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Market Design for Cross-Border Co-Optimised Energy-Reserve Allocation

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Abstract. To achieve its energy goals, the European Union (EU) needs to establish a geographically large market by initially improving its cross-border electricity interconnections. The Hungarian project focuses on this topic. A geographically large market, based on imports and exports of electricity, could increase the level of competition, boost the EU's security of electricity supply through creating alternative routes to the customers and integrate more renewables into energy markets. Electricity should, as far as possible, flow between Member States as easily as it currently flows within Member States, in order to increase sustainability potential and real competition, as well as to drive economic efficiency of the energy system. To this end, Facilitating Regional CROSS-border Electricity Transmission (FARCROSS) aims to address this challenge by connecting major stakeholders of the energy value chain and demonstrating integrated hardware and software solutions that will facilitate the "unlocking" of the resources for the cross-border electricity flows and regional cooperation. The targets of the project are to optimise the usage of the available cross-border capacity for reserve procurement while transitioning from ATC to Flow-based mechanism, to achieve simultaneous interconnector reservation for energy and balancing capacity to enable reserve market coupling and to create state-of-art technologies to materialise market coupling platforms.

Key words. cross-border flow, wide-area monitoring systems (WAMS), dynamic load ability calculation, capacity allocation, Transmission System Operators (TSOs).

1. Introduction

The FARCROSS project prefers modern technologies in order to maximise their use, capacity and efficiency for both production and transmission. Used technologies will increase the monitoring of the grid, thus facilitating territorial interventions, increasing the electricity flow in most of the transmission channels which will facilitate flow-based market interconnection, taking into account cross-border trade as well. The project develops an innovative regional forecasting platform that will enable more efficient forecasting of renewable energy sources and assess their expected demand. A tool to optimise reserve capacity is also tested to maximise cross-border electricity flows.

Basic information about the project:

- 31 European partners, 16 countries.
- Duration: 48 months, 10. 01. 2019 – 09. 31. 2023.
- Total budget: EUR 13.5 million, of which 70 % support for industrial partners and 100 % support for public institutions.

Main objectives of the project are:

- Testing the state-of-the-art digital technologies installed on the electricity grid and communication infrastructure – such as energy flow controllers, dynamic load ability calculation systems for transmission lines and wide-area monitoring systems (WAMS) – to maximise the optimal utilisation and reliability of transmission corridors.
- Developing and deploying advanced software solutions, including capacity allocation and reserve optimisation tools to increase the potential of interconnection services and an advanced generation and demand response forecasting platform.
- Developing robust technical and market codes (pathways) that would allow the harmonisation of network codes to be built and then implemented at the national level, the integration of national electricity markets – if possible, regionally.
- Cost-benefit analysis (CBA) of the results of the project implementation and demonstrations, and lessons learned from the implementation and cross-border investments to improve the planning of cross-border investments.

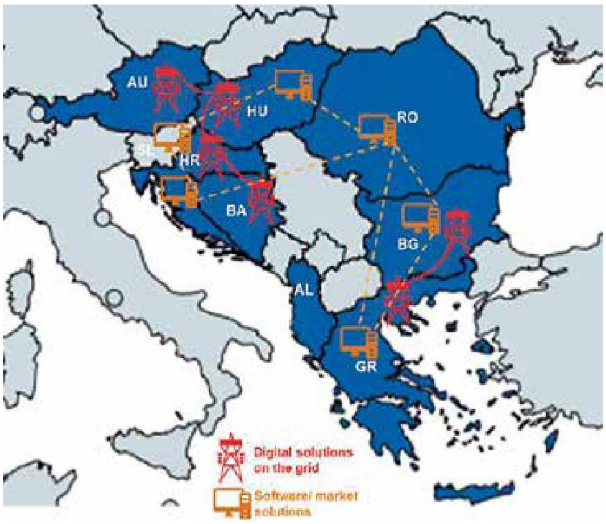


Fig. 1. Countries participating in the FARCROSS project

- Demonstrating the hardware and software technologies and relevant concepts mentioned above in a real environment. The FARCROSS project has been implemented in 8 countries (Austria, Greece, Bulgaria, Croatia, Hungary, Bosnia and Herzegovina, Romania and Albania), energy producers and actors in the energy value chain illustrate the specific functions, the real needs and existing challenges.
- Promoting further research and new market opportunities in the energy industry by ensuring effective dissemination of project results to key stakeholders.

