Refinement and Calibration of Optimization Models for Baltic Region Energy System Development

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***Abstract*—In this paper, we present the outcomes of the calibration efforts of two Baltic energy system operational optimization models developed in different open-source modelling frameworks. While there are a number of similarities between both approaches, there are also several differing assumptions, simplifications and data selection choices employed. Through continuous calibration we find a state of both models in which its outputs replicates the actual historical power system operational data of the year 2020 with satisfactory accuracy. Nevertheless, there are select outputs which have more notable differences either between both modelling approaches or with the historical data. We discuss these deviations and their possible reasons. Overall, the calibrated models provide a robust foundation for future scenario planning and analysis of the Baltic power system and development of the Baltic region.**

Keywords—calibration, modelling, open-source, power system, simulation

I. INTRODUCTION

Modelling, especially open-source, is becoming increasingly valuable for guiding the evolution and transition of power and energy systems [1]. Energy system models influence investments, guide operations, and support research on emission reduction and technology costs.

The value of these models is directly tied to their accuracy and replicability. Accurate models enable stakeholders to make sound decisions that optimize resources, reduce environmental impact, and ensure the stability and sustainability of energy systems. Replicability is equally important, as it allows results to be independently verified, ensuring consistent application across different scenarios and contexts. The use of open-source data for model inputs further enhances both usability and transparency [2]. Moreover, the availability of open-source data allows other researchers and stakeholders to replicate studies, compare results, and validate findings, which is critical for advancing the field.

An overview of the overall state-of-the-art concerning open-source modelling of the Baltic countries electricity markets, as well as the requirements for future model developments are summarized in [3]. The main goal of this study, however, is to calibrate on historical data the models (including data used) employed by the authors for studying the operation and future development scenarios of the Baltic power system and electricity market.

For our research, we utilize energy system modelling frameworks and tools, such as Backbone [4] and SpineOpt [5], [6]. Both frameworks are flexible and open-source, making them suitable for conducting both operational and planning studies. They also support the implementation of highly diverse case studies, allowing for a wide range of applications and analyses.

However, like in any other case, models developed using these tools need to undergo calibration. It is a critical stage in the modelling process, involving the fine-tuning of model parameters to ensure that it accurately reflects real-world data and conditions. This step is particularly crucial for energy systems, which are shaped by a multitude of interacting variables, including economic factors, technological advancements, and policy decisions. Calibration ensures that the model outputs are reliable and reflective of actual system behaviours, thereby enhancing its utility in decision-making through scenario and sensitivity analyses.

The calibration process typically involves comparing the model outputs with historical or current data and iteratively adjusting the model parameters until the outputs sufficiently align with observed trends and values. This process is particularly important when updating models with new data, as it ensures that the model remains relevant and reliable in the face of changing conditions. Data quality issues, their accessibility and consistency are also of utmost importance and the model calibration process enables researchers to also identify and rectify issues in data sources [7].

The remainder of the article is organized as follows: Section II describes the modelling methodologies, highlighting the specifics and distinguishing features of each approach. Section III presents the calibration results, discussing potential reasons for discrepancies with the statistics. Finally, Section IV offers concluding remarks to wrap up the paper.

II. MODELLING APPROACHES

A. First approach

The Baltic Backbone model was developed to analyse energy system (including the electricity, heat, building and transport segments) performance and explore decarbonisation opportunities as part of the Nordic Energy Research project Fasten [8]. Created using version 1.5 of Backbone modelling framework [4], it was originally calibrated and verified against statistical information of 2017 [9], [10]. The model performed well overall, with minor discrepancies compared to the statistical data. However, to meet current modelling needs, it is necessary to update the model to reflect 2020 data. Additionally, with the release of the latest version of the Backbone modelling framework, which offers enhanced features and improved performance, we have updated the model accordingly.

