all Baltic states. Consumption data for each node corresponds to actual planned proportions and expected consumption developments in grid planning according to each TSO.

Large scale wind RES developments on transmission network were allocated according to best estimate for each nodal location and smaller developments on distribution network were aggregated. All solar developments were distributed on equal proportions in each node.

2. Explanation of the applied simulation chain of the LMP calculations in BZRR Baltics

2.1. Description for the different steps of the simulation

To compute reliable LMPs for the Baltic's power system, a proper simulation chain has been set up. This chain is composed by the 3 main steps:

1. CNEC list definition: the list of Critical Network Element and Contingencies to be considered when computing LMPs is defined.
2. N-1 final simulations: LMPs are computed implementing N-1 security criterion.
3. Identification of relevant TRAs: TSOs carried out investigation for identification of relevant topological remedial action (TRAs) to be applied to relieve detected congestions in the "Final N-1 simulation".

In addition, an ex-post workstream investigated the impact of topological remedial actions of selected hours for extreme load and generation levels. For this scope, additional two steps have been carried out:

1. Identification of relevant TRAs (no relevant TRA found necessary).

A DC (optimal) power flow approach has been applied in each relevant step of this study and no necessary TRA shall be implemented.

2.2. Description of the CNEC selection procedure and final N-1 simulation

Article 11.5.c of the "Methodology and assumptions that are to be used in the BZR process" confirms that security constraints based on Operational Security Limits (OSLs) and contingencies shall be reflected in the LMP computation, in line with Article 4.2 of the same document. This clarifies that:

- Contingencies and OSLs related to network elements operating at nominal voltage higher than or equal to 380 kV shall be included.
- Contingencies and OSLs related to network elements operating at nominal voltage levels below 380 kV shall be excluded, unless TSOs are able to justify properly their inclusion (considering the potential reasons provided in the methodology).

In the Baltic region network is operating on 330 kV lines and is relatively small, therefore Baltics have applied contingencies and OSLs to all CNE operating at 330 kV reflecting the operational planning. For all CNE Baltics has applied contingencies and OSLs used when calculating market capacities:

- Temperature restriction; for summer +20c and winter -10c.
- Contingencies (min value from): (a) Conductor permitted normal current, A; (b) Current transformer current, A; (c) Relay protection settings current, A; (d) High frequency line trap current.
- Formula for max flow value: ([MIN rate in amperes]/1000) **voltage level**3^0,5
    - Voltage levels: Elering 347 kV; AST 355 kV; Litgrid 330 kV

Also, network grid changes foreseen till 2026 are included in the model and updated accordingly.

Final Locational Marginal Price simulations have been run. Main features of this runs are:

- 330 kV grid model of the Baltic's Power system extensively modeled
- N-1 security criterion implemented
- Explicit and implicit DSR modeled
- Power plant modelling on unit basis (wind and solar RES units were aggregated)
- Topological Remedial Actions optimized and relieved within market simulations framework (network simulations also did not show any structural congestions on 330 kV level)

2.3. Snapshot creation and selection

For the creation of grid models/snapshots requested by ACER the software PSSE was used. Baltic TSOs imported hourly market outcomes values obtained from the market model in the network model, taking demand, generation and flow values in aggregated form for each node.

The snapshots selection was carried out to identify the most extreme cases from each climate year. For this purpose, one hour during winter period under maximum load was taken and another one hour during summer season under minimum load was chosen. The results of the network modelling for extreme cases indicate the edge cases for the system and it can be assumed that all other representative hours lie in between. The network simulations were performed for each climate years agreed in the reference case scenario.

3. Results of the LMP calculations in BZRR Baltics

3.1. Nodal prices

The outcome of the LMP simulations are the nodal prices reflecting the marginal costs of an additional load at a specific node in the grid. For all 3 climate years with hourly granularity, the model has calculated a separated nodal price for each node.

The hourly nodal prices per country for all the nodes within the country are presented in figures below. Following figures show very low-price differential gradient in the Baltic states. On average, price differences between nodes in EE and LT are below 0.5 Eur/MWh. Only nodes within Latvia have higher differences nevertheless it lies within 2 Eur/MWh range.

Under nodal configuration, Baltic LMP analysis indicated no structural congestions between nodes in the Baltic states. However, Baltic TSOs would like to emphasize that reserve sharing requirements as they are intended in the target year were not fully reflected in Plexos modelling (described in paragraph 1.1.8). This could significantly reduce allocated NTCs between the nodes and cause congestions in different nodes.

