European Network of
Transmission System Operators
for Electricity

IMPLEMENTATION IMPACT ASSESSMENT

For the Methodology for a Co-Optimised Allocation Process of Cross-Zonal Capacity for the Exchange of Balancing Capacity or Sharing of Reserves

17 December 2021

From: All TSOs

EXECUTIVE SUMMARY

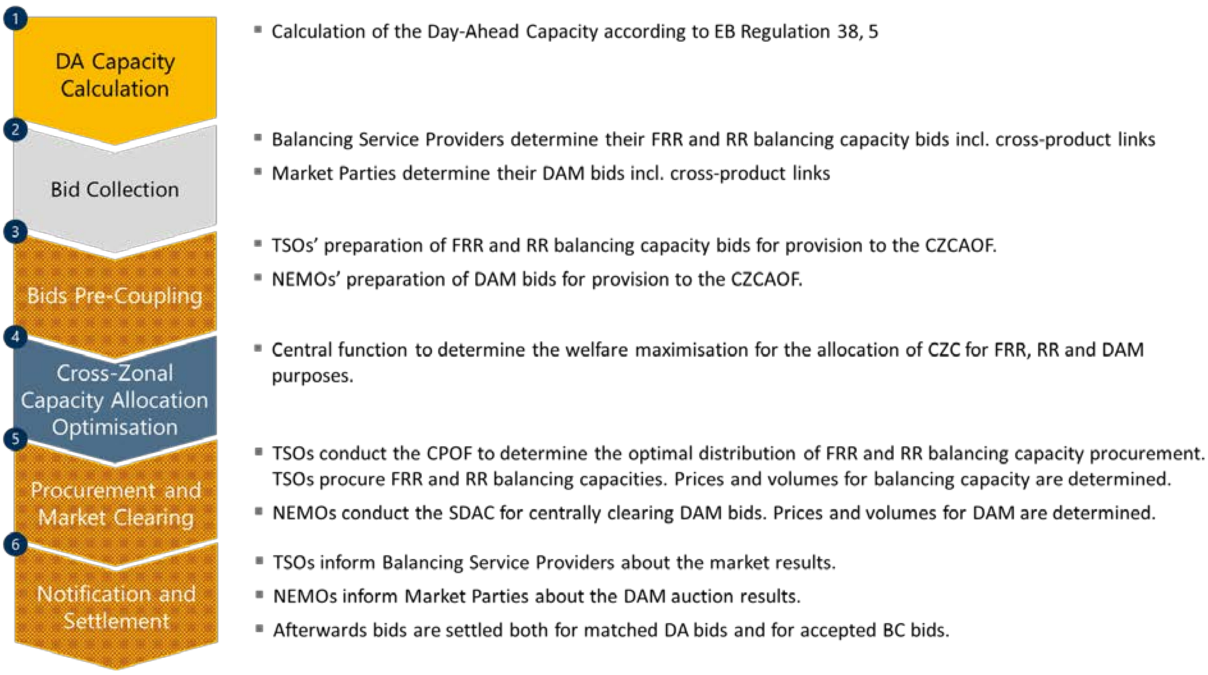
Background

The "Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing" (EB Regulation) requires all Transmission System Operators (TSOs) to develop and implement methodologies for the allocation of cross-zonal capacity (CZC) for the exchange of balancing capacity (BC) and sharing of reserves for the purpose of establishing European balancing capacity markets (BCMs). Following Articles 40 to 42, three implementation approaches apply depending on the time of allocation of CZC, the economic efficiency analysis (Art. 42), the market-based approach (Art. 41) and a methodology for a co-optimised allocation process of CZC for the exchange of BC or sharing of reserves and cross-border matching of Day-Ahead (DA) energy bids, hereafter referred to as co-optimisation, (Art. 40). Co-optimisation shall be performed when both Day-Ahead Market (DAM) and BCM bids are firm.

During the drafting of the Methodology for Co-optimised Allocation (the Methodology), the complexity of co-optimisation made clear that several market and process related aspects require deeper investigation. The Agency for the Cooperation of Energy Regulators (ACER) therefore confirmed to let TSOs conduct an implementation impact assessment (IIA) as part of the implementation phase in cooperation with the Nominated Electricity Market Operators (NEMOs). This report summarises the results of IIA.

General provisions

Co-optimisation will align existing TSO and NEMO processes. The following graph provides a general overview of the six main processes of co-optimisation and how they interact:



Each of these processes covers TSOs' and/or NEMOs' tasks and sub-processes and, consequently, different responsibilities which also depend on the approach how co-optimisation will be implemented. The central processes of co-optimisation are processes 4 and 5 covering the allocation of cross-zonal capacity via the cross-zonal capacity allocation optimisation function (CZCAOF) and covering market clearing of DAMs and BCMs. While EUPHEMIA is the optimisation algorithm for Single Day-Ahead Coupling (SDAC), such an optimisation function for balancing capacity procurement (capacity procurement optimisation function abbreviated by CPOF) needs to be elaborated for the three BC types, i.e., positive and negative automatic Frequency Restoration Reserves (aFRR), manual Frequency Restoration Reserve (mFRR) and Replacement Reserve (RR) of BC, which corresponds to (maximum) six dependent BCMs per control area.

Strands of analysis

Four major strands of analysis are followed in the IIA report:

- The economic analysis considers welfare effects of co-optimisation and demonstrates the convenience of a requirement of cross-product linking of bids between the different products to support Balancing Service Providers (BSPs)/market parties (MPs) and TSOs and NEMOs in their individual optimisation approaches.

- Implementing co-optimisation from a processual point of view requires the consideration of implementability as well as the required alignment of impacted stakeholders and their process adjustments. Therefore, a direct 1-step co-optimisation implementation option is contrasted with alternative implementation options based on a 2-step co-optimisation.

- The technical feasibility analysis discusses the implementability of co-optimisation subject to already existing functionalities in EUPHEMIA. It also considers the most practical implementation path of co-optimisation from a technical point of view.

- From a governance perspective, the three optimisation functions (CZCAOF, CPOF, and EUPHEMIA) and corresponding responsibilities are discussed to best meet current and future roles in the European energy sector. The focus of the analysis was dedicated to a functional and efficient implementation of co-optimisation.

<u>Economic Analysis:</u>

Co-optimisation requires three functions to be optimised in parallel to maximise European economic surplus:

(1) The cross-zonal capacity allocation optimisation function (CZCAOF) determines the allocation of CZC for DAM purposes or for BCM purposes.

(2) The capacity procurement optimisation function (CPOF) defines which BSP offers should be procured by TSOs for balancing capacity reservation.

(3) The Single Day-Ahead coupling (SDAC) provides the welfare maximising match of DAM bids using EUPHEMIA.

As co-optimisation requires one gate closure time (GCT) of BCMs which should also be aligned with DAM GCT, BSPs/MPs bear the risk of non-acceptance of bids. Sequential BC procurement and subsequent DAM GCT (as implemented in most European countries today) enables BSPs/MPs to offer non-accepted production capacities in earlier markets to a subsequent auction. E.g. if a production capacity offer has not been accepted for positive aFRR BC provision, the BSP can offer exactly this production capacity for positive mFRR BC purposes afterwards. Simultaneous market clearing of all BCMs and DAMs as required for co-optimisation disables the provision of bids for one and the same unit of production capacity to multiple markets. Beyond, there is also a risk for TSOs as non-acceptance of bids in a simultaneous market-clearing regime could reduce liquidity in some BCMs resulting from an under-provision of less attractive BC types for BSPs.

To avoid such downsides from co-optimisation, this IIA report investigates the introduction of cross-product linking of bids. Cross-product linking of bids allows BSPs/MPs to offer the same production capacity to multiple markets at the same time and allows TSOs to link their balancing capacity demand across the different quality products of BC. If one of the bids of market participants is accepted in one market, the linked other bids are withdrawn from the other auctions, exclusive group linking. Bids do not need to have the same price in different markets nor the same volume. BSPs/MPs can maximise their production portfolios without forming a precise expectation of market prices. Therefore, cross-product linking of bids reduces the risk of non-acceptance of bids for BSPs and also TSOs' risk of market illiquidity.

An additional complexity appears in CCRs using flow-based. Calculating CZCs in a flow-based domain requires the differentiation of actually employed CZCs and reserved CZCs for potential usage. While accepted cross-border DAM bids will initiate a cross-border energy flow in the period of fulfilment, an energy flow need not be initiated by cross-border reserved BCs. An energy flow will only exist when the reserved BC will be activated. In consequence, CZC for BC purposes must be considered differently than CZC allocation for energy market purposes when determining the available CZC in the flow-based domain.

Implementation Options of Co-Optimisation

Since a fully integrated co-optimisation in SDAC will severely impact the current processes, alternative implementation options are explored to search for an optimal implementation of co-optimisation by taking into account not only technical (incl. algorithmic performance), but also economical aspects (market & regulation) and governance perspectives. In total, four implementation options of co-optimisation have been identified:

In the 1-step co-optimisation option, the CZCAOF, the CPOF and EUPHEMIA are run jointly. This allows for multilateral cross-product linking in the sense that a BSP/MP does not need to consider the order of optimisation across markets in its portfolio optimisation calculus. As all three processes are optimised in parallel and as there is no order-of-linking restriction across markets, this implementation option is expected to provide the first best optimisation result. Nevertheless, this perfect bid matching and CZC allocation comes along with a complex optimisation problem and, therefore, a more complex optimisation run which requires sufficient optimisation time. Also, the bid preparation for market participants requires an evolution due to the full price and bid interaction between the markets.

2-step co-optimisation implementation options add more requirements to the optimisation approach but reduce the complexity of the optimisation process and the optimisation time at the cost of a second-best optimisation outcome. The following 2-step co-optimisation implementation options are considered in the IIA report:

- The implementation option CZCAOF together with CPOF [CZCAOF&CPOF] performs the CZCAOF including all the requirements of the CPOF(s) and simplified requirements of SDAC in the first step, interacting with the CPOF(s). Based on the outcome of the BC procurement and the remaining CZC, the CZCAOF optimises the available CZC for SDAC and the available bids from linking. In a second step, SDAC runs separately using EUPHEMIA.

- The implementation option CZCAOF together with SDAC [CZCAOF→←SDAC] performs the CZCAOF including all the requirements of the CPOF(s) and simplified requirements of SDAC in the first step, interacting with the SDAC. Based on the outcome of the DA market clearing and the remaining CZC, the CZCAOF optimises the available CZC for BC and the available bids from linking. In a second step, CPOF will be run. This implementation option is considered as an intermediate solution for a fast-track implementation where all stakeholders could learn how co-optimisation and cross-product linking of bids change the market outcomes.

- The implementation option CZCAOF together with SDAC [CZCAOF↔SDAC] is the more comprehensive solution of the prior implementation option. Here, the CZCAOF is performed together with EUPHEMIA, taking into account all the requirements of the CPOF(s). In a second step, the CPOF(s) perform the BCM after SDAC has been cleared. It is more comprehensive in the sense that it requires a continuous exchange between the CZCAOF and EUPHEMIA during the first step and there is a possible risk of non-satisfied TSO BC demand since clearing of the BCM is the last step. On the other hand, it is expected that it would be possible to consider all types of DAM bids during the CZC allocation. Based on the outcome of the DA market clearing and the remaining CZC, the CPOF will be run in the second step.

Due to the required stepwise optimisation approach, the 2-step co-optimisation implementation options support only unilateral cross-product linking of bids, not multilateral cross-product linking of bids to keep the market clearing consistent where bids in the money will always be cleared. In consequence, the 2-step co-optimisation implementation options prioritise the market outcomes of the first step over the market outcomes of the second step.

Technical Feasibility Analysis

While all considered implementation options are feasible from a processual perspective, the technical feasibility analysis provides insights into potential technical obstacles. Implementing co-optimisation by any of the determined implementation options requires a detailed understanding of feasible optimisation functionalities.[1] The challenge of optimising three functions together is to structure the computational functionality of the optimisation approach. In so doing, the complexity can be reduced without essentially reducing the solution space. Multiple computational variations exist how a 1-step co-optimisation implementation option can be solved whereof the inscribed boxes approach seems to be most promising from a qualitative technical expert assessment.