2. Contributing partners

Table I shows that there are altogether 14 companies or institutions contributing int the FARCROSS project. There are three Transmission System Operators (TSOs): the Croatian HOPS, the Hungarian MAVIR and the Romanian TRANSELECTRICA. Two Power Market Operators (MOs): the Slovenian BORZEN and the Hungarian HUPX. Three universities: the Hungarian BME, the Croatian UNIZG-FER and the Romanian UPB. One technology provider company: the Hungarian MEI. Two generation companies: HSE and UNIPER. Finally, three managing companies: UBI, UBE and CINTECH.

The last coloumn of Table I shows the role of the specific company or institution in the project. In the middle, the logo of the company or institution can be seen.

Table I. The list of the contributing partners and the description of their role in the FARCROSS project

		Contributing partners	Logo	Role in the project
Work Package 8 Team	TSOs	HOPS	HOPS	To develop a market design for the co-optimisation of energy and reserves capacity calculation, compatible with the latest EBGL[1] proposals.
		MAVIR	MAVIR	
		TRANS	Transelectrica	
	MOs	BOR	Borzen	To align new market platform for reserve trading with the existing energy market timeline, products.
		HUPX[2]	hupx HUNGARIAN POWER EXCHANGE	
	Universities	BME	MŰEGYETEM 1782	Development and tuning of the algorithm, market and product design finalisation.
		UNIZG-FER[3]	FER	
		UPB[4]	POLITEHNICA 200 1818	
	Technology provider	MEI[5]	ME Mobility Energy Innovations Ltd.	To develop a software platform for co-optimisation of interconnector capacity.
	Generation companies	HSE[6]	hse	To enrich the market platform with the expertise and aspirations of energy producers for viable business opportunities in cross border grid services.
		UNIPER	uniper	
	Managing companies	UBI	UBITECH ubiquitous solutions	Project management, technical coordination, result exploitation, regulatory recommendations.
		UBE	UBITECH digitizing energy	
		CINTECH	CINTECH SOLUTIONS	

[1]EBGL: Electricity Balancing GuideLine,
[2]HUPX: Hungarian Power Exchange,
[3]UNIZG-FER: University of Zagreb, Faculty of Electrical Engineering and Computing,
[4]UPB: Universatea Politehnica din Bucuresti,
[5]MEI: Mobility Energy Innovations Kft.
[6]HSE: Holding Slovenske Elektrarne d.o.o.

3. Refined market process and product specifications for the OPTIC-CAP algorithm

Historical energy bids will be provided by the Nominated Electricity Market Operator/Market Operator (NEMO/MO) partners of the Project, while the historical Balancing Capacity (BC) supply bids and the demand (which mostly equals with the procured volume) will be provided by the TSOs of the Project well ahead of the algorithm runs. The new energy, BC or linked bids given by the Project Members can be submitted between the Gate Opening Time (GOT) and Gate Closing Time (GCT) via a platform which will be set up for the Demonstration.

The co-optimisation process for balancing capacity and for day-ahead energy markets consist of a 3-stage process:

- **Pre-processing stage,** in which the bids are sent from Participants to the relevant entity (TSOs/MOs), then are anonymised and converted into a standardised, OPTIM-CAP market animation algorithm format.
- **Optimisation process stage,** in which bids are matched (both energy and BC bids) and where the CZCs are allocated firmly between balancing capacity market and the day-ahead energy market.
- **Notification process stage,** in which the results of the auctions are published to the Participants.

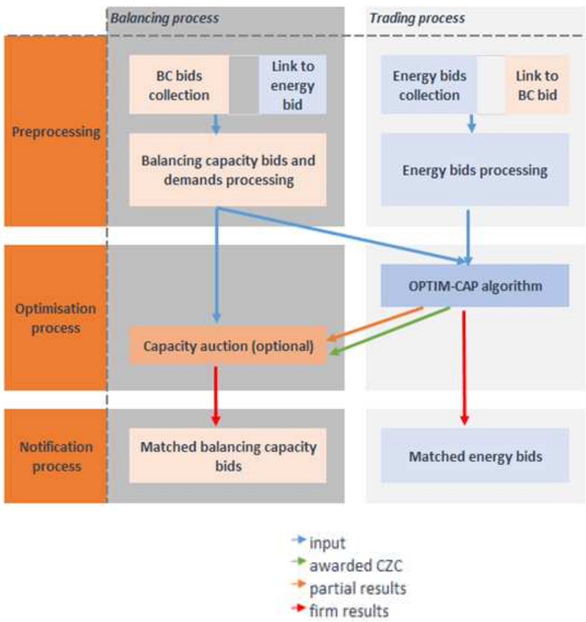


Fig. 2. Linking by exclusive group only

4. Algorithm realisation

We consider multi-zonal day-ahead trading, in which the following product types are taken into account:

- Energy
- Automatic frequency restoration reserve (aFRR)
- Manual frequency restoration reserve (mFRR)
- Restoration reserve (RR), if applicable
- Combined orders

In each product type, various orders may be submitted with characteristic parameters (e.g., block orders). Reserve substitution is not considered in the model, i.e., aFRR reserve supply orders cannot be allocated to mFRR demand orders. Combined orders may hold energy and aFRR or energy and mFRR components (both positive and negative).

The market clearing algorithm aims to maximise total social welfare over all order types, while ensuring that the transmission lines between the various zones cannot be overloaded in any considered reserve activation scenario.

Total social welfare is the sum of the following:

- Sellers’ surplus for exchange of energy
- Buyers’ surplus for exchange of energy
- TSOs’ surplus from balancing capacity allocation
- Balancing Service Providers’ (BSCs) surplus from balancing capacity allocation
- Congestion income

Surplus for BSPs is the difference between the price of the accepted bids and the clearing price per capacity unit multiplied by the accepted capacity volume of the bid (in the case of marginal pricing). Surplus for TSOs is the difference between the technical (price-taker) price limit and the clearing price per capacity unit multiplied by the volume of balancing capacity demand.

The clearing algorithm *allocates* the accepted reserve supply bids, i.e., every fully or partially accepted reserve supply bid is dedicated to one or more TSOs (in case of cross-border BC exchange) that submitted reserve demand bids of the respective type. Regarding the concept of ‘considered reserve activation scenarios’, the following principles are formalized by the clearing model:

- If no reserves are activated (i.e., the ‘nominal flow’ is realised), transmission lines should not be overloaded.
- If any allocated reserves are activated fully or partially to cover reserve demand in the zone to where the respective reserve supply order has been dedicated, transmission lines should not be overloaded.

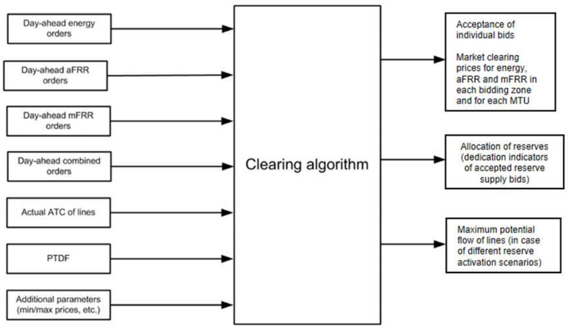


Fig. 3. Input and output of the bid matching algorithm

5. Small scale example from algorithm prototype results

This section presents an example to demonstrate the operation and results of the co-optimisation algorithm realized. Although the example is simplified, there are still many equations in the mathematical model which cannot be detailed here for the sake of clarity.

A) *Parameters of the small scale example*

There are two neighboring zones, Zone A and Zone B. Only one energy bid, one positive and one negative balancing capacity bid are placed in each zone. The last BC bids form the BC requirements of the local TSOs.

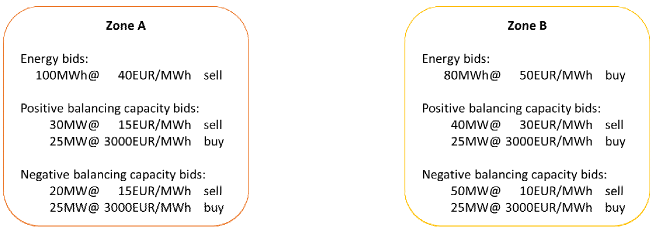
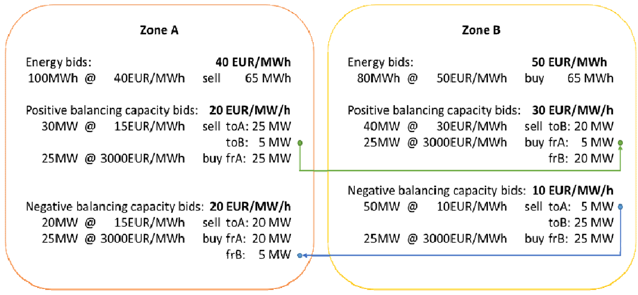