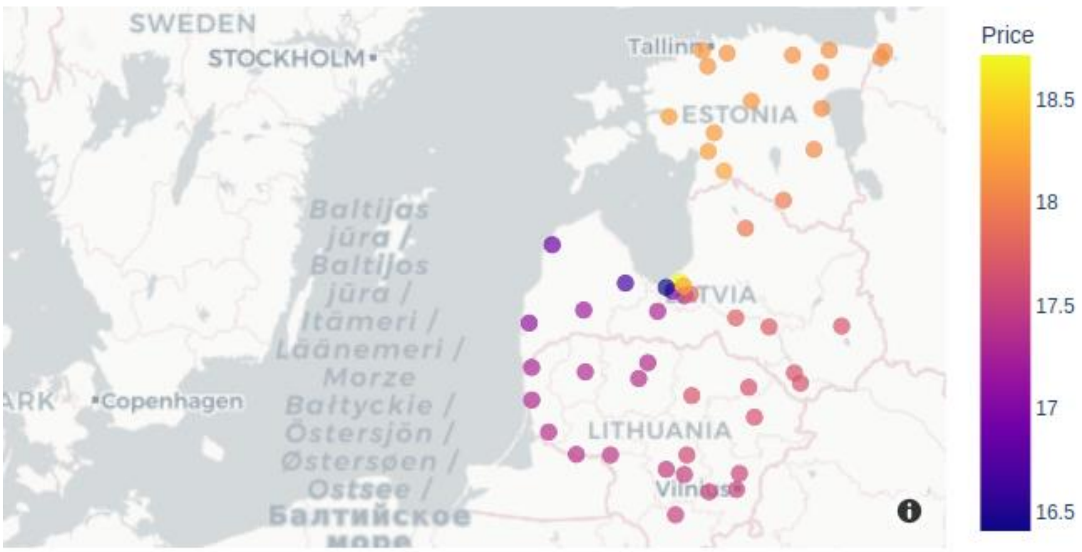

Figure 2. Average nodal prices in Baltics for CY 1989

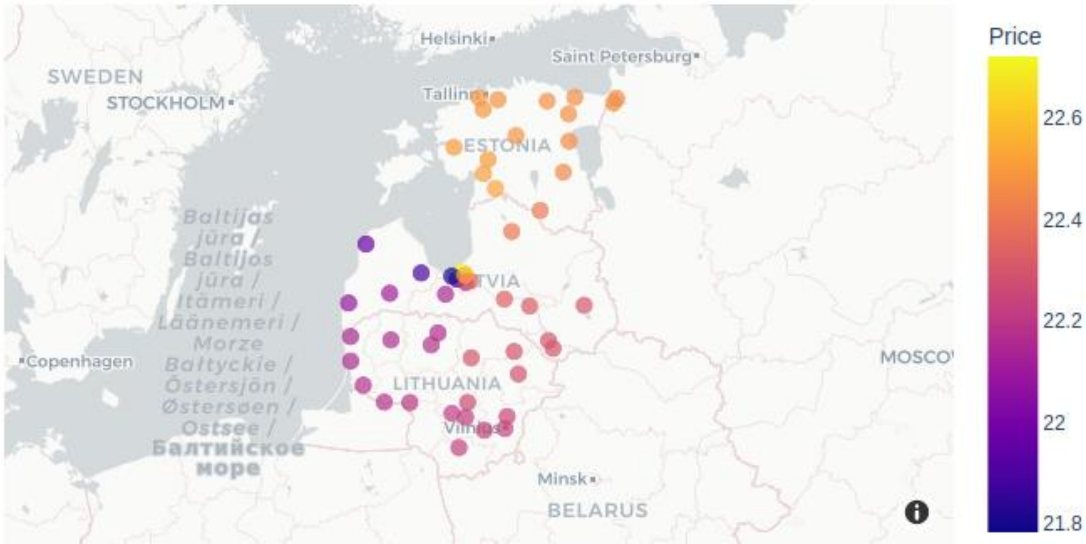

Figure 3. Average nodal prices in the Baltics for CY 1995

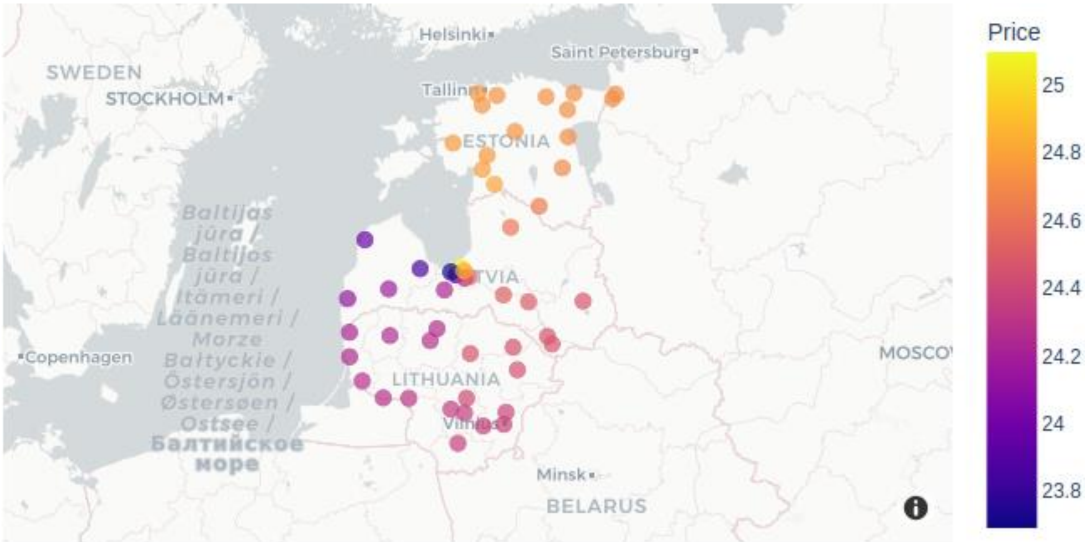

Figure 4. Average nodal prices in Baltics for Climate year 2009

Nodal price volatility is laid out in figures below. Price volatility can be observed between all three climate years. However, maximum hourly prices remain homogenous in all Baltic countries. The lowest hourly prices also remain homogenous except certain Latvian nodes around Riga area. The congestions around this area can be explained by high concentration of loads and lower available flexible generation resources.