In contrast to the reduction of complexity by structuring the computational functionality, implementation options of 2-step co-optimisation options reduce calculation complexity by structuring the co-optimisation process itself. This simplification provides market outcomes which reach at most the same total European economic surplus as a 1-step co-optimisation implementation option. However, computational complexity and, thus, also optimisation time is expected to be lower with the 2-step co-optimisation implementation options than with a computational variation of the 1-step co-optimisation implementation option.

As the inscribed boxes approach seems to be feasible based on this high-level qualitative analysis, it is technically prioritised over the 2-step co-optimisation implementation options from the qualitative technical expert assessment which should be further investigated with a prototype analysis.

Governance Perspective

Co-optimisation requires a distributed setup of optimisation functions:

- Subject to current provisions of Capacity Allocation and Congestion Management (CACM) 2.0, the CZCAOF is expected to become a central function governed by the market coupling operator (MCO) function.
- The operation of SDAC is also governed by the MCO function.
- The CPOF operation is a TSO function. As it is not yet decided how BC procurement should be implemented between TSOs, this could be a local function of individual TSOs, a joint function of some TSOs or it could also be a central function for all European TSOs.

The three functions mentioned are the core functions of co-optimisation. Local process responsibilities such as reserve dimensioning, the bid preparation processes as well as the settlement processes will remain with the same responsible as today. These processes will be

[1] The qualitative technical feasibility analysis has been conducted by NEMOs with a strong support of NEMOs' IT service provider.

governed by individual TSOs or NEMOs. As the optimisation functions as well as the local process steps are required in all implementation options, the governance is the same as today.

Next Steps

The technical feasibility analysis provides a detailed but high-level qualitative overview for the set of requirements for the implementation of co-optimisation. As the set of requirements will be provided by TSOs to NEMOs in June 2022, the IIA report highly recommends a prototype-based analysis of the identified implementation options before. Foreseen detailed requirements for a 2-step implementation and a 1-step implementation need to be further assessed. It is also expected that such a prototype analysis provides detailed insights into the technically most favourable implementation approach. This could be a "one-shot" 1-step co-optimisation implementation. It could also be a stepwise implementation starting with a hands-on 2-step co-optimisation implementation and a subsequent 1-step co-optimisation implementation. Therefore, it is recommended to conduct a prototype analysis which compares computational variants of a 1-step co-optimisation implementation option with 2-step co-optimisation implementation options, and which facilitates the definition of the set of requirements.

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GLOSSARY

Cross-product linking describes the possibility to combine bids for products of different quality. E.g. a positive aFRR BC order can be linked with a DAM supply bid order. The aim of cross-product linking is to prevent the choice to be made by BSPs and MPs to engage in only one market. Since co-optimisation requires one GCT for all products, cross-product linking enables the provision of the same production or consumption capacity to multiple markets. Thus, cross-product linking reduces the market-related uncertainty for BSPs and MPs that their bid is not taken in a market and, at the same time, increases market liquidity. The following possibilities of bid provision and acceptance of linked bids exist:

(1) Linked bids must be either both accepted/rejected or
(2) the acceptance of the bid in a first market leads to the deletion of the linked bid in a second market or
(3) the rejection of the bid in a first market sets free the offer of the linked bid in a second market.

See also *multilateral linking* and *unilateral linking for types of cross-product linking.*

Implementation options are possibilities how co-optimisation can be technically implemented. Co-optimisation requires the joint optimisation of CZC allocation and, at least, either the SDAC or the CPOFs and the optimisation of the remaining markets subsequently. Whether co-optimisation should be done in one step or in two steps and alternative arrangements of two-step solutions are summarised as different implementation options in this report. See also *1-step/2-step co-optimisation options.*

MARI: **M**anually **A**ctivated **R**eserves **I**nitiative, Project for implementation of European platform for the exchange of balancing energy from frequency restoration reserves with manual activation in accordance with Article 20 of Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing (mFRR Implementation framework)

Multilateral linking describes a combination of bids from different markets (different quality) defined by the BSP or the MP offering the bids. The selection of linked bids in either market depends on their marginal value in each market in the sense that the linked bid is provided to the market where it adds higher Europe-wide social welfare. Market prices and/or volumes of linked bids do not need to be identical. See also *cross-product linking* and *unilateral linking.*

PICASSO: Project for implementation of European platform for the exchange of balancing energy from frequency restoration reserves with automatic activation in accordance with Article 21 of Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing (aFRR Implementation framework)

1-step/2-step co-optimisation options are different arrangements of co-optimisation.

In the 1-step co-optimisation option, the CZC allocation, the SDAC and the CPOFs are optimised in parallel. This option is the most complex but also the most efficient arrangement of co-optimisation.

2-step co-optimisation options first optimise the CZC allocation either together with the SDAC or with the CPOFs and, in a second step, optimise the remaining markets based on the outcomes of the first step. Thus, results of the first step influence the outcome of the second-step optimisation. In consequence, 2-step co-optimisation options result in second-best solutions compared to a 1-step implementation but implementation may be less complex and BSPs/MPs as well as TSOs could become more familiar with the underlying rules of co-optimisation with a potential stepwise implementation starting with a 2-step implementation before the final 1-step implementation. See also *implementation options.*

TERRE: European platform for the RR exchange in accordance with Article 19 of Commission Regulation (EU) 2017/2195 establishing a guideline on electricity balancing (RR implementation framework)

Unilateral linking describes a combination of bids from different markets (different quality) defined by the BSP or the MP offering the bids. Unilateral linking prioritises a priori a first market clearing over a second market clearing in the sense that the acceptance or rejection of a bid in the first market determines the offer of the linked bids in the second market. With respect to unilateral linking between BCM, markets for higher quality products must be cleared before markets for lower quality products, i.e. aFRR before mFRR before RR BCM. Market prices and/or volumes of linked bids need not be the identical. See also *cross-product linking* and *multilateral linking.*

LIST OF ABBREVIATIONS

Abbreviation	Term /Acronym
ACER	Agency for the Cooperation of Energy Regulators
aFRR	Automatic Frequency Restoration Reserves
AOF	Activation Optimisation Function
BC	Balancing Capacity
BCM	Balancing Capacity Market
BECC	Balancing Energy Capacity Calculation
BRP	Balance Responsible Party
BSP	Balancing Service Provider
BTCC	Balancing Timeframe Capacity Calculation
BZB	Bidding Zone Border
CACM	Capacity Allocation and Congestion Management
CCR	Capacity Calculation Region
CEP	Clean Energy Package
CMM	Capacity Management Module
CNEC	critical network elements and contingency
CGM	Common Grid Model
CPOF	Capacity Procurement Optimisation Function
CZC	Cross-Zonal Capacity
CZCAOF	Cross-Zonal Capacity Allocation Optimisation Function
CZCL	Cross-Zonal Capacity Limit
DA	Day-Ahead
DACC	Day-Ahead Capacity Calculation
DAM	Day-Ahead Market
EB Regulation	Electricity Balancing Regulation Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing
ENTSO-E	European Network of Transmission System Operators for Electricity
FRR	Frequency Restoration Reserve
GCT	Gate Closure Time
GSK	Generation Shift Key
ID	Intraday
IDCC	Intraday Capacity Calculation
IGCC	International Grid Control & Cooperation
IGM	Individual Grid Model
IIA	Implementation Impact Assessment

KPI	Key Performance Indicator
LFC	Lead Frequency Control
MCO	Market Coupling Operator
mFRR	Manual Frequency Restoration Reserves
mFRRda	Manual Frequency Restoration Reserve directly activated
MP	Market Party
MTU	Market Time Unit
MW	Megawatt
NEMO	Nominated Electricity Market Operator
NRA	National Regulatory Authority
PTDF	Power Transfer Distribution Factor
RA	Remedial Action
RAM	Remaining Available Margin
ROSC	Regional Operational Security Coordination
RR	Replacement Reserves
SDAC	Single Day-Ahead Coupling
SIDC	Single Intraday Coupling
SO Regulation	System Operation Regulation
SPBC	Standard Product of Balancing Capacity
TSO	Transmission System Operator

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1 Background

1.1 The Electricity Balancing Regulation

The first steps towards pan-European competitive and liberalised energy markets to lower costs for end-consumers and increase security of supply were taken back in the nineties. Nevertheless, safeguarding the stability of the grid, where cross-border trades take place today, was until recently more a national matter. This is based on the fact that balancing supply and demand differs between the countries as each Transmission System Operator (TSO) developed specific products and mechanisms to do so.

On 23 November 2017 the European Commission published the Electricity Balancing Regulation (EB Regulation, formerly Commission Regulation (EU) 2017/2195). It focuses on defining standard balancing products, European balancing platforms for their exchange and harmonizing the balancing capacity markets (BCMs) while allowing new players such as demand response and renewables to take part in this market. Furthermore, it is an additional step towards an increased security of supply, limited emissions and diminished costs to customers.

1.2 Co-Optimisation and the Implementation Impact Assessment

The EB Regulation requires all TSOs to develop and implement methodologies for the allocation of cross-zonal capacity (CZC) for the exchange of balancing capacity (BC) and sharing of reserves for the purpose of establishing European BCMs. Following Articles 40 to 42, multiple allocation approaches are possible depending on the available lead-time. The economic efficiency analysis shall be used if CZCs are allocated with no firm Day-Ahead Market (DAM) bids and no firm BCM bids (Art. 42). A market-based approach shall be used if either DAM or, alternatively, BCM bids are firm but not the others (Art. 41). EB Regulation Art. 40 describes a methodology for a co-optimised allocation process of CZC for the exchange of BC or sharing of reserves and cross-border matching of Day-Ahead (DA) energy bids, hereafter referred to as co-optimisation. Co-optimisation shall be applied when both DAM and BCM bids are firm.

During the drafting of the Methodology for co-optimised allocation, the complexity of co-optimisation made clear that several market and process related aspects require deeper investigation. The Agency for the Cooperation of Energy Regulators (ACER) therefore confirmed to let TSOs conduct an implementation impact assessment (IIA) as part of the implementation phase.

This chapter will elaborate on the aspects of the timeline, the content and the working approach for the IIA, as a result of the approval of the methodology for co-optimised allocation by ACER.

1.2.1 Implementation Timeline

By ACER's Decision on a Methodology for Co-Optimised Allocation[2], the legal obligation of EB Regulation Art. 40, 1 has been met. EB Regulation Article 13(3) of the Decision requires all TSOs to send the new set of requirements for the price coupling algorithm to the Nominated Electricity Market Operators (NEMOs) and to publish it on the European Network of Transmission System Operators for Electricity (ENTSO-E) website after two years after approval, i.e. on 16 June 2022.

1.2.2 Work Packages

Article 13, 2 of the Methodology lists eight topics which shall be addressed within the IIA report:

(a) Governance of the cross-zonal capacity allocation optimisation function (CZCAOF)

Chapter 10 of the IIA report gives insights about responsible entities, the data owner, the platform under which the process of co-optimisation executed by the CZCAOF would be performed and the decision body that would manage any evolution in the process.

(b) Technical feasibility of the implementation of the CZCAOF

The technical feasibility is analysed in chapter 9. The technical feasibility analysis focuses on required adjustments of existing EUPHEMIA processes, a technical evaluation of different market structures and the identification of more efficient optimisation approaches to the implementation with EUPHEMIA. It also considers technical requirements for alternative implementation options of a 2-step co-optimisation.

(c) Flow-based compatibility

Chapter 7 summarises the results of the study 'CZC Allocation with Co-Optimisation' about the implementation of co-optimisation in the flow-based domain. It discusses the effects of CZC allocation for BC purposes on the single Day-Ahead coupling (SDAC) volume and possible processual solutions.

(d) Compatibility with the methodology for the price coupling algorithm and the continuous trading matching algorithm pursuant to Article 37 of the Capacity Allocation and Congestion Management (CACM) Regulation

Chapter 11 analyses the compatibility of the co-optimised allocation of CZC according to EB Regulation Article 40 with ACER Decisions on Algorithm – Annex I to V for different approaches.

[2] https:/ / documents.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

(e) Impact analysis on the operational security of the interconnected transmission system

The impact on the operational security will be discussed in chapter 12. It highlights direct and indirect consequences on operational security.

(f) Level of linkage between standard BC bids in time and between products and between standard BC bids and DAM bids

This topic will be handled in chapter 4, in chapter 5 as well as in chapter 6. Chapter 4 focuses on the consequences of co-optimisation on the market, compliance and welfare. A simulation study shows the impact of cross-product linking on economic surplus in chapter 5. Chapter 6 refers to a study that explores the feasibility of linking of bids between BCMs and DAMs, so-called cross-product linking.