Fig. 4. Bid parameters in the small algorithm example

B) *Results of optimisation*

The optimal allocation of the volumes is the following where cross-zonal capacity allocation is highlighted:

- Positive BC requirement of TSO B is partly supplied from Zone A. (The activation of this BC will result in balancing energy flow from A to B.)
- Negative BC requirement of TSO A is partly supplied from Zone B. (The activation of this BC will result in balancing energy flow from A to B.)
- Energy demand of Zone B is fulfilled from Zone A, ie. energy flows from A to B.



$$Flow_{max} = 0.9(65+5+5) - 0.1(65+5+5) = 60$$

Fig. 5. Results of small algorithm example – baseline case

6. Demonstration sites

Three demo sites have been created in the project.

- Demo site "A": Smart Grid Innovations to increase cross-border capacity by involving the grid infrastructures of transmission system operators, using specially designed regional use cases (scenarios) to improve network resilience and to increase cross-border flows significantly.
- Demo site "B": Developing Regional System Operation Platforms that enable better TSO-level management of system operation forecasting, which contributes to transmission grid security and quality of supply. Pilot projects in SEE and SCC countries ensuring the best possible information flow between TSO participants and achieving optimal system operation at minimum cost and maximum use of existing infrastructure.
- Demo site "C": Capacity allocation at the cross-border trade, available transfer capacity for reserve procurement and energy trade, optimising the use of the current ATC based simple transfer capacity to auction algorithms to ensure system security and more efficient and valuable network capacity allocation.

As described above, the FARCROSS project aims to make the electricity system more flexible, resilient and reliable by better interconnecting the different actors in the electricity system, to achieve a more reliable energy distribution. The project participants are the Department of Electric Power Engineering of the BME (research Institute), MAVIR Zrt. (transmission system operator), HUPX Zrt. (energy exchange), Uniper Hungary Kft. (energy producer) and Mobility Energy Innovations Kft. (technology provider).

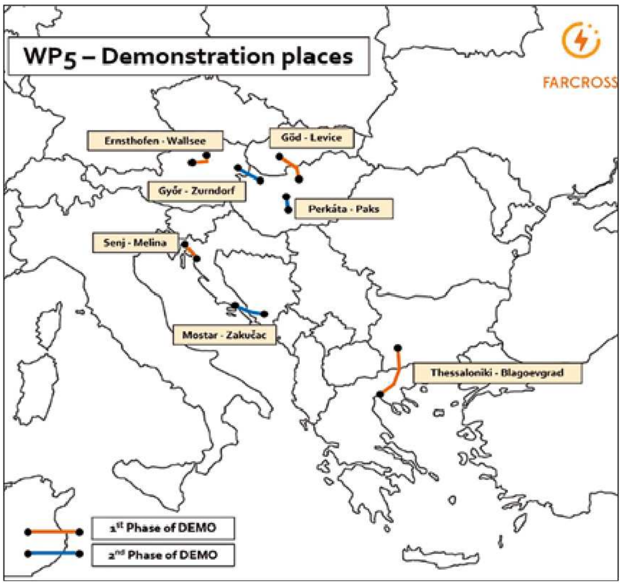


Fig. 6. DLR-H demonstration sites

One of the central elements of Work Package 5, managed by the High Voltage Engineering and Equipment Group at the BME, is the capacity expansion of cross-border transmission lines through dynamic calculation of dynamic transmission line load limits. In the DLR-H demo project, system operators, research institutes, educational institutions and sensor manufacturing companies work together on an extended, multi-site implementation of the DLR system (UBITECH, UBE, IPTO, MAVIR, APG, HOPS, NOSBiH, OST, BME, UNIZEG-FER, MONITEC, CINTECH, MEI, C&G).