After updating the Baltic model to Backbone framework version 3.8, the results were consistent with previous outcomes achieved in the prior version. Following this, we recalibrated the model using 2020 statistics. In terms of input data preparation, the following adjustments and assumptions have been implemented:

- Natural gas prices are differentiated for each country instead of a single price for all Baltic countries as previously.
- For ETS emission price the daily auction prices are used instead of the annual average price.
- In terms of the installed capacities, to reflect the latest changes the renewable (non-combustible) sources have been updated, the conventional power plants remain as in 2017.
- Baltic countries' load profiles, wind/solar capacity factors, as well as hydropower profile for Lithuania is updated from ENTSO-E data, calibrated to match statistical data. Water inflow timeseries for Latvia are derived using inflow measurement data, in the same way as reported in [11].
- Heat demand and generation is updated using the previous methodology (i.e., incorporating actual temperature data and statistics).
- Sectoral and regional division is updated following the previous methodology. To calibrate the model in this dimension, Eurostat data is used as the primary source.
- For export and import flows we use the historical electricity day-ahead market prices of the neighbouring systems (Finland, Sweeden, Poland), excluding Russia and Belarus, for which due to unavailability of public information we use hourly prices as estimated in a previous project [8]. In general, the cross-border transfer capacities are modelled with their nominal values, which has been updated for the LitPol link compared to the previous version of the model.

B. *Second approach*

The second modelling approach is based on the SpineOpt modelling framework [5] and the Baltic power system/electricity market model developed using it during the SignAture project. In terms of validation efforts, previous work during the project focused particularly on the detailed modelling of the hydraulically link cascade of the three hydroelectric power plants (HPPs) on the Daugava river [11]. In general, the current model structure is similar to the one reported in [11], but with some important updates in assumptions and data made during calibration, namely:

- Including the day-ahead trade flows with Russia/ Belarus, which were still taking place in the calibration year of 2020.
- Updated information on the fuel costs (natural gas, oil shale), and the marginal cost of renewable producers now takes into account the financial support they were subject to.
- Included ramping and/or shut-down and start-up constraints on thermal power units.
- Separated the natural gas generation in Latvia in the three main units – Riga CHP-1, CHP-2.1 and CHP-2.2. These were previously lumped together.
- Implicitly included generation cost dependence on heat demand for these units. This was achieved by making the efficiency temperature-dependent during the heating season, since the CHPs can fully work in cogeneration mode when the heating demand is sufficiently large, otherwise they operate in a mixed mode. During Summer, it is assumed that these plants work only in condensing mode.
- Included realistic unavailability profiles due to planned and unplanned power plant outages, as sourced from the ENTSO-E Transparency Platform database.

C. *Main differences and similarities*

The most important differences of both these Baltic power system modelling approaches as implemented by the authors for the calibration stage, lie in the model scope and treatment of outages. Namely, in the first approach the scope includes not only the electricity system, but also the heating, building and transport sectors. On the other hand, outages of power plants and interconnections are currently considered in more detail in the second approach, wherein we incorporated in the model the actual historical timeseries of power system asset unavailability.

Other differences concern power plant modelling, whereby the first approach employs a more sophisticated method for detailed modelling of thermal plant efficiencies, whereas the second approach pays more attention to the details concerning the Daugava HPPs, i.e., by also considering their hydraulic linkage and consequent mutual influence. There are also differences in statistical data fed into the model, whereby the first approach mostly relies on Eurostat data [12], while the second – on the ENTSO-E Transparency Platform [13] data. Both approaches however use publicly available data, abstaining from proprietary information, which could in theory be useful for achieving better accuracies, but would not be in line with open science practices.

In principle, since both the Backbone and SpineOpt frameworks have very similar underlying philosophy and functionalities [14], the two Baltic power system models we use could be refined to work with the same assumptions and simplifications. However, due to the additional data processing and model fine-tuning efforts this would entail, it was deemed more rational to compare the current iterations of the models as is. Should they provide sufficiently similar results not only to statistical data, but also to each other, they could be considered to be cross-validated.

It should be noted that both approaches utilize linear programming/mixed integer linear programming to minimize the total operational costs of the energy system. Likewise, both models are run in hourly resolution.