(g) The reasoning for the separate procurement step performed by TSOs to clear the BCM, after the co-optimised CZC allocation

The reasoning of a separate procurement step can be found in chapter 13. The effects of a separate procurement step on various factors such as governance and liability agreements are evaluated.

(h) Costs estimation, categorisation and sharing

Chapter 14 provides a cost estimation, categorisation and cost sharing based on the co-optimisation options introduced in chapter 8.

1.2.3 Working Approach

Next to the implementation timeline, Article 13(1) of the Methodology for Co-optimised Allocation points out that the report shall be prepared by all TSOs in cooperation with all NEMOs. Progress and content shall be regularly reported to ACER and national regulatory authorities (NRAs).

2 Process of Co-Optimisation

2.1 Introduction

Co-optimisation will align existing TSO and NEMO processes comprehensively. Therefore, it is important to provide a detailed overview of the processes, their required inputs and outputs. The focus of this chapter is on the joint processes between TSOs and NEMOs and between TSOs applicable for any possible implementation option of co-optimisation. Individual TSO, NEMO, Balancing Service Provider (BSP) and market party (MP) processes which provide inputs or receive outputs from joint processes are not further elaborated.

The following graph provides a general overview of the six main processes of co-optimisation and how they interfere:

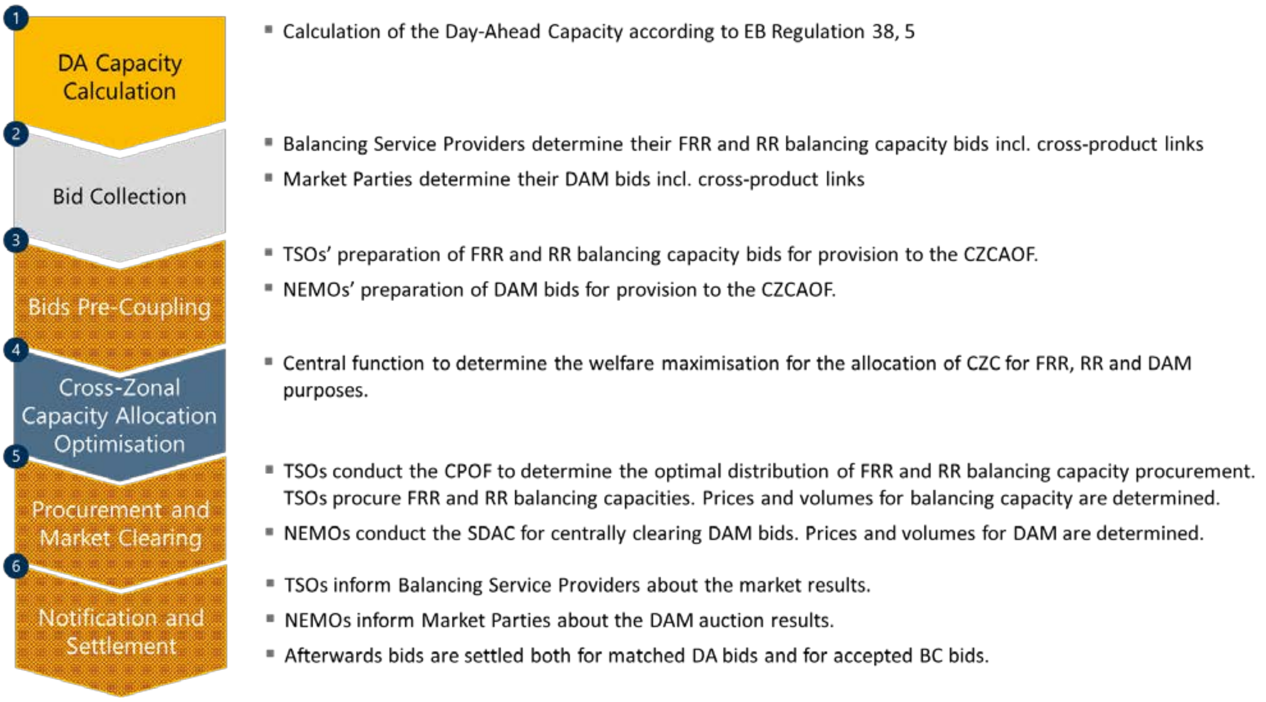

Figure 1: The six main processes of co-optimisation

1. In the Day-Ahead Capacity Calculation (DACC), the CZC for the DAMs and the BCMs are determined.

2. In the Bid Collection process, BSPs determine their BC bids as do MPs for DA. Bids are then provided to TSOs and NEMOs.

3. TSOs and NEMOs prepare the bids for providing them to the CZCAOF. They pseudonymise the bids and build the individual merit orders taking into account the particular links in the bid preparation process.

4. The central process of co-optimisation is the CZCAOF. The CZCAOF determines the total welfare maximising allocation of CZC for DAM purposes and for BCM purposes.

5. Based on the CZCAOF outcome, the DAMs can be cleared and BCM bids are provided to the capacity procurement optimisation function (CPOF), for determining the bids to be procured from BSPs.

6. In the notification and settlement process, MPs are informed about their matched bids and results are published. TSOs inform their BSPs and settle the procured BC offers. NEMOs inform MPs about clear bids.

In the remainder of this chapter, the individual co-optimisation processes will be shown in a graph and explained in more details.

2.2 Flow-Based Computation[3]

The DACC is implemented per capacity calculation region (CCR). The following process graph summarises inputs, processing and outputs.

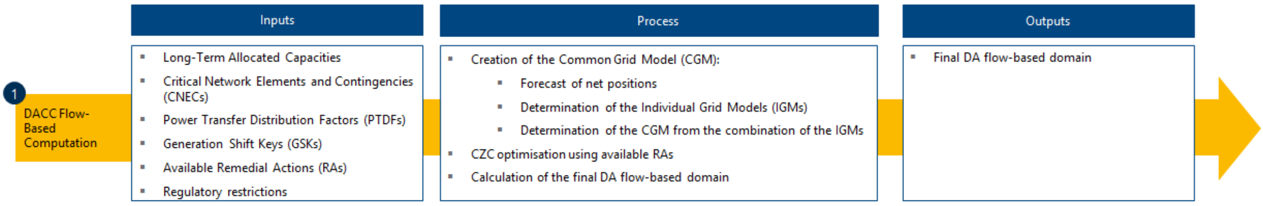

Figure 2: Process graph of the DACC flow-based computation

The flow-based computation determines the flow-based domain, both, for the DAMs and the BCMs on D-1 for the next day. This requires the long-term allocated CZCs, the information about critical network elements and contingencies (CNECs) as well as Power Transfer Distribution Factors (PTDFs), Generation Shift Keys (GSKs) and available remedial actions (RAs). Beyond, regulatory restrictions need to be taken into account.

[3] The flow-based computation is explained e.g. in the Explanatory Note DA FB CC methodology for Core CCR.

From this information the final DA flow-based domain is determined. This is done in a multistep process. First, the net positions are forecasted together with the DC flows in the Common Grid Model Alignment and provided to each CCR. TSOs develop scenarios for each Market Time Unit (MTU) and determine their Individual Grid Models (IGMs). The IGMs are merged to obtain the Common Grid Model (CGM) for each MTU. Subsequently, CZCs are optimised taking into account RAs and the final DA flow-based domain is calculated.

2.3 Bid Collection

BSPs and MPs optimise their portfolios based on the available market and system information. Therefore, they split their production capacities into offers to the DAM and the BCMs especially considering the single Gate Closure Time (GCT) (D-1 noon). The according bid preparation and provision is shown in the following graph.

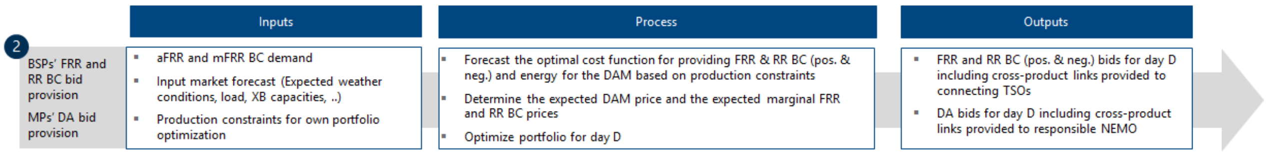

Figure 3: Process graph of the bid preparation and provision of BC and DAM bids

When BSPs determine their offers to the BCM and MPs their provisions to the DAM, they know the total demand from their TSO as well as external market, system and weather conditions and their own production constraints.

With these inputs, BSPs and MPs forecast their optimal production function and cost function for providing BC and energy bids. In combination with the external conditions, BSPs determine their expectations for the DAM price and the marginal BCM prices. By bringing price expectations and cost functions together, BSPs and MPs optimise their portfolio for day D and their offers to the DAM and the BCMs.

The output of the individual portfolio optimisation are the bids to the DAM and the BCMs including cross-product links (exclusive bid linking between the different products). These bids are provided to NEMOs and TSOs.

2.4 Bid Preparation

In the bid preparation process, NEMOs and TSOs separately prepare the bids provided by MPs and BSPs for further processing in the CZCAOF. This is shown in the following graph.

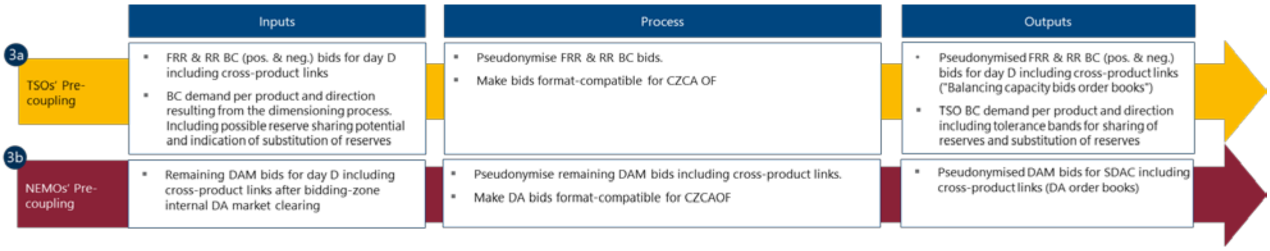

Figure 4: Process graph of the bid preparation by TSOs and NEMOs

TSOs pseudonymise bids and make them format-compatible for the CZCAOF. Pseudonymised bids for each BCM are combined in BCM bids order books.

BC demand per product and direction has been determined in the TSOs' (individual) dimensioning process including possible reserve sharing potential and an indication of substitution of reserves. TSOs provide this demand information including tolerance bands for sharing of reserves, substitution of reserves and bid indivisibility to the CZCAOF.

NEMOs take the DAM bids including cross-product links from MPs and make them format-compatible for the CZCAOF.

Pseudonymised DAM bids are then provided as DA order books to the CZCAOF.

2.5 Cross-Zonal Capacity Allocation

The CZC allocation is determined from the provided DA order books and TSOs' BCM bids order books and demand and tolerance bands for sharing and substitution of reserves and bid indivisibility. Total available CZC is provided from the flow-based computation. The CZCAOF also takes into account CZC allocation constraints per border or per product and minimum local reserve requirements. CZC allocation applies a Europe-wide total economic surplus maximising algorithm. CZC is allocated to DAM if DA market value from the next Megawatt (MW) of CZC allocated to the DAM is equal or higher than the market value from the next MW of CZC allocated to any BCMs. The high-level CZCAOF process is shown in the following graph.