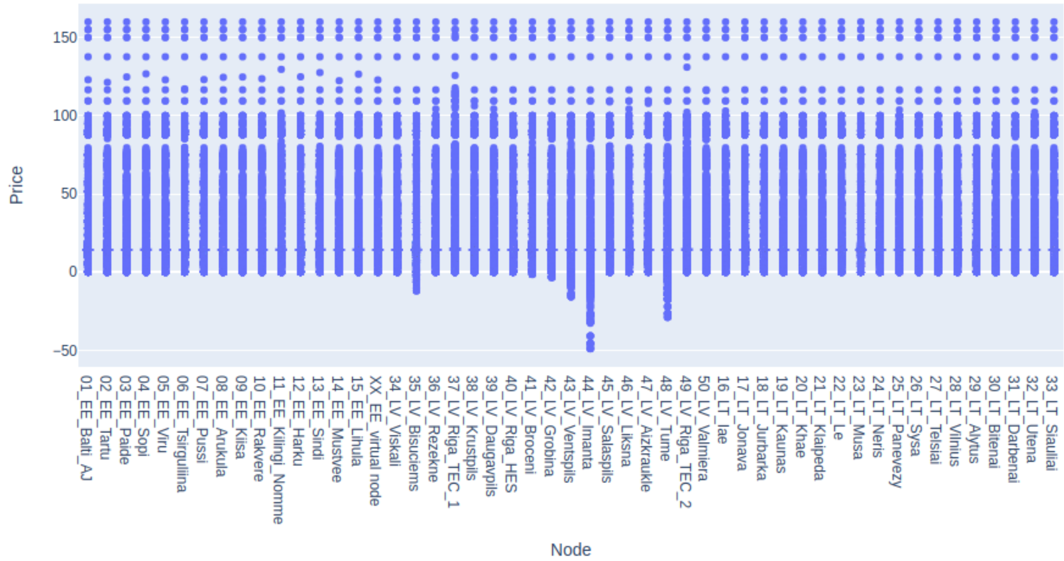

Figure 5. Hourly nodal price distribution in the Baltics for CY 1989

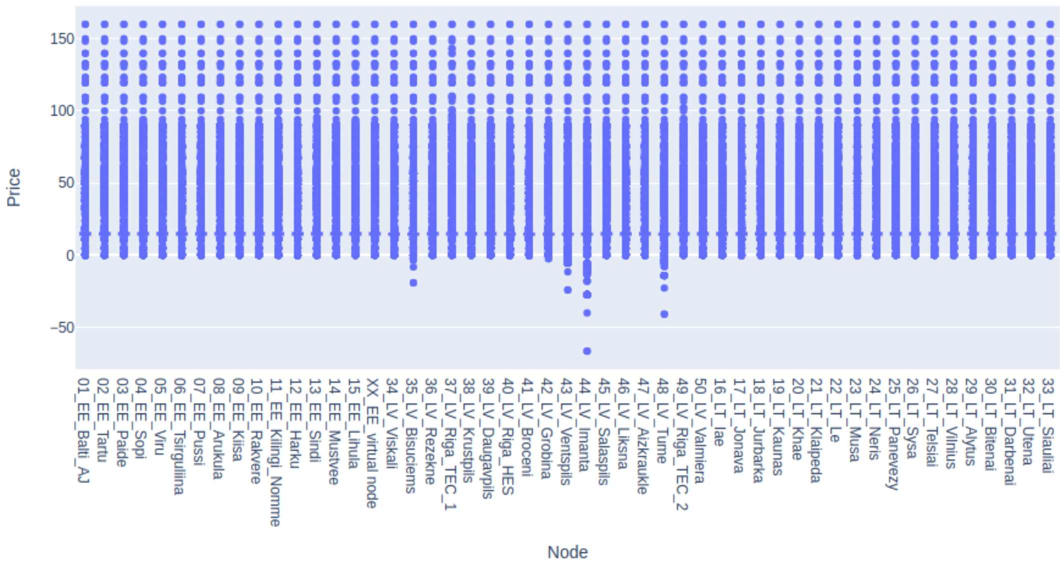

Figure 6. Hourly nodal price distribution in the Baltics for CY 1995

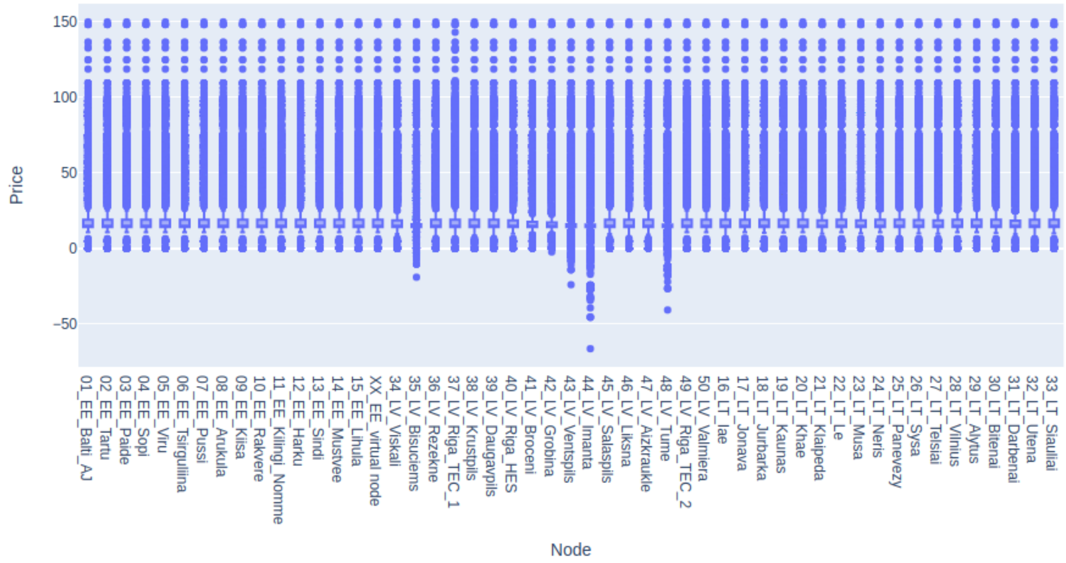

Figure 7. Hourly nodal price distribution in the Baltics for CY 2009

3.2. Price ranges comparison

Comparing Baltic LMP results with CE LMP analysis it can be observed very similar average price levels. Baltic region is influenced by import flows from Nordic prices low areas causing lower price levels in Baltic areas ranges between 20 and 30 Eur/MWh. Depending on climate scenarios in Baltic LMP analysis average prices range between 18-25 Eur/MWh.