III. RESULTS

Both models were continuously calibrated on statistical data of the Baltic power system operation in the year 2020. The data was sourced from such databases as Eurostat [12], ENTSO-E [13], meteorological data [15], emission trading system data [16] etc. Each model was updated using its specific approach, and their performance was compared to ensure cross-validation. Further in this section, the current calibration results are reported, aiming to determine if sufficient accuracy has been achieved to deem the models as validated.

A. *Validation of electricity production*

We start by comparing the electricity production simulated with both approaches versus the respective historical data source used for input data preparation and model calibration. Thus, unless stated otherwise, we compare the first modelling approach results to Eurostat data, whereas the second approach is primarily contrasted to ENTSO-E data. In Fig. 1 and Fig. 2, the corresponding total electricity production volumes in the verification year are summarized per type of generation source.

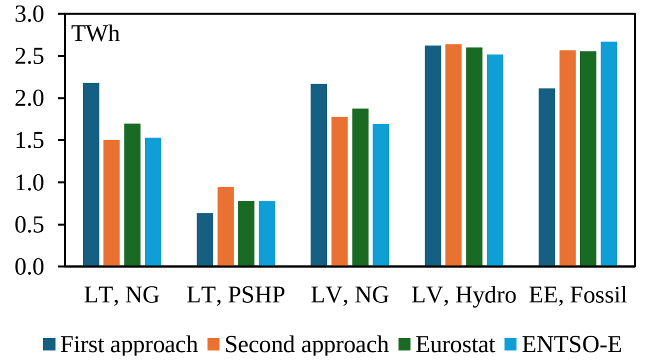

Fig. 1. Modelled and actual electricity produced in 2020 from flexible power generation plants

As concerns the flexible, conventional generation technologies, it can be seen in Fig. 1 that the simulated Latvian HPPs have, in absolute terms, the smallest deviation from the historical values, i.e., in the range of 0.08–0.12 TWh. While due to their reservoirs the three large HPPs situated on the Daugava river do have some notable short-term flexibility, unlike thermal power plants they ultimately are limited by the water inflow in the river system. Because of this, it is expected for the simulated HPP production to closely resemble the actual generation on the annual basis.

More pronounced differences can be observed in the simulated and historical output of the natural gas (NG) power plants in Lithuania and Latvia. Using the first modelling approach, there is an evident 28.4% overproduction of electricity from natural gas in Lithuania if compared to data from Eurostat, and 15.68% overestimation in Latvia. In absolute terms, this amounts to 0.48 TWh and 0.29 TWh respectively. Conversely, using the second approach, we obtain less electricity from natural gas, leading to an 1.85% underestimation compared to ENTSO-E data for Lithuania and mere 5.02% overestimation for Latvia (i.e., -0.03 and 0.08 TWh difference respectively).

Both modelling approaches lead to somewhat underestimated fossil fuel-based power plant activity in Estonia. Note that here the fossil fuel category primarily comprises oil shale, but it includes also coal-derived gas and some natural gas capacities. Both modelling approaches lead to less simulated electricity production from this category than suggested by their calibration data sources. For the first approach, the reduction is 0.44 TWh (17.3%), whereas for the second it is 0.1 TWh (3.79%).

Similar tendencies were observed when the first approach was used to calibrate a 2017 model, as noted in [17], the largest discrepancies occurred in Estonian oil shale and retort gas (9.2 TWh vs. 8.9 TWh), and Latvian natural gas (1.7 TWh vs. 2.0 TWh).

Finally, the last flexible power source to compare is the Kruonis pumped storage hydropower plant (PSHP) in Lithuania. The observation here is that while the first modelling approach underestimates the pumped storage contribution to power generation by 18.41%, the second one overestimates it by 21.9%. In absolute terms, it is -0.14 TWh and +0.17 TWh respectively. Albeit in the total generation portfolio this is a minor deviation, this points to specifics of Kruonis PSHP operation that neither of our modelling approaches have accounted for. This could potentially be related to suboptimal bidding behaviour of the storage plant in reality, since in the models we currently assume the power plant operators to have perfect information during the optimization windows. Additionally, the PSHP might be operating less or more in certain time instances than we might expect due to providing reserve services to system operators, the capacity reservations and activations of which are not necessarily reflected in public data attributable to specific power plants.