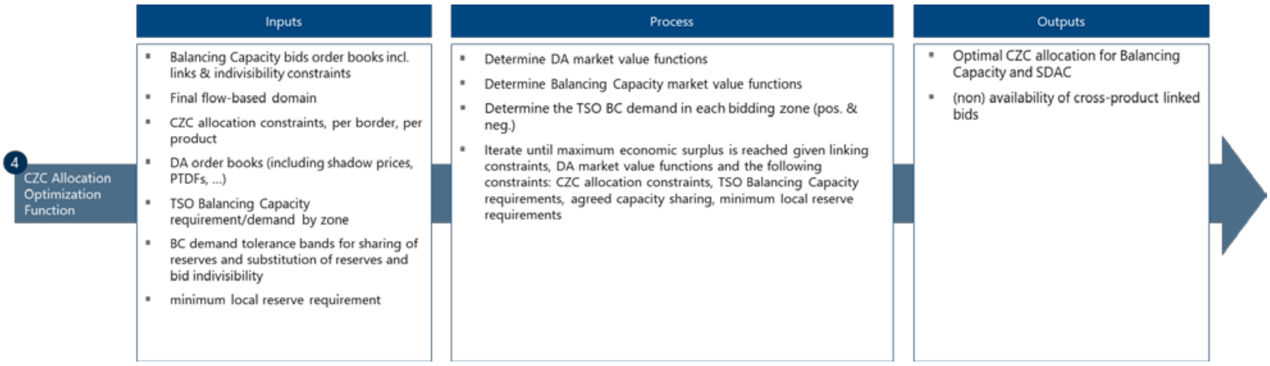

Figure 5: Process graph of the CZCAOF

In an optimisation process the CZCAOF determines the optimal CZC allocation for BCMs and for the SDAC, taking into account cross-product linking between the different markets.

2.6 Procurement and Market Clearing

After or together with CZC allocation, depending on the implementation option[4], the DAMs and the BCMs are separately cleared. The market clearing processes for DAMs and BCMs are displayed in the following figure and explained thereafter.

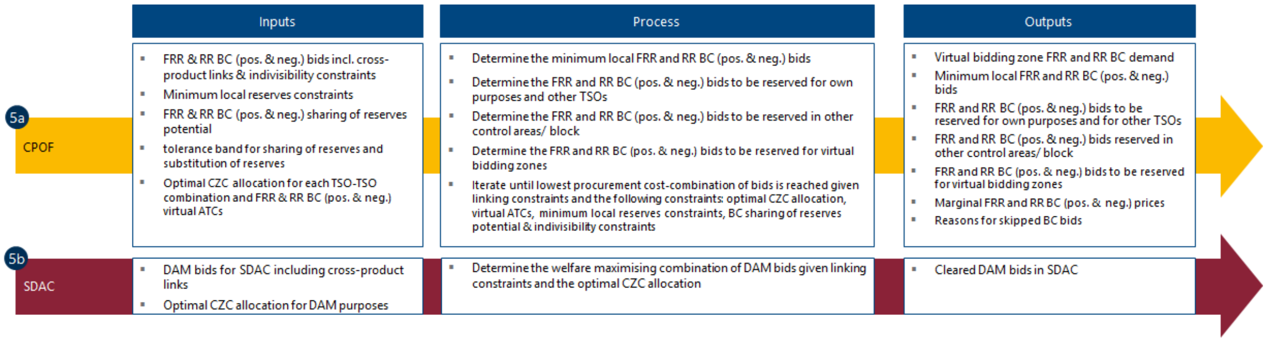

Figure 6: Process graph of the market clearings of the DAMs and BCMs

2.6.1 Balancing Capacity Market Clearing

The clearing of the BCMs, also named the procurement of BC, is conducted by the CPOFs. Therefore, the outcomes of the CZCAOF relevant for BC products is provided directly to each CPOF. Beyond, outputs from prior functions and technical or regulatory requirements are inputs to the CPOF. From these inputs, each CPOF determines the most beneficial distribution of BC procurement for control areas considered in the CPOF given the actual CZC allocation. Thus, the CPOF determines the minimum local BCM bids per control area and the bids to be reserved for

[4] See chapters 8 and 9.

own purposes, for other TSOs and also for each virtual bidding zone in one TSO's control area. In line with this, it also determines for each TSO of the application the BC to be reserved abroad.

Consequently, a CPOF provides the optimal procurement pattern including volumes, marginal prices and cross-product links for each TSO within the application. It also provides the reasons why bids have been skipped.[5]

2.6.2 Day-Ahead-Market Clearing

Similar to the BCM clearings in CPOFs, NEMOs have already installed an algorithm to clear the DAM (EUPHEMIA). For the SDAC, EUPHEMIA requires the allocated CZC for DAM purposes and the DAM bids including cross-product links. It also determines the Europe-wide welfare maximising matching of bids, taking into account cross-product links and finally provides the cleared DAM bids.

2.7 Notification and Settlement

The notification and settlement process informs MPs and BSPs about matched bids, exact volume and prices. The process is organised as shown in the graph.

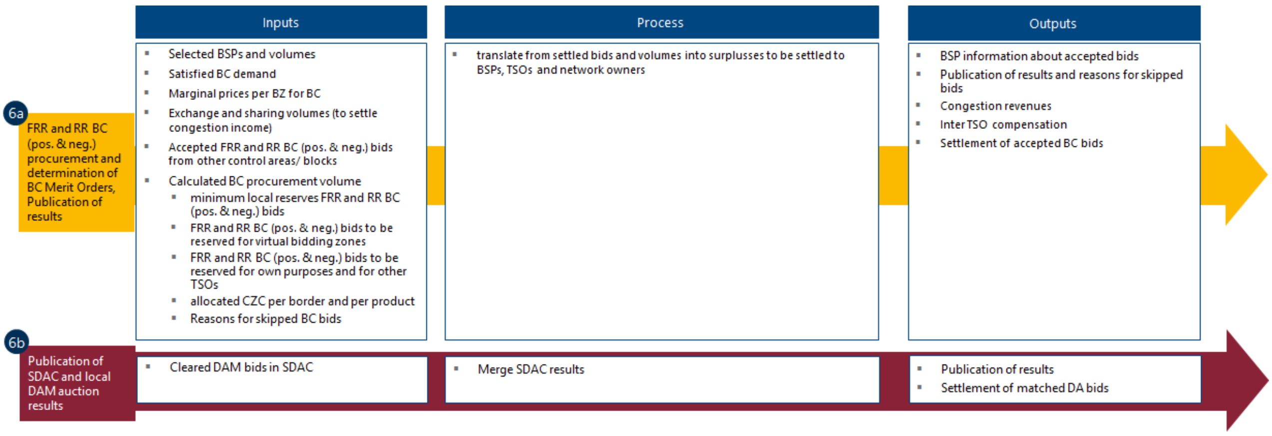

Figure 7: Process graph of the notification and settlement process

Notification and settlement are done separately by individual TSOs and NEMOs for BSPs and MPs in their control areas or their bidding areas. Therefore, the outputs of the CPOF and of the SDAC process enter the notification and settlement process.

TSOs re-pseudonymise the settled bids and calculate the surplus for each of their BSPs, network owners and themselves. Subsequently, they inform BSPs about accepted bids and publish results and reasons for skipped bids. As further outcomes, TSOs determine the congestion revenues and

[5] How CPOFs will be exactly implemented and operated, i.e., as a joint function, as a joint function of a subgroup of TSOs or individually, and how interfaces to the CZCAOF are developed, needs to be further elaborated by TSOs before final implementation of co-optimisation.

the inter-TSO compensation. Finally, TSOs settle the accepted BC bids with BSPs and inter TSO-TSO settlement.

NEMOs re-pseudonymise cleared DAM bids, publish the results and settle the matched DAM bids.

2.8 Summary and Conclusion

This chapter provides a high-level overview of the joint processes required for each option for the implementation of co-optimisation. This overview should be seen as a reference point for subsequent chapters. It has been clarified how the central CZCAOF interacts with the process of SDAC and the procurement of BC. In particular, chapters 8, 9 and 10 will discuss key aspects of this high-level process overview, namely the different co-optimisation implementation options, the technical feasibility of implementation and the governance of the CZCAOF based on the outline provided in this chapter.

3 Balancing capacity markets

3.1 Introduction

In this chapter, the general process of the procurement of BC is elaborated and the requirements for this market and products are listed. It indicates which features are at least required for the implementation of co-optimisation.

3.2 Procurement of Balancing Capacity

TSOs are responsible for the secure planning, maintenance and operation of their Load Frequency Control (LFC) Blocks. They shall regularly and at least once a year review and define the reserve capacity requirements for the LFC block or scheduling areas of the LFC block pursuant to dimensioning rules according to EB Regulation Art. 32(1).

- Reserve capacity is needed to ensure the quality of the common system frequency.

Each TSO shall perform an analysis on optimal provision of reserve capacity aiming at minimisation of costs associated with the provision of reserve capacity. Minimisation of costs in the context of BC means the minimisation of payments from TSOs to BSPs. Options for the provision of reserve capacity are:

a) procurement of BC;

b) sharing of reserves with other TSOs;

c) the volume of non-contracted balancing energy bids which are expected to be available, both within their control area and within the European platforms of balancing energy taking into account the available CZC.

For most European TSOs, the procurement process of BC is (mainly) required to fulfil the reserve dimensioning requirements. In line with European legislation, cross-border procurement enables cross-border markets for BC.

3.2.1 Cross-Border Procurement

The EB Regulation defines two options for cross-border cooperation for the procurement of frequency restoration reserves (FRR) and replacement reserves (RR) BC:

1. Exchange of BC

Exchange of BC means the provision of BC to a TSO in a different scheduling area than the one in which the procured BSP is connected (EB Regulation Art. 2), with the objective to procure cheaper by saving costs.

TSOs determine the required BC for their balancing area, which is called dimensioning. By exchange of BC, TSOs can activate balancing energy from other balancing areas instead of balancing energy from production units in the own balancing area. Thus, exchanging BC between balancing areas may lead to increased efficiency, competition and cost savings. The total amount of BC within the two areas is not reduced.

2. Sharing of reserves

“Sharing of reserves means a mechanism in which more than one TSO take into account the same reserve capacity unit to fulfil their respective reserve requirements resulting from their reserve dimensioning processes” according to the System Operation Regulation (SO Regulation). The objective is to procure less and thus prevent costs.

Since TSOs do not always use their maximum procured BC simultaneously, TSOs can share part of their reserves. Consequently, they can reduce the total amount of BC to be reserved within the two areas and prevent unnecessary procurement costs.

A comparison between exchange of BC and sharing of reserves is depicted in the following table:[6]

	Exchange of Reserves		Sharing of Reserves	
	TSO A	TSO B	TSO A	TSO B
	MW		MW	
Requirement				
total	400	300	400	300
local	200	150	200	150
Sharing Potential	0	0	100	50
Sharing Agreement	0	0	0	50
Exchange Agreement	-50	50	0	0
Connecting TSO	350	350	400	250

Table 1: Difference between Exchange of Reserves and Sharing of Reserve

Table 1 shows two TSOs (A and B). TSO A requires 400 MW of BC, TSO B requires 300 MW. The left part of the table is the example for exchange of BC, the right part of the table corresponds to sharing of reserves.

<u>Exchange of BC</u> means in the example that TSO A can reserve 50 MW of the required 400 MW through TSO B in control area B. Thus, TSO A procures 350 MW BC in control area A and TSO B procures 350 MW in control area B whereof 50 MW are for TSO A. This requires 50 MW CZC allocated from control area B to control area A.

[6] The example is taken from the publicly available TenneT report “Process assessment of cross-border procurement of balancing capacity”.

Sharing of reserves means in the example that TSO A allows TSO B to let activate 50 MW of reserves through TSO A in control area A. As both TSOs assume that they need not fully activate their reserves at the same time, they fulfil their system requirements even though TSO B reduces his individual procurement. This requires 50 MW CZC allocated from control area A to control area B.

3.3 Market Requirements for Balancing Capacity Markets

For an effective application of the co-optimisation process, the following market requirements of all BCMs shall be considered for the establishment of co-optimisation and respected by all applications for the exchange of BC and/or sharing of reserves:

1. The TSO-BSP GCT for all BC products exchanged and shared within the co-optimisation process shall be equal, and equal to the DAM GCT for MPs.
2. In case of cross-product linked bids, they shall be submitted according to external or internal linking as assessed in the linking of bids study according to chapter 6;
3. BSP bids (pure or linked) are sent/submitted to the connecting TSOs;
4. For each application, the separate procurement step determining the prices and volumes of procured BC using the CPOF can be performed centrally or decentrally by TSO(s);
5. At each bidding zone border (BZB) between TSOs sharing/exchanging balancing capacity and willing to reserve CZC for this purpose, up to 6 different BCMs/products should be capable of being in competition on CZC with the DAMs. These are:
    a) Automatic frequency restoration reserve (aFRR) up, and aFRR down;
    b) Manual frequency restoration reserve directly activated (mFRRda) up, and mFRRda down;
    c) RR up, and RR down.
6. Each BCM is settled at cross-zonal marginal pricing and has a unique price and a unique volume at each side of a BZB. At each BZB; the exchange of BC also has a unique volume and a delta price as the difference of the two marginal prices at each side of the BZB.
7. In case of unsatisfied local TSO BC demand as a result of insufficient local volumes (bids) offered by BSPs, the TSO surplus is calculated as the difference of the technical price limit of the volume of unsatisfied demand and the marginal price of the importing BSP bids.
8. The clearing price of each BCM per bidding zone as a payment from TSOs to BSPs shall be equal to the highest bid price of a BSP that is awarded.
9. The BCM clearing shall be optimised by minimising the procurement costs of TSOs (Clean Energy Package (CEP) requirement and EB Regulation Art. 58, 3(a)).