3.3. Flow patterns

The simulation results reflect familiar flow and price patterns observed in the power system and in simulations with other simulation tools. The patterns observed are very similar to flow patterns in ERAA studies. The main flow pattern in Baltic is from the North to South nodal areas. There are also significant import flows from Nordic areas to LT and EE.

3.3.1. Grid congestions and seasonal patterns

The main limiting factors are thermal power line capacities during summer, winter seasons and N-1 contingencies. Due to lower available capacities during summer season, there is lower exchange between North to South nodes and southbound flow pattern is distinct throughout entire year period.

More visible contingency appears in Latvia in high population area due to higher consumption ration and relatively lower generation availability. However, the price differences remain insignificant.

3.4. Sensitivity analysis

Sensitivity analysis was carried out in the same manner as main scenarios simulating all three climate years (ie. 1989, 1995, 2009) including Harmony Link project. Sensitivity was selected as Harmony Link project initially was intended as part of the synchronization project. However, due to changes in the project plan, project was postponed for two years but still remain as significant part from development projects as it will used for commercial purposes between Poland and Lithuania.

The market results of sensitivity analysis show that greater exchange with Poland increase flows patterns from North to South and maintains higher price levels. Nevertheless, the price differential gradient remains similar between Baltic states nodes as in reference case scenarios.

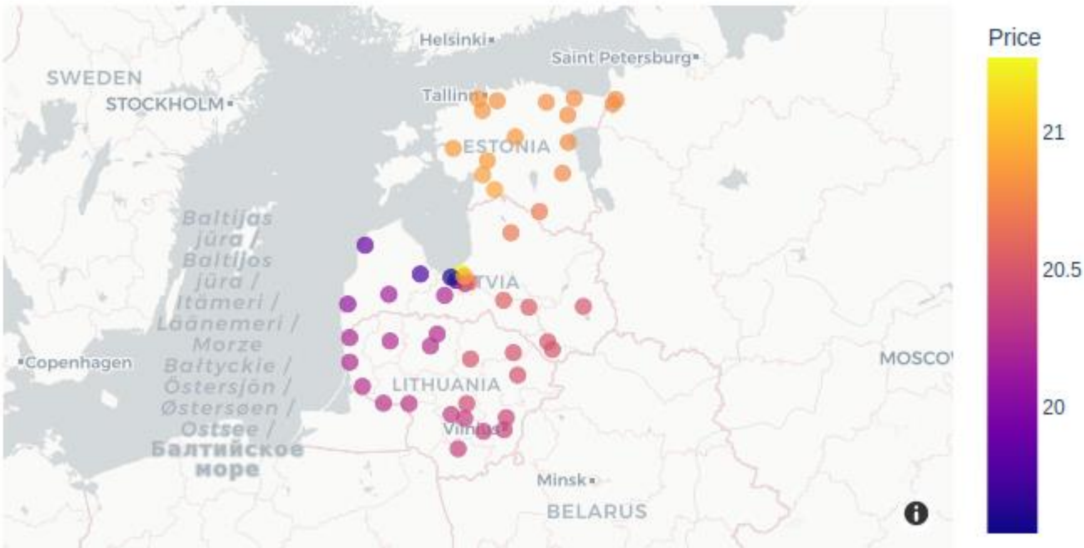

Figure 8 Average nodal prices in the Baltics for CY 1989 with Harmony Link project

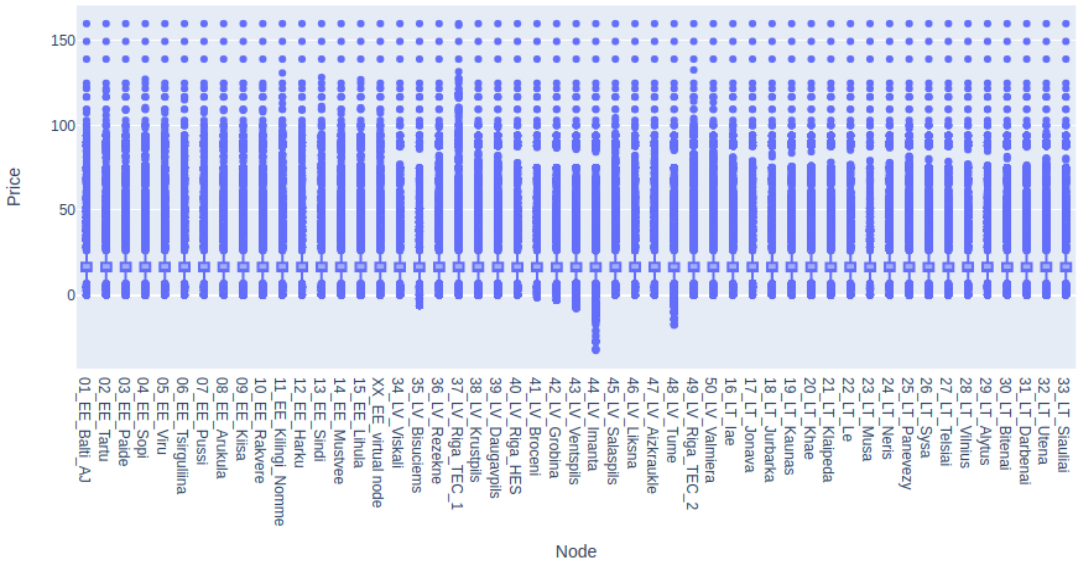

Figure 9. Hourly nodal price distribution in the Baltics for CY 1989 with Harmony Link