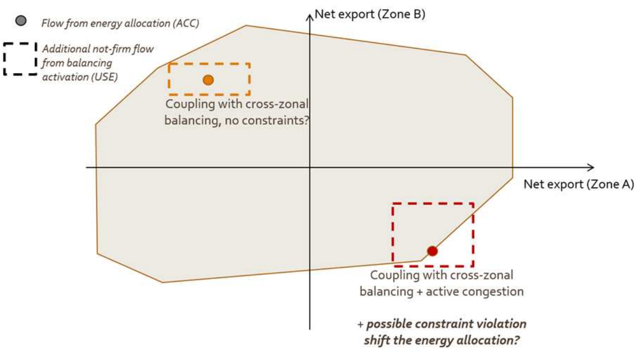


Fig. 7. Possible solutions for the allocation of cross-border capacity

Over the 4-year project period, products from two sensor manufacturers will be installed on Austrian, Hungarian, Croatian and Greek inland and cross-border transmission lines. During the implementation, an extended expert system, including both the software and the hardware, will be developed for the selected transmission lines.

The aim of the work package is to compare the measurement results of the individual sensors, to use the complex DLR expert system and to gather operational experience under real conditions. The complex transmission line management system developed by the Department of Electric Power Engineering of the BME allows, in addition to real-time load ability calculations, load forecasting, real-time drift temperature and free height reserve tracking and ice forecasting. With the help and experience of system operators, further developments and subsystems can be added to the model to further expand the spectrum of services provided by the expert system. In the work of OPTIM-CAP 8, the Department of Electric Power Engineering of the BME is also involved as the work package leader.

The goal in this case is to create a co-optimised electricity market concept for the international reserve market that considers the implicit transmission capacity, implicit allocation and the conceptual framework of the market. The optimisation can result in an increased efficiency of international energy trading and increased utilisation of congested transmission congestion. The algorithm will be tested in the electricity systems of Croatia, Hungary and Romania, involving the countries' system operators, and market operators (UBITECH, UBE, MAVIR, TRANS, HOPS, BME, UPB, UNIZEG-FER, CINTECH, MEI, HSE, UNIPER, BORZEN, HUPX).

7. Conclusion

The aim of this project is to improve the electricity network and communication infrastructure and to test the most advanced technologies available for the modernisation of the electricity network, DLR systems and large-scale monitoring systems (WAMS), to optimise and maximise capacity utilization and to manage transmission congestion. Furthermore, aims include the development and deployment of advanced software solutions, including capacity allocation and reserve optimisation tools, as well as an advanced forecasting and demand response platform for power generation, cross border capacity and the potential of cross-border grid services to increase the potential of cross-border trading. Robust technical and market codes (pathways) are developed and proposals of robust market rules are formulated, and harmonisation of operational and commercial codes and the integration of national electricity markets is carried out – possibly on a regional basis. It is essential to design and present a cost-benefit analysis (CBA) based on the results and lessons learned from project implementations and demonstrations in order to improve the planning of cross-border infrastructure investments.

Co-optimised (linked) products have been described, along with a single optimisation model representing the co-optimised auction with mathematical precision. Appropriate solving techniques for the complex, multi-product auction have been explored and prototyped to carry out the demonstration. The unique solving techniques needed for the mixed-integer optimization problems required the introduction of various general, solver specific and problem specific heuristics to ensure a well-performing solution. To deliver demonstration, various, partner specific datasets have been transformed into a single, unified order book.

Parallel to the hereby detailed product, auction, mathematical model and algorithm development, in the demonstration environment of the market auction has been set up and developed into an allocation process that is run parallel to the real market runs, capable of real-time re-runs of day-ahead auctions.

Further work is scheduled after the start of demonstration to ensure good performance of the auctions. This requires fine-tuning of the capacity allocating algorithm. The objective here is to have stable and short computation times and high precision of optimality and secure runs. Realistic data-based demonstration runs of the clearing software are required, to improve the solution process and to adjust the mathematical model or energy-reserve orders if necessary. The performance of the OPTIM-CAP markets is also going to be analysed with benefit calculation. Results of the market auction will be compared to split energy and balancing capacity market outcome. Market efficiency KPIs will be analysed, whereas recommendations will be provided for modifications which might needed on the existing market framework in relation to energy, reserve and cross-border transmission right settlement processes to the future co-optimized allocation.

The discussion of the demonstrated market solution will be summarized in the concluding Deliverable 8.5 *(Report on demonstration performance – Pilot 5)*. In order to facilitate the replicability of results, a high-level concept will be presented which together with the information about the possible demo benefits, will form one specific input for FARCROSS WP9 to deliver a final evaluation and scalability potential assessment, for policy makers, regulators, IT solution providers and end users.

Last but not least, to promote further research and new market opportunities in the energy industry, FARCROSS will contribute to the development of the subject by ensuring the effective dissemination of the results and identifying the key stakeholders.