An even more evident discrepancy between the historical data sources can be seen in Fig. 2, which summarizes the comparison results for inflexible generation sources. Namely, electricity production from biomass in Estonia in 2020 was 1.5 TWh according to Eurostat but only 0.62 TWh per ENTSO-E Transparency Platform. At the time of writing, we have not managed to identify a reason for this major difference. Curiously, it is not so pronounced in the statistical data of other years. There is also a difference in biomass and biogas power production in Latvia in these information sources, albeit smaller (0.31 TWh) and in the opposite direction.

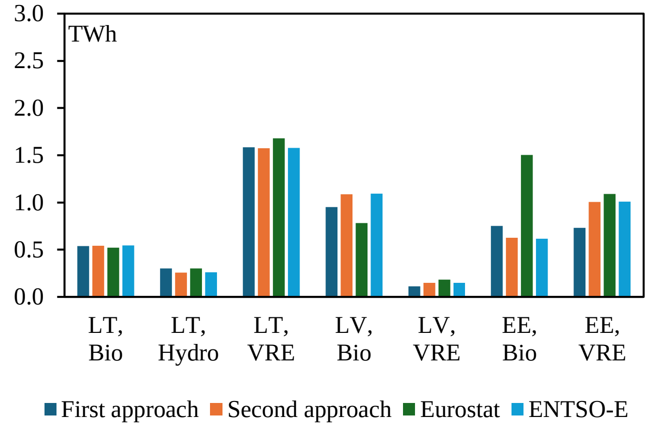

Fig. 2. Modelled and actual electricity produced in 2020 from inflexible power generation plants

As could be expected, the results of the simulations do not stray far from the historical values concerning the inflexible power plants. With the second modelling approach these values understandably match the ENTSO-E data, since these power plants were modelled as essentially must-run sources (ensured by setting their variable cost to zero or even negative, if accounting for financial support mechanisms they are subject to). With the first approach, however, there is evidently some counterfactual variable renewable energy (VRE – wind and solar) curtailment for Latvia (-0.04 TWh) and, more so, Estonia (0.28 TWh). It is likely that this phenomenon is caused by ramping constraints, thermal energy demand or other considerations that might prioritize the operation of nominally more expensive power plants in some short select time periods. The exact reason however remains to be narrowed down in further calibration efforts.

Please note that to ensure readability, the visualizations in this subsection excluded small and marginally negligible power plants. Namely, these are waste incineration power plants in Lithuania and Estonia, as well as the small HPPs in Estonia. With the second modelling approach these were also treated as must-run plants and were not curtailed, whereas with the first approach the differences in their annual production in total amounted to –0.03 TWh to 0.04 TWh, depending on the statistical information source used.

B. *Verification of import/export flows*

The performance and calibration of both modelling approaches is also verified in terms of the import and export electricity flows with those regions that are outside of the model scope (i.e. not the Baltic countries), and are thus simulated only through their interconnection capacities and the respective electricity day-ahead market prices. These countries are Finland (connected to Estonia), Sweden and Poland (both connected to Lithuania).

Note that, for the Baltic countries, there were day-ahead electricity market transactions and consequent physical deliveries in 2020 also with third-countries, namely, Russia (RU) and Belarus (BY). In November of 2020, trading via the BY-LT interconnection was suspended after the commissioning of the Astravec nuclear power plant, instead opening the RU-LV link for commercial trading [18]. These links have been taken into account in both modelling approaches, albeit differently due to uncertainty regarding the costs of the electricity imported from third-countries into the Nord Pool bidding areas of the Baltic countries.