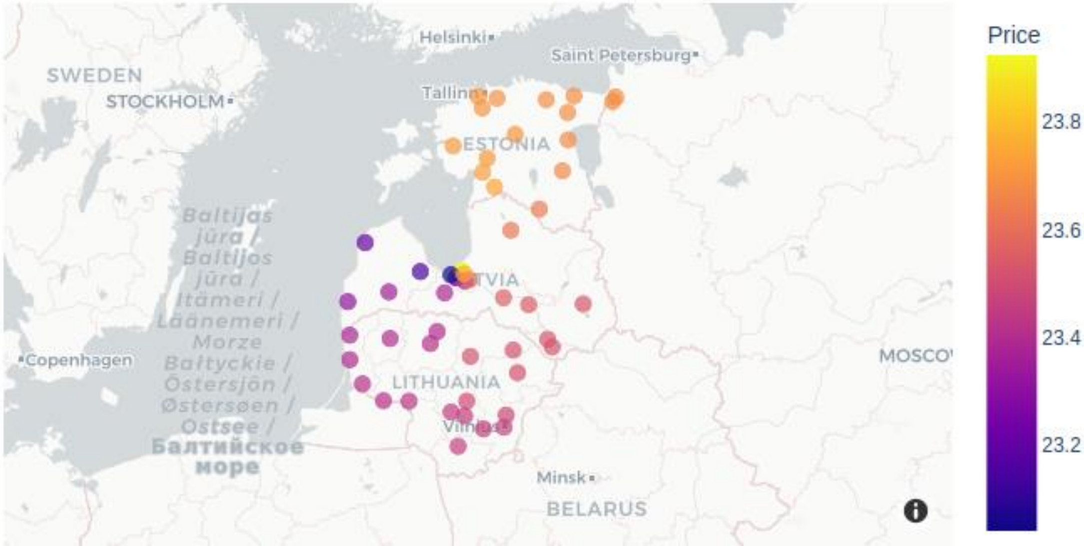

Figure 10. Average nodal prices in the Baltics for CY 1995 with Harmony Link project

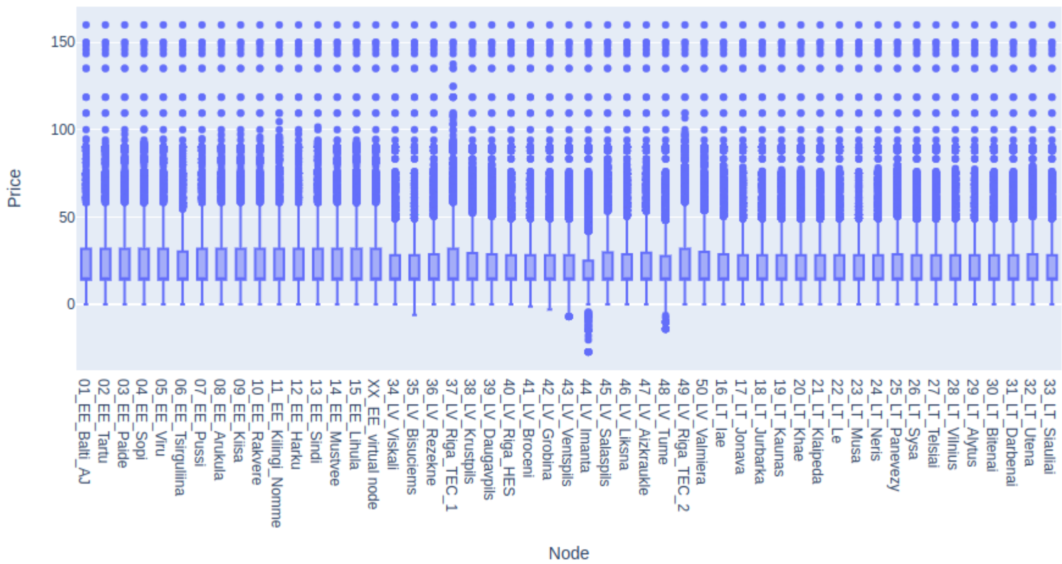

Figure 11. Hourly nodal price distribution in the Baltics for CY 1995 with Harmony Link