10. In case of indeterminacies between DAM and BCM, according to Art. 40 of the Methodology, CZC shall be allocated to the DAM.

11. In case of indeterminacies between the different BC products, the priority is still to be determined at each BZB by respective TSOs.

3.4 Product Requirements for Balancing Capacity Bids

Within the co-optimisation process, only standard products of balancing capacity (SPBCs) according to the SPBC methodology shall be exchanged or shared. For an effective application of the co-optimisation process, the following product requirements for each BCM shall be considered by each application for the exchange of BC and/or sharing of reserves performing an exchange of BC and/or sharing of reserves and consequently have to be considered for assessing the feasibility of the co-optimisation options:

12. Each TSO BC demand shall only have a volume and is price-inelastic;

13. TSO BC demand shall be settled at a price equal to the highest cleared BSP bid;

14. Always satisfy completely BC demand for each product in case of sufficient local BSP bids;

15. Cross-product linking of TSO BC demand shall be able between the products of aFRR, manual frequency restoration reserve (mFRR) and RR;

16. Due to the linking of TSO BC demand, the TSO BC demand may be volume-sensitive for the purpose of:

    a) sharing of reserves (decrease of demand) according to SO Regulation and EB Regulation Art. 40;

    b) bid indivisibility (increase of demand) according to Art. 8, 3 of the Methodology;

    c) substitution of reserves for cost minimisation (decrease of demand of lower quality product, increase of demand of higher quality product) according to CEP;

    d) substitution of reserves for volume shortage (decrease of demand of lower quality product, increase of demand of higher quality product).

17. BCM bids shall be divisible and indivisible according to EB Regulation Art. 25, 2;

18. BCM bids of the same product submitted by BSPs may be block bids (linked in time) and mutually exclusive bids (linked in quantity);

19. BCM bids may be linked only with other BC products in the same direction (between aFRR up, with mFRR up, with RR up, and in the other direction, aFRR down linked with mFRR down and with RR down);

20. Bid linking between BC products and DAM shall be investigated in this IIA;

3.5 Summary

This chapter explains the need for balancing BC procurement and explains the major approaches for cross-border reservation and procurement of BCs. Until now, BC is mainly procured within a TSO's LFC block.[7] CZC allocation for BCM purposes enables TSOs to use BCs from outside their LFC blocks either by the exchange of BC or by sharing of reserves. This requires a common understanding and implementation of market rules as well as the definition of standard products for exchange, the SPBC.

[7] Currently, there exist some pilot projects such as the German-Austrian aFRR project where the exchange of balancing capacity is tested. However, these projects are based on individual market rules.

4 Requirements of Linking of Bids

4.1 Introduction

Co-optimisation implies one GCT for the DAMs and for all the BCMs which – next to other changes – has an unneglectable impact on BSPs. Current sequential markets enable BSPs and MPs to re-optimise their portfolios after the market clearing of one single market in which the prices and volumes of cleared bids are known. With one single GCT for several markets, this re-optimisation of MPs' portfolios is not straight forward anymore. MPs would have to choose between markets upfront with missing potential to be taken in a market.

Furthermore, DAM rules are aligned across bidding zones and SDAC is used for the exchange of DAM bids, BCM rules are aligned nationally or at most at a regional level. Consequently, exchanging BC or sharing of reserves requires a further alignment of the product definitions as explained in chapter 3.

Cross-product linking of bids is a way forward to keep national and regional flexibility while facilitating the BC product trade and to mitigate potential negative consequences from co-optimisation with one single GCT. This means that BCMs will interdepend as a result of the cross-product linking of BCM bids (aFRR, mFRR and RR). Cross-product linking would also enable to link the BCM bids with bids from the DAM. Consequently, a market interaction is created of the bids and therefore the markets.

The necessity of this dependency is elaborated in this chapter with arguments explaining the level, the need for and importance of cross-product linking. Those were gathered in interviews with experts from different stakeholders – including TSOs, BSPs and NEMOs. Furthermore, different options of cross-product linking will be explained and the different modifications are identified.

4.2 Cross-Product Linking of Bids

Cross-product linking is a linking of bids type by which the execution is related to different products. E.g., a positive aFRR BC order is linked with a DAM supply bid order.

The aim of cross-product linking is to prevent the sole choice to be made by BSPs or MPs to engage in only one market, since one GCT for all products within co-optimisation without cross-product linking disables to resubmit liquidity by bids for other markets in case the bid is not taken in the market it was placed in.

This type of cross-product linking between the different BC products and between BC products and the DAM is exclusive bid linking.

Cross-product linking can be applied to the following conditions:

- Bids with exclusive acceptance of one bid among a set of bids. Exclusive group bids link offers from which only one can be accepted.

The acceptance of one offer of the exclusive group has the same economic value for the BSP/MP as the acceptance of any other offer within the exclusive group.

Disclaimer: the actual surplus for the MP shall be determined by the clearing price of the market where the bid is accepted.

- Bids which link products of the same or of different quality for the same MTU.

If one offer of the linked bids is accepted, the other offer cannot be accepted or must be accepted. This is relevant for BSPs which offer one and the same share of a production unit e.g., as negative aFRR BC and as a DAM supply bid in the same MTU. If the bid is not accepted in the DAM, the production unit cannot be used in the same MTU for negative aFRR provision. This is an example for so-called linking families.

The CPOF will then select the offer or combination of offers whose acceptance provides highest economic welfare.

4.3 Justification of Cross-Product Linking of Bids

Different MPs face different challenges by the application of co-optimisation. In order to assess holistically, feedback from TSOs, BSPs and NEMOs was collected on the question to what extent cross-product linking of bids can be useful.

The results are formulated threefold – market, compliance, and welfare consequences – and a conclusion on how cross-product linking intends to prevent those effects:

Market consequences

With the implementation of co-optimisation, today's sequential market framework in most European control areas/blocks will be replaced by a market framework consisting of several markets with one single GCT. Accordingly, BSPs are obliged to determine bids in terms of volumes and prices for all BCMs at the same time without being able to take into account (neither explicitly nor implicitly) the outcomes of bid selection and market clearing prices of other BCMs. The required one-step portfolio optimisation of BSPs induced by co-optimisation introduces additional uncertainties in BSPs' portfolio optimisation process. Consequently, BSPs will add a risk premium in their bid price calculation as simultaneous GCT may drive incomplete usage of offered production capacities and individually sub-optimal choices of bid placement per market.[8] This is in particular important as the selection of bids by the CPOF does not consider the order of

[8] Today's sequential market clearing (in some control areas) enables BSPs to offer not-accepted production capacity in a first market to a subsequent market. This avoids the uncertainty induced by simultaneous GCTs.

individually provided bids across BCMs by BSPs. However, the production level and, thus, the capacity reservation costs associated with a bid depend on the accepted bids in all markets. This is demonstrated in the following example:

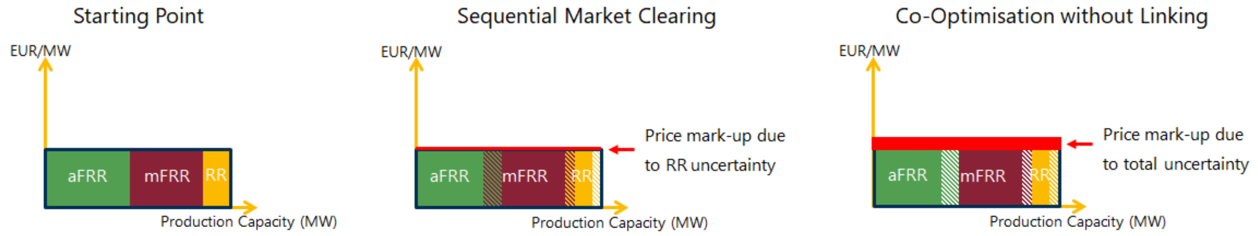

Figure 8: Depiction of theoretical bid optimisation of a MP subject to different market settings

Assume a BSP offering for ease of explanation only positive BC from his production portfolio. Total start-up costs are illustrated by the blue frame in each of the graphs in Figure 8. These start-up costs are shared between BC bids for aFRR, mFRR and RR (left graph).

In a sequential setting, the BSP for example first offers aFRR, then mFRR and last RR BCM bids. After the aFRR market is cleared, the BSP knows how many of his bids were accepted. Consequently, he reallocates production capacity not accepted for aFRR to mFRR and does the same with production capacity not accepted for mFRR to RR. This corresponds to the reallocated costs represented by the colour-shaded areas in the middle graph. As non-acceptance of RR BC is unclear to the BSP in advance, he forms an expectation of the uncertainty of unaccepted RR BCM bids (the yellow-white shaded area). As start-up costs need to be covered, he adds these costs as risk premium to all foreseen accepted bids (the narrow red area).

With co-optimisation, the BSP cannot shift production capacities between BCMs in an iterative process. Consequently, costs for unaccepted bids in one market cannot be covered by additional bids in other markets. Therefore, the BSP adds a risk premium to all bids which corresponds to the expected uncertainty of all unaccepted BC bids (the colour-white-shaded areas which corresponds to the red area in the right graph). Consequently, in the example the 20 percent cost uncertainty translates into an almost 30 percent risk mark-up.

The example demonstrates the feedback received by BSPs that their bid placement contains uncertainties which results in inefficient use of mark-ups to cover these uncertainties and opportunity costs. As a result, with no linking-possibility the markets are inefficiently organised: BSPs add a mark-up to their prices to cover the uncertainty of bids being not accepted.

To reduce aforementioned inefficiency, it will be crucial for BSPs to make the preliminary decision, in which market to be active, based on an efficient and accurate market-bidding algorithm. The competitive position of larger, integrated (BSP and Balance Responsible Party (BRP) portfolios) and experienced BSPs with sufficient portfolio capacity to develop such a market-bidding algorithm will increase. At the same time, smaller BSPs with a lack of those resources may be forced out of the market.

Both arguments mentioned above may consequently lead to a drop of the total market liquidity across all markets in the co-optimisation timeframe which will be further elaborated within the compliance consequences.

Compliance consequences

In many European countries, procurement of BC is firm before the DAM auction and is set up in a sequential process in which BSPs can decide themselves about volumes and prices of offered bids. Liquidity is available and only in rare cases not sufficient to satisfy TSOs' BC demand. Without cross-product linking, the risk and occurrence of unsatisfied demand may increase and lead to incompliant systems for capacity availability at the balancing energy timeframe.

As mentioned above, MPs have to choose and prioritise a certain market and exclude the other markets and guess how to achieve maximum portfolio optimisation if co-optimisation is implemented without cross-product linking. In the example of Figure 8 above, this can be seen by comparing the shaded areas in the middle and in the right graph: If in the aFRR or in the mFRR BCM the BCs are not accepted, they can be provided to the subsequent BCM in the sequential setting. Thus, in total more bids are provided to subsequent BCMs. As this shift is not possible in co-optimisation without cross-product linking, the corresponding capacity is lost for balancing purposes. Therefore, fewer liquidity is available per BCM and/or part of the liquidity is only submitted to the DAM or directly to the Single Intraday Coupling (SIDC). This has been confirmed by MPs such as aggregators. Their BRP and BSP portfolios are disconnected and not integrally optimised, since assets and customers behind the bids are distributed.

In consequence, without cross-product linking, the probability of unsatisfied demand increases, and the system is put at a risk of incompliancy to reserve availability at the balancing energy timeframe. This risk shall result to the lack of application of co-optimisation by TSOs, meaning that co-optimisation shall not be (primarily) used to procure BC across borders.

Welfare consequences

Co-optimisation without cross-product linking will add uncertainty to MPs on market optima, disables the explanatory power of the market price and has a market liquidity impact. Cross-product linking of bids can prevent these potential downsides.