Curiously, in initial calibration runs of the model being developed with the second approach, it was found that the simulation results imply significantly greater electricity export in the Lithuania>Poland direction than evident in the historical ENTSO-E data. After looking into this matter, it was found that the cross-zonal day-ahead trade capacities for the PL-LT (and also PL-SE4) interconnections as reported in the ENTSO-E database are insufficient to model import/export capabilities between Poland and Lithuania. This is due to the Polish electricity transmission system operator, at times, applying additional allocation constraints, which, in essence, ensure that the net import into this country does not exceed the net export. In practice, this means that some capacity of the SwePol and LitPol links can be used to carry out additional electricity trade (transit) from Sweden to Lithuania or vice versa [19], on the condition that it does not affect Poland's net position. Consequently, the handling of trade flows in the second modelling approach was adjusted to reflect this transit possibility, identifying from historical data the hours when this might have occurred. The identification was done by looking for the so-called counterintuitive flows in the historical data (i.e., trade flows where electricity goes from a more expensive area to a cheaper one, counter to economic logic).

Comparisons of the various modelled and actual electricity trade flows is presented in Fig. 3 for one direction, Fig. 4. for the opposite direction, and, finally, in Fig. 5 for the net flows. Note that the historical data from ENTSO-E Transparency Platform are the Scheduled Commercial Exchanges in the day-ahead timeframe. Arguments could be made for comparisons also with the total commercial exchange (including intraday trades) or the physical flows, but for the purposes of this study the day-ahead flows are deemed to be sufficient.

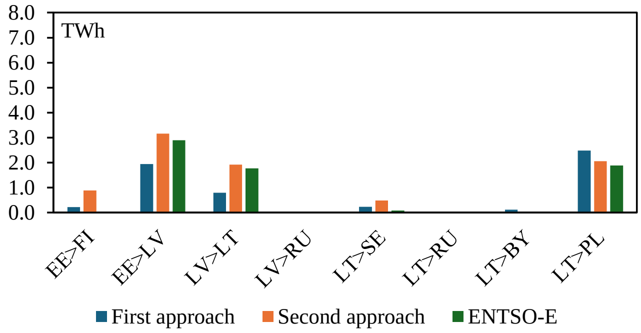

Fig. 3. Modelled and actual electricity trade flows (From > To)

As concerns the flows displayed in Fig. 3, the first observation is that both modelling approaches envision some electricity trade going in the EE-FI direction (0.21 TWh and 0.88 TWh respectively), despite the actual trade flow in that direction being only 0.02 TWh in 2020. Similarly, although to a lesser degree, both models simulate some trade in the LT-SE direction (0.22 TWh and 0.48 TWh), despite it actually being just 0.08 TWh. Concerning the Baltic North-to-South corridor for exploiting cheaper Nordic electricity from Finland, the first modelling approach envisions lesser (by 0.96 TWh and 0.98 TWh), while the second approach higher (by 0.26 TWh and 0.15 TWh) trade flows in both the EE-LV and LV-LT directions compared to the historical data. Both modelling approaches lead to larger export to Poland, with a 0.59 TWh increase for the first, and 0.17 TWh increase for the second model.

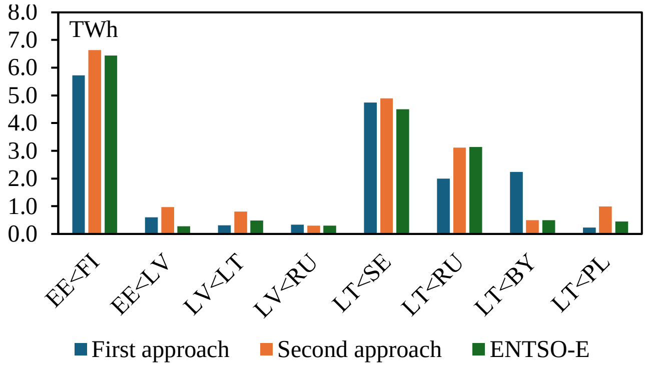

Fig. 4. Modelled and actual electricity trade flows (To < From)

The results for the same interconnections as in Fig. 3, but in the opposite trade direction are summarized in Fig. 4. Interestingly, taking both the figures into account, it is evident that the second approach, in general, generates more cross-border electricity trading than the first one. The only exceptions to this observation are the LT-PL and BY-LT directions. Nevertheless, both models provide for realistic electricity exchange with neighbouring countries.