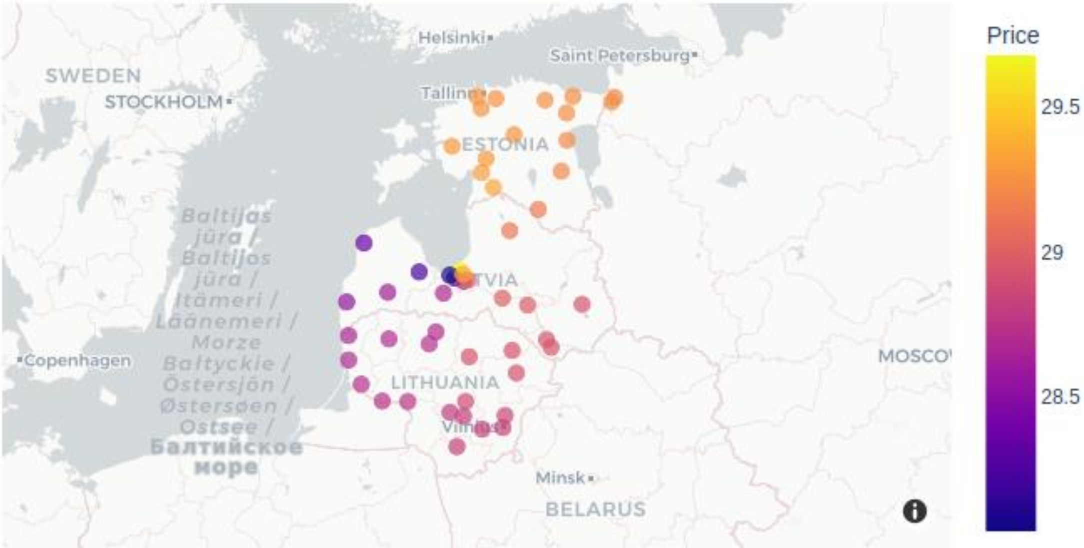

Figure 12. Average nodal prices in the Baltics for CY 2009 with Harmony Link project

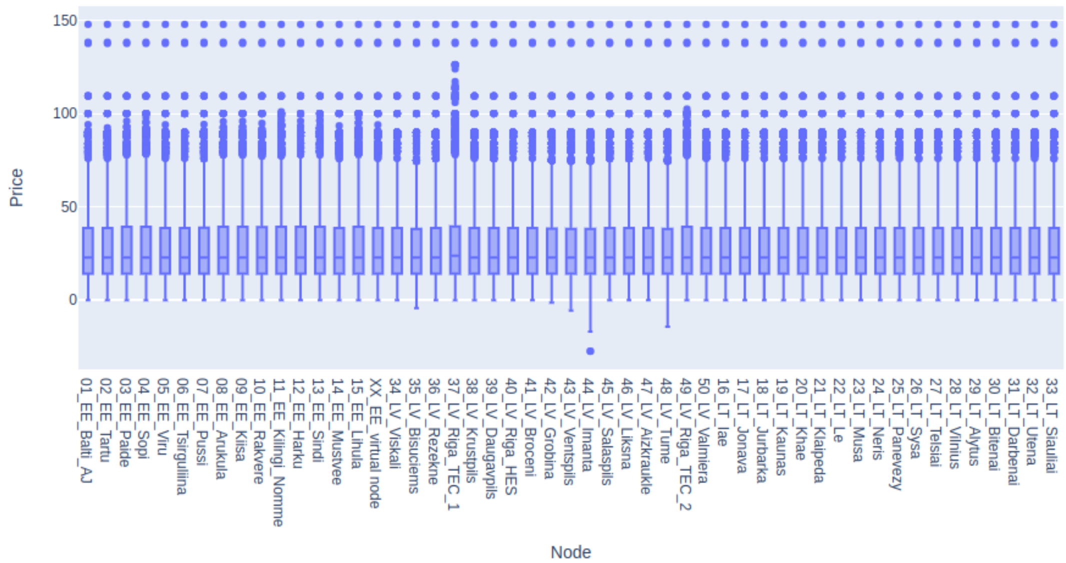

Figure 13. Hourly nodal price distribution in the Baltics for CY 2009 with Harmony Link

4. Appendix

4.1. Annex 1 Methodology and process from CE for selection of the Climate years

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. Load

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

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

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 (see **Error! Reference source not found.**). The residual load V for each macro region r is derived as follows:

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

Table 1. Macro Regions from TYNDP

Macro region	Zones*
Scandinavia	DKe, DKkf, DKw, FI, NOm, NOn, NOs, SE1, SE2, SE3
Baltic countries	LV, EE, LT
Central west 1	BE, FR, NL
Central west 2	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

*Study Zones may differ from Bidding Zones

Methodology for the selection of representative climate years

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:

a. 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;
b. Compute delta indicators to assess how years compare to the 30-year average on a regional level;
c. Selection of most representative combination of 3 years for the study (LMP analysis and Bidding zone assessment).

Figure 1. Overview of the approach for the definition of representative years/weeks

a. 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.

The following graphs show the obtained histograms of residual load per region and year[2]. Each color represents the distribution of the 8760 values of one year. One can see that the variability, and shape of distributions change per year and region, depending on the climatic conditions prevailing in each year. Areas with high variable RES shares (wind and solar), such as CW2 and SW present high variability and even negative net load. Areas with high hydro resources such as the Nordics, present significant differences between years, due to the yearly hydro resource availability (e.g. dry versus wet years).