This can be demonstrated by the example provided in Figure 9. Assume the co-optimisation situation (with equal GCT for each market), the BSP still does not know if bids are accepted as proposed. However, by cross-product linking, the BSP can offer one and the same production capacity to multiple markets. If the linked bid is accepted in one market, it is not available for another market, since cross-product linking means exclusive bid linking between different products. The BSP will choose (minimum) price for each market which at least covers the corresponding costs (including opportunity costs). Thus, the economic difference for the BSP after settlement is only due to the difference between the market-clearing price and the cost-covering price of the BSP's bid.[9] In consequence, for current sequential market settings with highest quality products procured first, *ceteris paribus* the price mark-up on BC offers corresponds at most to the RR uncertainty as demonstrated by the following graph (which corresponds to the situation of sequential BCMs).[10]

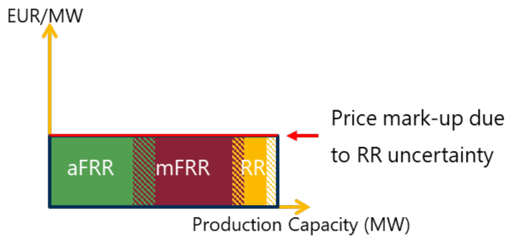

Figure 9: Co-optimisation with cross-product linking

Co-optimisation without cross-product linking would require an even more well-designed bid placement algorithm, market knowledge, and portfolio organisation. However, not each MP has the same possibilities leading to (unequal) distribution of market power by market design among the BSPs not contributing to a level playing field.

Conclusion

The illustrations above demonstrate the clear advantages of combining co-optimisation with cross-product linking. Cross-product linking makes the decision of each BSP obsolete where to offer its production capacity as the capacity of one asset can be taken into account in several markets. The chances of being awarded increase in comparison to no-linking structures within co-optimisation. Therefore, the flexibility options introduced by cross-product linking are similar, for some MPs almost identical to the current sequential market settings.

Nonetheless, even with cross-product linking, MPs have to consider how to place their bids according to what volumes and prices, without information of cleared prices of the other markets. This will by default increase the complexity of current bidding. However, bidding for all markets in a simultaneous setting will be based on the same external influencing parameters. Since the individual MP's experience, size and organisation become less relevant, the obstacles for efficient bidding are reduced that might have hindered smaller MPs to submit bids. An easy and transparent bidding process supports this development.

With cross-product linking, market liquidity is higher than without linking. This is in particular of importance for countries with a low number of BSPs and/or lower number of prequalified assets/portfolios.

For some type of cross-product linking (multilateral), which will be discussed in the next section, the CZCAOF shall also decide in which market a certain linked bid should be used, without prior

[9] Note that this differs in the balancing energy domain.

[10] Colour-shaded areas correspond to linked bids.

market prioritisation. The bid shall be chosen in the market where it provides highest overall economic surplus. Consequently, the steering of individual MPs by smart bidding reduces, since the central CZCAOF has much more accurate information to optimise all markets together. As demonstrated by the graphs above, it can be expected that MPs will offer bids closer to actual costs.

In theory, cross-product linking increases overall welfare. Depending on the type of cross-product linking, welfare is distributed more evenly based on real scarcity per market instead of inaccurate portfolio decisions made by individual MPs.

In general, it can be said that with cross-product linking of bids overall market performance will increase. This includes the avoidance of unused capacity or assets due to inaccurate bidding. Bid prices will reflect available information of the actual value of the underlying asset related to the market situation.

4.4 Level of Market Integration with Cross-Product Linking of Bids

Generally, cross-product linking can be implemented in two different ways:

- unilateral cross-product linking of bids; and
- multilateral cross-product linking of bids.

The linked bids can vary between the markets both in price and volume. Hereinafter the two main cross-product linking approaches are presented and variations of no-linking-, unilateral linking and multilateral linking are described. Further assessment concerning the effect of each approach on welfare gains and surplus distributions across the markets and MPs can be found in the subsequent chapter 5.

4.4.1 Unilateral Cross-Product Linking of Bids

Within the process of unilateral cross-product linking, unilaterally linked bids can be transferred from one market to the next market in case the bids were not accepted due to a higher absolute bid price than the marginal price of the prior market (bid is not in the money). Hence, this approach comes with a predefined prioritisation of the different market clearings. To simplify the understanding of the concept, it will be explained with an example where aFRR is prioritised over mFRR, mFRR is prioritised over RR and RR is prioritised over the DAM.

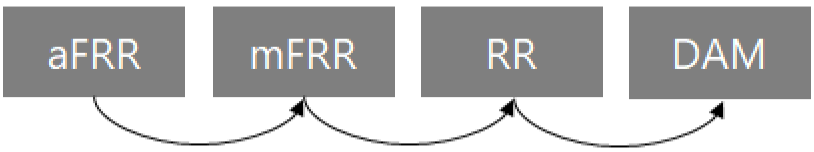

Figure 10: Outline of the unilateral cross-product linking of bids

Figure 10 illustrates the logic graphically: In the first step, the aFRR BCM will be cleared based on a minimisation of TSOs' costs to fulfil the aFRR BC demand. Linked bids which were accepted in the aFRR BCM cannot be further considered in the mFRR BCM. Not accepted aFRR bids that are linked to mFRR bids shall be forwarded and enter the mFRR merit order with their mFRR price and volume indicated by the BSP during provision of all of the bids for co-optimisation. Accordingly, the target function for the mFRR market clearing is the minimisation of the TSOs' costs to fulfil the mFRR BC demand. Linked bids are again either selected in the mFRR BCM or transferred to the RR in case this was indicated by the BSP/MPs that offered the bids. The same logic follows as in mFRR market for the RR market. Linked bids not accepted in RR can be transferred to the DAM in case this was indicated by the BSP/MPs that offered the bids. The DAM is cleared according to maximisation of total economic surplus of all bidding zones – corresponding to today's proceedings.

4.4.2 Multilateral Cross-Product Linking of Bids

Multilateral cross-product linking of bids waives the prioritisation of a market and clears each market according to a maximisation of the total economic surplus of all markets combined. The allocation of a bid to a specific market is solely based on maximising the economic surplus of all markets including the seller surplus, the buyer surplus and congestion rents. This scheme can be seen in Figure 11.

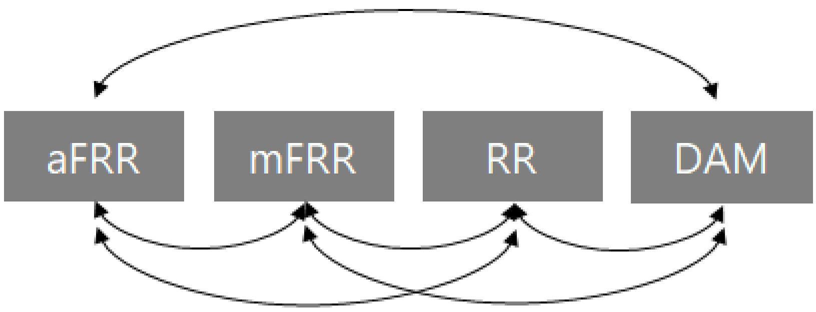

Figure 11: Outline of the multilateral cross-product linking of bids

Depending on the price and the volume of the emitted bids, an algorithm will allocate the bids to a certain market in case of multilateral cross-product linked bids.

4.4.3 Variations of Unilateral and Multilateral Cross-Product Linking of Bids

Next to the option of linking bids across markets in the same manner, variations are conceivable. Three of them which are evaluated as practicable will be presented in this paragraph.

Two closely related alternatives are linking bids for the different BCMs using the unilateral or the multilateral approach, but without a link between the BCMs and the DAM. Figure 12 shows schematically the difference.

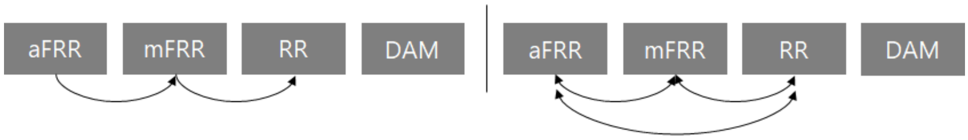

Figure 12: Outline of cross-product linking of bids within the BCM using the unilateral approach (left) and the multilateral approach (right)

Unilateral cross-product linking of bids is again explained with an example which favours aFRR over mFRR and mFRR over RR. Thus, bids not selected in the aFRR BCM will be transferred to the merit order of the mFRR BCM and those not accepted in the mFRR BCM are forwarded to the RR BCM with the corresponding price and volume.

There will be again no market prioritisation, but an optimisation based on maximising the welfare across the BCMs and by taking into account minimisation of the costs of fulfilling the demand within the multilateral cross-product linking of bids.

The last evaluated option is a combination of both approaches: BCM bids (like aFRR, mFRR and RR bids) are linked mutually while unselected bids are transferred unilaterally to the DAM. This is illustrated in Figure 13.

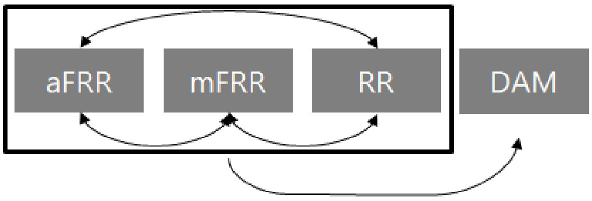

Figure 13: Outline of cross-product linking of bids using the multilateral approach within the BCM and the unilateral approach between the BCM and the DAM

By doing so, BCMs as a whole are prioritised above the DAM in regard to the bid usage, which corresponds to the sequential markets which are currently organised in for example Austria, Germany, the Netherlands and Nordic systems. These minimise the risk of unsatisfied demand since liquidity is first offered and used for BC before left overs can be offered to the DAM clearing. Also, within the BCMs, prioritisation can be made, like performing the auction of the higher quality product aFRR before the lower quality mFRR BC auction and the lower quality RR BC auction, such that MPs can re-optimise the bids of the second auction based on the results of the first auction. The DA market clearing is performed with pure DAM bids and the linked bids that were not in the money in the BCMs.

4.5 Summary and Conclusion

The implementation of co-optimisation, especially without cross-product linking, might evoke negative consequences, including for example an inefficient bidding process with higher market entry barriers generating the threat of scarce resources, not contributing to a level playing field. Especially the consequent risk of reserve incompliancy that may reinforce TSOs in not procuring any cross-border capacity and the loss of information about the real value of the asset related to the market situation within the bids are crucial for a future-oriented market.

The different levels of cross-product linking of bids cures those consequences and offers various advantages with effects on the welfare gains and distributions of economic surplus across the markets and MPs and support securing reserve compliancy of the system to a maximum extent. The welfare gains and distributions will be further discussed in the following chapter.

Please note: Implementing linking of bids also requires a fallback solution for the improbable situation that an optimisation algorithm is not able to handle two linked bids adequately. Default rules need to be defined for processing the concerned linked bids. This could be either to prefer the BCM bid over the DAM bid or vice versa or to ignore both bids during optimisation.

5 Welfare Impact of Cross-Product Linking of Bids

5.1 Introduction

In chapter 4, the justification of linking of bids and different ways of linking bids between DAMs and BCMs have been introduced. Cross-product linking of bids which enable to link the BCM bids with bids from the DAM, has been introduced as a way forward to keep national and regional flexibility while facilitating the BC product trade. The necessity of cross-product linking of bids has been provided based on interviews with experts from different stakeholders and the conclusion was that different ways of linking bids can have an impact on welfare gains and lead to different welfare distribution among MPs.

Chapter 5, therefore, aims, first, to present a more detailed description for cross-product linking of bids and, second, analytically shows how cross-product linking of bids can have an impact on market flexibility, welfare gains and welfare distributions among MPs. For this, the effect of different linking of bid options – with and without cross-product linking of bids – on two case studies of Germany and the Netherlands are compared to each other to show that different ways of linking of bids option can have an impact on market outputs.

This chapter is organised as follow. First, in section 5.2, six proposed options for linking of bids between DAMs and BCMs are described in detail. Later in sections 5.3, the analytical study of these six linking of bids options and their effect on the total cost of fulfilling demands and welfare distributions within national markets and also in presence of CZC between two zones are presented. Lastly, the main conclusions are provided in sections 5.4.