The largest deviation expressed in absolute value for the trade directions illustrated in Fig. 4 are concerning the BY-LT direction as obtained with the first approach (+1.74 TWh), as well as the FI-EE direction for it (-0.71 TWh), and the LV-EE direction with the second approach (+0.69 TWh. The BY-LT deviation is however partly offset by reduced estimated flow in the RU-LT direction (–1.14 TWh).

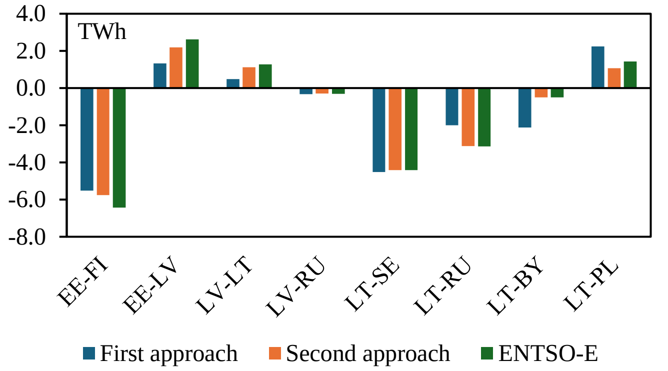

Fig. 5. Modelled and actual electricity trade net flows

Finally, let us consider the total electricity net import/export in all the modelled interconnections as summarized in Fig. 5. The overall net direction is correct with both approaches, whereby Estonia, on the whole, exports to Latvia, which in turn exports to Lithuania, whereas there is a net import for the Baltics from all directions except for Poland, to which Lithuania exports.

Generally, the second modelling approach provides net flows closer to the historical values, but the first is not far behind. With the first, the net position of Estonia is off by –0.39 TWh, Latvia +0.45 TWh and Lithuania +1.03 TWh, whereas with the second these deviations are +0.23 TWh, +0.27 TWh and -0.18 TWh respectively. The overall Baltic net position is thus off by +1.10 TWh with the first, and 0.31 TWh with the second modelling approach, which is approximately 4.09% and 1.17% of the total annual demand in the Baltic countries in the modelled year. Altogether, the deviations can be considered to be acceptable and the models suitable for further studies.

IV. CONCLUSIONS

Both approaches to Baltic power system operational modelling were successfully calibrated by achieving comparatively minor and acceptable deviations in the net positions of each Baltic country separately, and also in the Baltic power system as whole. However, there were some particular model outputs identified with each approach that showed larger individual deviations, e.g. electricity trade with Poland or the flow of electricity trade within the Baltics in the North-South direction. In terms of generation sources larger discrepancies can be observed when comparing electricity production from fossil sources both between the models and also with the statistical data. However, these differences have less influence on the feasible use of the models for future scenario assessment, since the role of fossil sources is expected to significantly decrease. Nevertheless, if deemed necessary, further calibration efforts can be carried out, e.g., if the subject of a particular modelling exercise is the study of these specific sources in more detail.

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REFERENCES

[1] M. Groissböck, "Are open source energy system optimization tools mature enough for serious use?," *Renewable and Sustainable Energy Reviews*, vol. 102, pp. 234–248, Mar. 2019, doi: 10.1016/j.rser.2018.11.020.

[2] S. Pfenninger, J. DeCarolis, L. Hirth, S. Quoilin, and I. Staffell, "The importance of open data and software: Is energy research lagging behind?," *Energy Policy*, vol. 101, pp. 211–215, Feb. 2017, doi: 10.1016/j.enpol.2016.11.046.

[3] Z. Broka and K. Baltputnis, "Open-source electricity market modelling for the Baltic states: review and requirements," in *2023 19th International Conference on the European Energy Market (EEM)*, Jun. 2023, pp. 1–6. doi: 10.1109/EEM58374.2023.10161953.