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References

[1] Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing [Online] Available: ELI: http://data.europa.eu/eli/reg/2017/2195/oj

[2] Commission Regulation (EU) 2015/1222 of 24 July 2015 establishing a guideline on capacity allocation and congestion [Online] Available at: http://data.europa.eu/eli/reg/2015/1222/oj

[3] Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity [Online] Available at: http://data.europa.eu/eli/reg/2019/943/oj

[4] Commission Regulation (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation [Online] Available at: http://data.europa.eu/eli/reg/2017/1485/oj

[5] NEMOs: All NEMOs’ proposal for products that can be taken into account by NEMOs in single day-ahead process in accordance with Article 40 of CACM GL, 13 November 2017 , [Online] Available at: http://www.nemo-committee.eu/assets/files/nemo_committee_files/20171113_DA-Products-Proposal-1.pdf

[6] ACER: ACER Decision No No 08/2018 on NEMOs’ proposal of the Methodology for the price coupling algorithm and for the continuous trading matching algorithm, also incorporating TSO and NEMO proposal for a common set of requirements

[7] Europex: EUPHEMIA Public Description [Online] Available at: https://www.europex.org/all-nemos/all-nemos/attachment/euphemia-public-description/

[8] ACER: ACER decision No 04/2020 on NEMOs’ proposal of the Methodology for the price coupling algorithm and for the continuous trading matching algorithm[…], 2020, [Online] Available at: http://www.nemo-committee.eu/publication-detail/in-force-algorithm-methodology

[9] NEMOs: All NEMOs’ proposal for the back-up methodology in accordance with Article 36(3) of the CACM Guidline, 2018 [Online] Available at: http://www.nemo-committee.eu/publication-detail/in-force-back-up-methodology

[10] Harmonised maximum and minimum clearing prices for single day-ahead coupling in accordance with Article 41(1) of Commission Regulation (EU) 2015/1222 of 24 July 2015 establishing a guideline on capacity allocation and congestion management (CACM Regulation), 2017, [Online] Available at: http://www.nemo-committee.eu/assets/files/nemo_committee_files/acer-sdac-anex.PDF

[11] MAVIR: Timing of cross-zonal processes in the target internal energy market (IEM) model, as described according to FCA GL, CACM GL, EB GL and SO GL, 2020, [Online] Available at: http://mavir.hu/documents/10258/235727487/FIEK+Timeline_NKFIH_enhu

[12] NEMO Committee: “Products that can be taken into account by NEMOs in single day-ahead process coupling in accordance with Article 40 of Commission Regulation (EU) 2015/1222 of 24 July 2015 establishing a guideline on capacity allocation and congestion management” [Online] Available at: http://www.nemo-committee.eu/assets/files/200408_Products%20Proposal_DA_TRACK-7640fe517cd9ee883ef94895d54cf2e2.pdf

[13] ENTSO-E: Supporting Document for the Network Code on Electricity Balancing, 06 August 2014, [Online] Available at: https://acer.europa.eu/Official_documents/Acts_of_the_Agency/ANNEXES_TO_RECOMMENDATION_032015/140806_NCEB_Supporting_Document.pdf

[14] ACER: Methodology for a co-optimised allocation process of cross-zonal capacity [...] in accordance with Article 40(1) EB GL – Annex I., 17 June 2020, [Online] Available at: https://www.acer.europa.eu/Official_documents/Acts_of_the_Agency/Annexes%20to%20the%20DECISION%20OF%20THE%20AGENCY%20FOR%20THE%20C11/ACER%20Decision%20on%20CO%20CZCA%20-Annex%20I.pdf

[15] ENTSO-E: Explanatory document for the all TSO proposal for the methodology for a co-optimised allocation process of cross-zonal capacity, 2019, [Online] Available at: https://eepublicdownloads.blob.core.windows.net/public-cdn-container/clean-documents/nc-tasks/EBGL/EB_GL_A40.1_191218_ALL%20TSOs_Co-optimised_CZC_allocation_Explanatory_doc.pdf

[16] ACER: Decision No 11/2020 on Methodology for a list of standard products for balancing capacity for frequency restoration reserves and replacement reserves, 2020 [Online] Available at: https://www.acer.europa.eu/Official_documents/Acts_of_the_Agency/Individual%20decisions/ACER%20Decision%2011-2020%20on%20standard%20products%20for%20balancing%20capacity.pdf