5.2 Balancing Capacity and DAM Cross-Product Linking of Bids

Based on multilateral and unilateral cross-product linking introduced in chapter 4, the linking of bids options between DAMs and BCMs can be classified into six different options. In this section, each option is explained in detail.[11]

Option 1. No linking between aFRR, mFRR and DAM

Option 1 implies no linked bid between aFRR, mFRR, and DAM products which is common practice for netting DAMs and BCMs in many European countries. Figure 14 shows the merit order lists for three markets, aFRR, mFRR BCMs and DAM. Demands in the BCMs are considered inelastic, represented by the vertical red lines in the figures. For the DAM, however, the demand is elastic. As there are no linked bids between the BCMs and the DAM, each market clears independently.[12]

[11] For ease of explanation, we apply only two BCMs, aFRR and mFRR. Methodologies and results do not change when also including RR. Beyond, many European countries have implemented only aFRR and mFRR markets today.

[12] The general market clearing process and its corresponding optimisation problem is explained in the appendix, section 15.1.

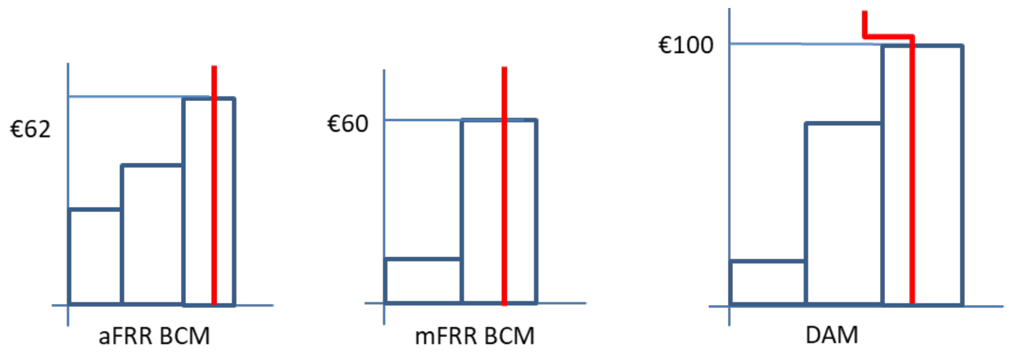

Figure 14: No linking of bids

Option 2. Unilateral cross-product linking between aFRR and mFRR and DAM

In this option, there is a unilateral cross-product linking relation between all the bids in the BCMs and the DAM. As explained in chapter 4, in the unilateral cross-product linking, the linked bids can be transferred from one market to the next when the bid was not accepted because the absolute bid price was higher than the marginal price of the previous market. The following example describes this option.

Figure 15 shows the merit order list for three markets where there are two linked bids, one between aFRR and mFRR BCMs shown by the blue bars, and another one between aFRR, mFRR BCMs and DAM, shown by the green bars. The vertical red lines and the red curve show the inelastic demands in the BCMs and the elastic demand in the DAM.

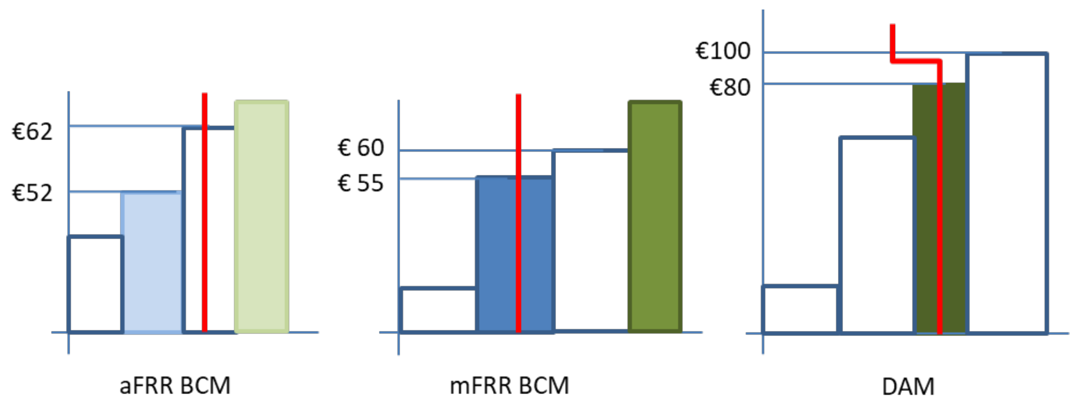

Figure 15: Unilateral cross-product linking of bids

First, the aFRR BCM is cleared, and the blue linked bid is accepted in the aFRR BCM. This means that this bid can no longer be present in the mFRR BCM. However, the green linked bid is not accepted in the aFRR BCM which means it can be present in the mFRR BCM. In the next step, the mFRR BCM is cleared. As the blue linked bid cannot be present in this market, the merit order in mFRR BCM list becomes as shown in Figure 16.

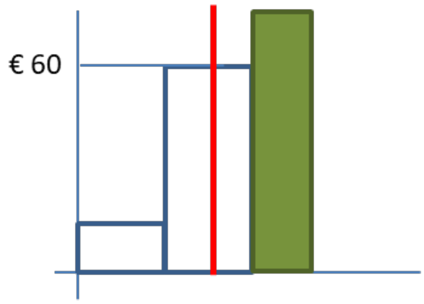

Figure 16: mFRR BCM after clearing of aFRR BCM

As shown in Figure 16, the green linked bid is not accepted in the mFRR BCM. Therefore, it can be transferred to the DAM. Lastly, the DAM is cleared while the green linked bid can participate in this market.[13]

Option 3. Multilateral cross-product linking between aFRR and mFRR BCMs and DAM

In this option, there is multilateral cross-product linking between all products in BCMs and the DAM. As mentioned in chapter 4, multilateral cross-product linking of bids waives the prioritisation of a market and clears each market according to a maximisation of the total economic surplus for all markets combined. In other words, in multilateral cross-product linking, an optimisation process decides which bids should go to the aFRR BCM, to the mFRR BCM or to the DAM in such a way that the economic surplus is maximised.

In this optimisation problem, it is important to define a proper objective function that ensures that the resulting marginal price will end up with the highest welfare.[14]

Option 4. Multilateral cross-product linking between aFRR and mFRR and Unilateral cross-product linking between BCM and DAM

As mentioned in chapter 4, there are options that are the results of the combination of multilateral and unilateral cross-product linking of bids. One possible option for the combination cases is multilateral cross-product linking of bids between aFRR and mFRR BCMs and a unilateral relation between BCMs and DAMs.

As there is a multilateral relationship between the aFRR and mFRR BCMs, the aFRR and mFRR BCMs are cleared first in an optimisation approach similar to the one in option 3 (except that the variables and parameters belong to the DAM should be omitted). After it becomes clear which BCM bids are accepted, the DAM is cleared. As explained in option 2, if there are exclusively linked

[13] The market clearing process of this option is similar to the one in option 1 and explained in the appendix, section 15.1.
[14] The detailed explanation for the optimisation problem of multilateral cross-product linking of bids can be found in the appendix, section 15.2.

bids that are accepted in the aFRR or mFRR BCMs, they can no longer participate in the DAM since there is a unilateral relation between the BCMs and the DAM.

Option 5. Multilateral cross-product linking between aFRR and mFRR and no linking between BCMs and DAMs

This option is a combination of the multilateral cross-product linking between aFRR and mFRR BCMs and no linking between the DAMs and the BCMs. Similar as with unilateral cross-product linking in option 2, the aFRR and mFRR BCMs are cleared through a similar optimisation procedure. The DAMs, however, are cleared independently of the market results of the BCM.

Option 6. Unilateral cross-product linking between aFRR and mFRR and no linking between BCMs and DAMs

This option is another way of combination in which there is a unilateral relation between the aFRR and mFRR BCMs while there is no linking between the BCMs and DAMs.

As there is unilateral cross-product linking between aFRR and mFRR BCM bids, first the aFRR BCM is cleared. As explained in option 2, if there are linked bids accepted in the aFRR BCM, these bids cannot participate in the mFRR BCM. Those which are not accepted in the aFRR BCM, however, can be transferred to the mFRR BCM. Finally, based on the accepted and non-accepted linked bids in the aFRR BCM, the mFRR BCM is cleared.

5.3 Welfare Impact of Cross-Product Linking of Bids

In this section, a numerical analysis is implemented to study the difference between the six linking of bids options introduced in section 5.2. This analysis divides into two parts. In the first part in subsection 5.3.1, the linking of bids options is compared in terms of the total cost of fulfilling demands and the buyer and seller surpluses within a national market. In the second part in subsection 5.3.2, the linking of bids options is compared to each other taking into account CZC between two zones.[15]

5.3.1 Welfare Impact of Cross-Product Linking of Bids in a National Market

This subsection presents and discusses the results of comparing the effect of different linking of bids options on the total cost of fulfilling demands and the surplus distributions among buyers and sellers in BCMs and DAMs. Figure 17 shows the total cost of fulfilling demands with each linking-of-bid option for the German (DE) case study. The total cost of fulfilling demands equals:

Total cost of fulfilling demands = aFRR BC marginal price*aFRR BC demand + mFRR BC marginal price*mFRR BC demand + DAM marginal price*DAM demand

[15] Input data and case studies used for the analysis in subsections 5.3.1 and 5.3.2 are described in the appendix, section 15.3.

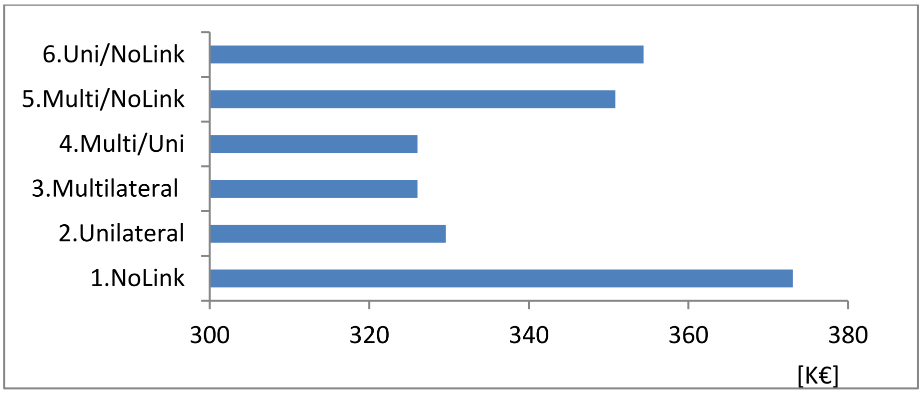

Figure 17: Total cost of fulfilling demands for six linking bid options in DE case study

As shown in Figure 17, the total costs of fulfilling demands in options 2, 3, and 4, where there is cross-product linking between BCMs and DAMs, are the lowest. When there is no link between BCMs and DAMs, the cost is the highest as shown in options 1, 5, and 6. In option 1, where there is no linking, the total cost reaches the highest point while option 3 – with the multilateral cross-product linking of bids between all BCM and DAM bids – has the lowest cost as expected.