[4] N. Helistö *et al.*, "Backbone—An Adaptable Energy Systems Modelling Framework," *Energies*, vol. 12, no. 17, p. 3388, Sep. 2019, doi: 10.3390/en12173388.

[5] M. Ihlemann *et al.*, "SpineOpt: A flexible open-source energy system modelling framework," *Energy Strategy Reviews*, vol. 43, p. 100902, Sep. 2022, doi: 10.1016/j.esr.2022.100902.

[6] J. Kiviluoma *et al.*, "Spine Toolbox: A flexible open-source workflow management system with scenario and data management," *SoftwareX*, vol. 17, Jan. 2022, doi: 10.1016/j.softx.2021.100967.

[7] J. Teremranova, Z. Broka, and K. Baltputnis, "Power System Modelling in the Baltic Countries: Data Accessibility and Consistency Aspects," in *2023 IEEE 64th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON)*, Riga, Latvia: IEEE, Oct. 2023, pp. 1–5. doi: 10.1109/RTUCON60080.2023.10412855.

[8] "FasTen, 'Baltic Backbone model [FasTen project].'" Accessed: Aug. 01, 2023. [Online]. Available: https://gitlab.vtt.fi/backbone/projects/fasten-model

[9] N. Putkonen *et al.*, "Modeling the Baltic countries' Green Transition and Desynchronization from the Russian Electricity Grid," *IJSEPM*, vol. 34, pp. 45–62, May 2022, doi: 10.54337/ijsepm.7059.

[10] J. Teremranova and D. Zalostiba, "Modelling of Building Sector Impact on Decarbonization of the Baltic Energy System," in *2022 IEEE 7th International Energy Conference (ENERGYCON)*, May 2022, pp. 1–7. doi: 10.1109/ENERGYCON53164.2022.9830169.

[11] K. Baltputnis and Z. Broka, "Future scenarios of the Baltic power system with large penetration of renewables," in *2023 19th International Conference on the European Energy Market (EEM)*, Lappeenranta, Finland: IEEE, Jun. 2023, pp. 1–7. doi: 10.1109/EEM58374.2023.10161795.

[12] eurostat, "Energy Database." [Online]. Available: https://ec.europa.eu/eurostat/web/energy/database

[13] ENTSO-E, “ENTSO-E Transparency Platform.” Accessed: Mar. 14, 2023. [Online]. Available: https://transparency.entsoe.eu/

[14] L. Laveneziana, M. Prussi, and D. Chiaramonti, “Critical review of energy planning models for the sustainable development at company level,” *Energy Strategy Reviews*, vol. 49, p. 101136, Sep. 2023, doi: 10.1016/j.esr.2023.101136.

[15] SLLC “Latvian Environment, Geology and Meteorology Centre,” “Environmental Data Archive: Hydrology.” Accessed: Aug. 24, 2024. [Online]. Available: https://videscentrs.lvgmc.lv/noverojumu-arhivs/hidro

[16] eex, “EEX EUA Primary Auction Spot - Download.” [Online]. Available: https://www.eex.com/en/market-data/environmental-markets/eua-primary-auction-spot-download

[17] Nelli Putkonen, “Operational Modelling of Regional Energy System with High Share of Wind Power, Photovoltaics and Large Heat Pumps: Case Study in the Baltic Countries Towards 2030,” Master’s Thesis, Tampere University, 2022. [Online]. Available: https://trepo.tuni.fi/bitstream/handle/10024/138269/PutkonenNelli.pdf

[18] Andrius Sytas, “Lithuania stops Baltics power trade with Belarus, Russia over nuclear plant,” Reuters. Accessed: Aug. 22, 2024. [Online]. Available: https://www.reuters.com/article/world/lithuania-stops-baltics-power-trade-with-belarus-russia-over-nuclear-plant-idUSKBN27J2C9/

[19] PSE S.A, “Change of cross-zonal capacity allocation mechanism on LitPol and SwePol.” Accessed: Aug. 22, 2024. [Online]. Available: https://www.pse.pl/documents/31287/20735372/Ograniczenia_alokacji_LitPol_i_SwePol_EN.pdf