[2] *These graphs are based on preliminary data, as the PEMMDB dataset is updated at the moment of drafting this report.*

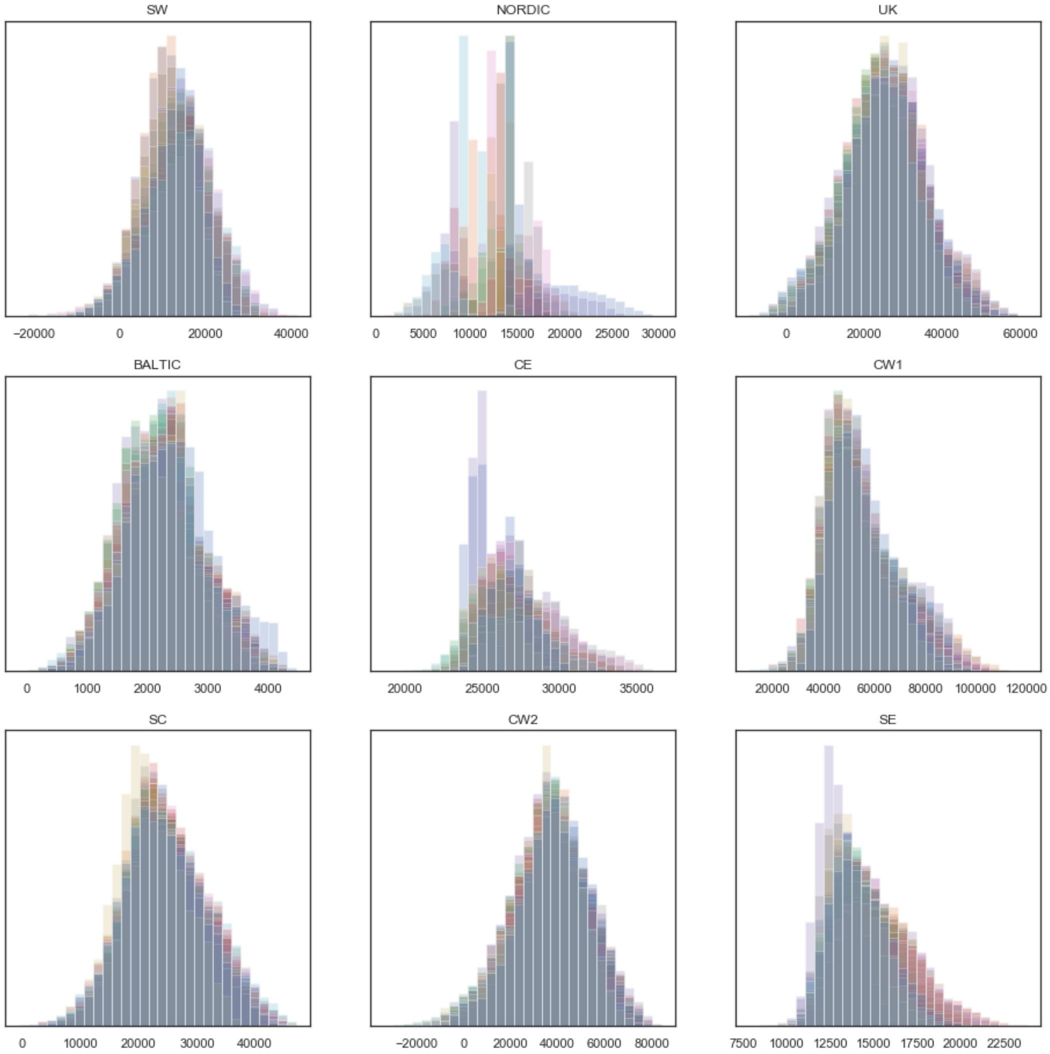

Figure 2: Distributions of residual load per region and year (each year is one color; x-axis: residual load in MW, y-axis: occurrences).

b. Delta Indicators

The goal of the assessment is to find the combination of 3 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:

$$\Omega_{r,g} = \left[V_{load,r,g} - \left(V_{solar,r,g} + V_{wind,r,g} + V_{hydro,r,g}\right)\right]$$

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 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:

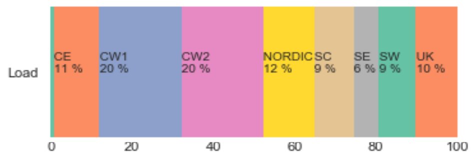

Figure 3. Weighting factors

c. Selection of candidate combination

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

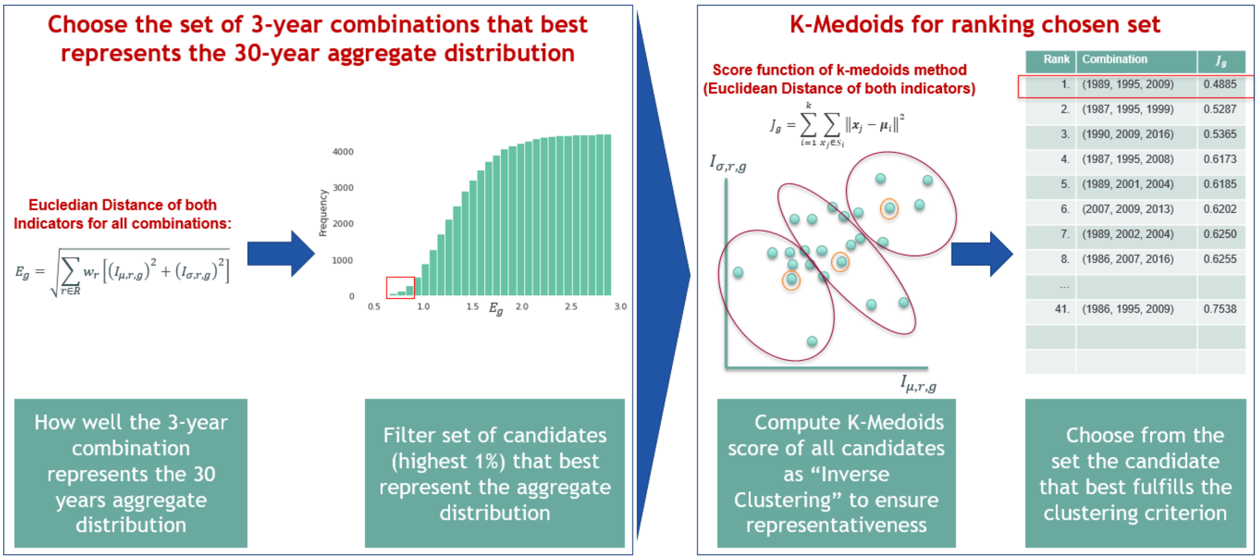

Figure 4. Two step-process for the selection of the representative candidate

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:

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

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.

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").

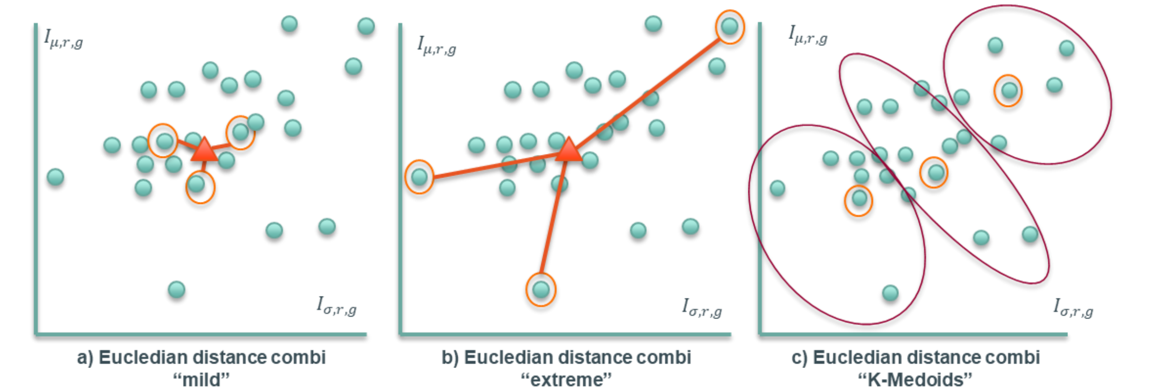

Figure 5.Examples on the selection of representative candidates

4.2. Annex 2 Development projects in the Baltics

No.	Estonia	Relevant to BZR (Over-head lines, substations, transformers, HVDC interconnector, storage)
1	L300 Balti-Tartu	Over-head lines
2	L301 Tartu-Valmiera	Over-head lines
3	L353 Viru-Tsirguliina	Over-head lines
4	Control system upgrades and new voltage control units (such as SVC) in EE	N.A.
5	Preparation works in Baltics: Baltic AGC system, frequency control monitoring system. (EE part)	N.A.
6	Network development studies (ENTSOE "catalogue of measures" study) (EE part)	N.A.
7	Two Synchronous condensers	N.A.
8	Upgrading SCADA, other IT-systems and their environment needed for real-time operations and for operational planning	N.A.
9	Development and implementation of Frequency Stability Assessment System (FSAS) together with upgrades to System Protection Schemes (SPS)	N.A.
10	Upgrading control systems of HVDC connections EstLink 1 and EstLink 2	N.A.
11	Schunt reactor Breaker reconstruction	N.A.

No.	Latvia	Relevant to BZR (Over-head lines, substations, transformers, HVDC interconnector)
1	Reconstruction of 330 kV OHL Valmiera (LV) –Tartu (EE)	Over-head lines
2	Reconstruction of 330 kV OHL Valmiera (LV) –Tsirguliina (EE)	Over-head lines
3	New voltage control units (such as SVC), WAMS, PMU, WAMPAC systems; PSS units at power stations in LV	N.A.
4	Preparation works in Baltics: Baltic AGC system, frequency control monitoring system. (LV part)	N.A.
5	Network development studies (ENTSOE "catalogue of measures" study) (LV part)	N.A.
6	Construction of Synchronous condencer for inertia requirement	N.A.
7	Battery Energy Storage System (BESS) for frequency regulation	Storage
8	Modernisation of instrument transformers and meetering system upgrade	N.A.
9	Modernisation of System Protection Schemes (SPS) and Under Frequency Load Shedding (UFLS)	N.A.
10	Power system upgrade (automatics modernisation), SCADA and dispatcher trainer	N.A.

No.	Lithuania	Relevant to BZR (Over-head lines, substations, transformers, HVDC interconnector)
1	Construction of new 330 kV ETL OHL Vilnius-Neris	Over-head lines
2	LitPol Link extension I stage (Construction of new 400/330 kV autotransformers in Alytus substation)	Transformers
3	New voltage control units (such as SVC) in LT	N.A.
4	Preparation works in Baltics: Baltic AGC system, frequency control monitoring system. (LT part)	N.A.
5	Network development studies (ENTSOE "catalogue of measures" study) (LT part)	N.A.
6	New 330kV Mūša substation	Substations
7	Reconstruction of 330 kV OHL Klaipėda - Bitėnai (from single to double circuit)	Over-head lines
8	Reconstruction of 330 kV OHL Bitėnai - Jurbarkas (from single to double circuit)	Over-head lines
9	New 330 kV ETL OHL Jurbarkas - KHAE-Sovetsk (single ETL)	Over-head lines
10	Harmony link PL-LT	HVDC interconnector
11	Construction of Darbėnai switchyard	Substations
12	Reconstruction of 330 kV OHL Klaipėda-Grobine	Over-head lines
13	Construction of synchronous compensators	N.A.
14	Development and implementation of Frequency Stability Assessment System (FSAS) together with Special Protection Schemes (SPS)	N.A.
15	Upgrading SCADA, other IT-systems and their environment needed for real-time operations and for operational planning	N.A.
16	Upgrading control systems of HVDC Nord Balt connection	N.A.