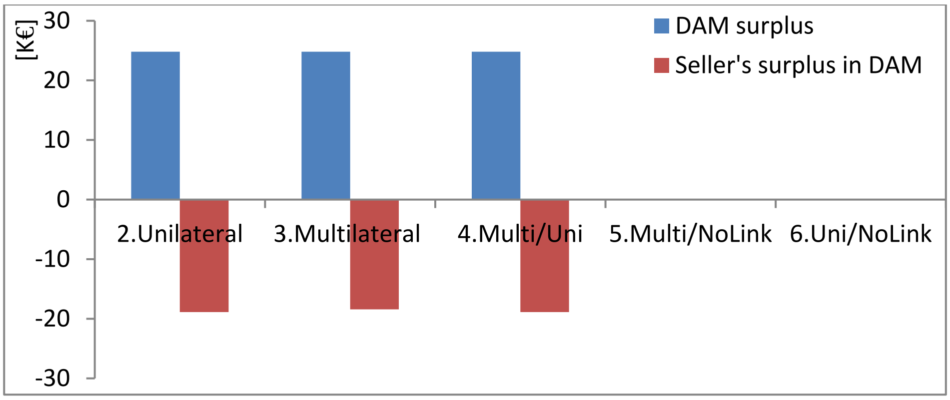

Figure 18: Sellers and buyers surpluses in DAM in DE case study

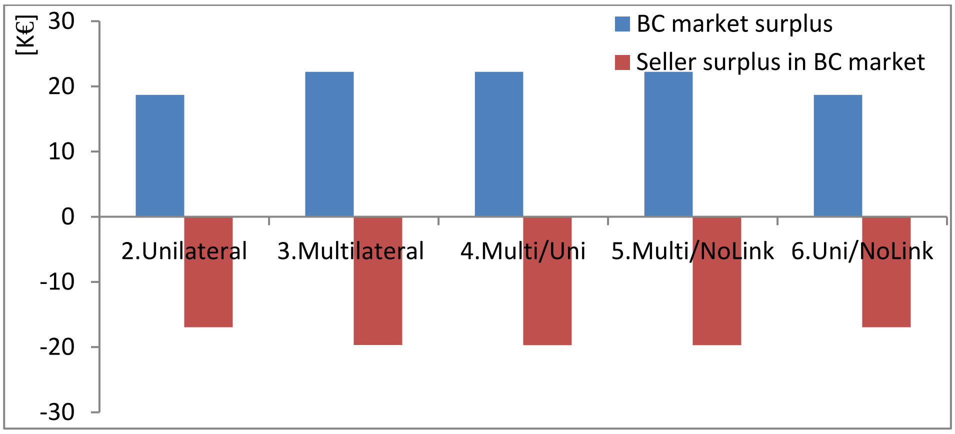

Figure 19: Sellers and buyers surpluses in BCM in DE case study

To see how the surplus among the MPs in the BCMs and the DAMs is distributed, Figure 18 and Figure 19 depict the sellers' and the buyers' surpluses in the BCMs and the DAMs, respectively, for the DE case study. Note that both figures show the relative surplus of different linking of bids options in comparison to the surplus in option 1, "No Link". This means, for each linking of bids option, the values shown in the vertical axis depict the difference between the surplus in the "No Link" option with that certain linking of bids option. As Figure 18 shows, the surplus in the DAM in options 2, 3, and 4, where there is cross-product linking between BCMs and DAMs increases while the surplus of the sellers decreases. In other words, by cross-product linking between BCMs and DAMs, the surplus in the DAMs increases while the sellers' surplus drops compared to the situation where there is "No Link" between BCMs and DAMs.

The same study is implemented for Dutch (NL) input data. Figure 20 shows the total cost of fulfilling the demand for each linking of bids option for the NL. Same as in the DE case study, options 2, 3, and 4, where there is linking between the BCMs and the DAM, have the lowest cost while options 1, 5, and 6, with no linking between the BCMs and the DAMs, have the highest cost. Figure 21 and Figure 22 show the relative buyers' and sellers' surpluses for the NL case study with respect to the "No-linking" option in the BCMs and the DAMs, respectively. Same as in the DE, in the NL case study, there is an increase in the DAM surplus in options 2, 3, and 4 compared to the ''No-linking" option. In the BCMs, for all the five options with linking, there is an increase in the economic surplus while there is a decrease in economic surplus of the BSPs.

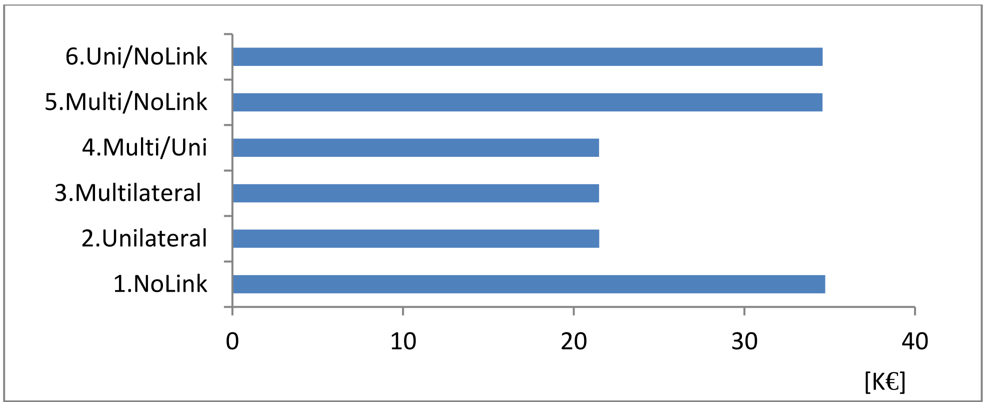

Figure 20: Total cost of fulfilling demands for six linking-of-bid options in the NL case study

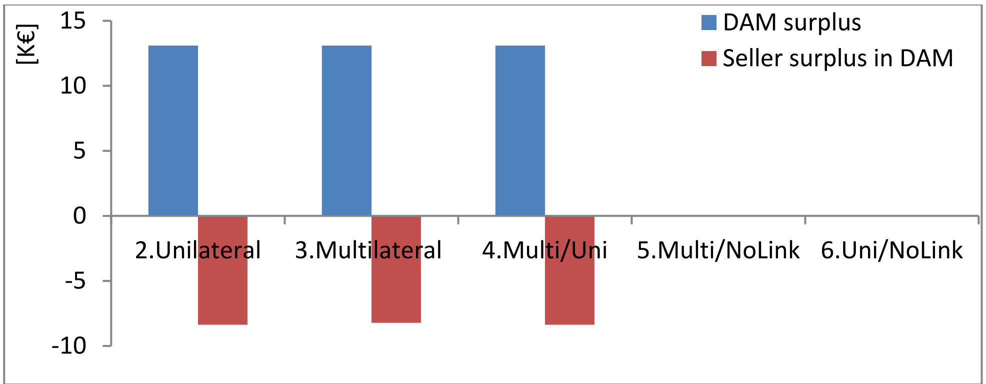

Figure 21: Sellers and buyers surpluses in DAM in the NL case study

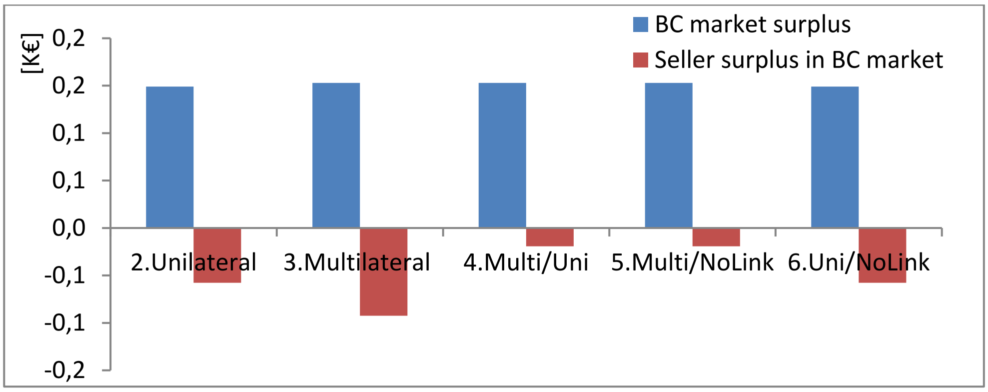

Figure 22: Sellers and buyers surpluses in BCM in the NL case study

The increase in the BCM and DAM surpluses, which happens for both DE and the NL case studies, is due to lower marginal prices resulting from linking between BCMs and the DAMs or linking between aFRR and mFRR BCM bids. Lower marginal prices, therefore, lead to a lower surplus for the sellers in both BCMs and DAMs. Note that although with linking of bids there is a decrease in total seller surplus, three situations can still happen for an individual seller:

1. Sellers being very cheap will always stay in the market – with or without linking. The surplus of these sellers decreases because of linking of bids since marginal price drops due to linking of bids.

2. Sellers leaving the market due to linking of bids. The surplus of these sellers will decrease.

3. Sellers staying in the market due to linking of bids and, therefore, their surplus will grow.

5.3.2 Welfare Impact of Cross-Product Linking of Bids with CZC

In this subsection, the impact of linking of bids is studied while there is the CZC between two case studies of DE and the NL. The methodology applied for the study of different linking of bids options with CZC is explained in detail in the appendix, section 15.4. This subsection presents the numerical results of the welfare impact of the linking of bids option when there is: 1) a congested BZB, 2) an uncongested BZB. The input data for NL and DE case studies are the same as applied in subsection 5.3.1. First, results with congestion between NL and DE are discussed, followed by the results for the uncongested BZB.

Congested BZB between DE and NL:

In this part, the results related to the total cost of fulfilling demand and distribution of buyers' and sellers' surpluses in the BCMs and DAMs with congestion between NL and DE are described.

Figure 23 shows the total cost of fulfilling demand including congestion rents for both the DE and the NL case studies. Same as in the situation in subsection 5.3.1, where NL and DE are isolated, the total cost of fulfilling the demand of the linking of bids options with cross-product linking of bids between BCMs and DAMs, is lower compared to the total costs with no linking. Here, also the total cost of fulfilling the demand for the multilateral cross-product linking in option 3 is the lowest while for no link in option 1 it is the highest.

To see how this cost is distributed, Figure 24 and Figure 25 show the relative buyers' and sellers' surpluses in relation to no linking in the BCMs and the DAMs for the rest of five different linking options, respectively. As Figure 24 shows, in option 2, 3 and 4, where there is linking between BCM bids and DAM bids, the surplus in the DAMs increases while the total surplus of BSPs decreases. Also, in the BCMs as shown in Figure 25, the buyers' surplus in all the options increases compared to no linking, however, BSPs' surplus decreases with linking between bids in the BCMs and the DAMs.

With a congested BZB between two zones, there is a higher increase in the BCM surplus and decrease in the surplus of the BSPs in options 3, 4, and 5 with multilateral cross-product linking between aFRR and mFRR BC bids. The increase in the BCM surpluses/decrease in the BSPs' surpluses is lower when there is unilateral cross-product linking between aFRR and mFRR BC bids.

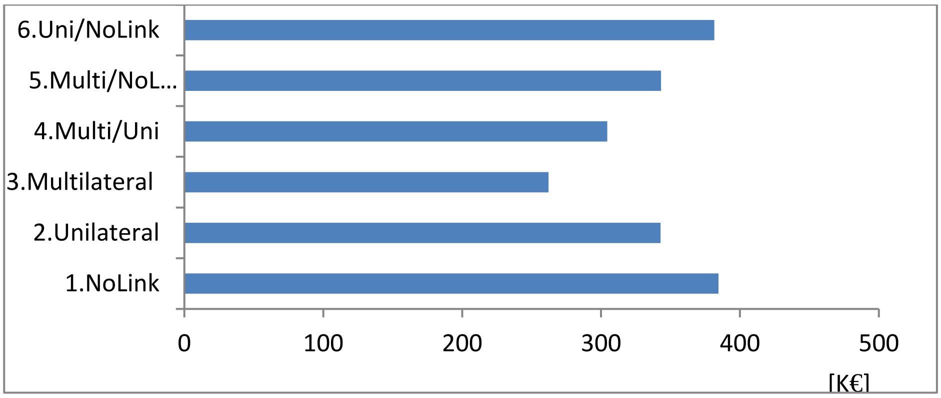

Figure 23: Total DE+NL cost of fulfilling demand with congested BZB

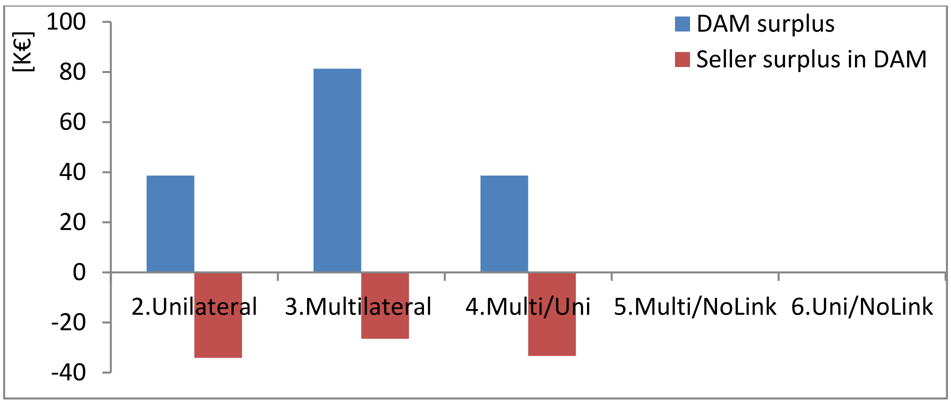

Figure 24: Total DE+NL buyer and seller surpluses in DAM with congested BZB

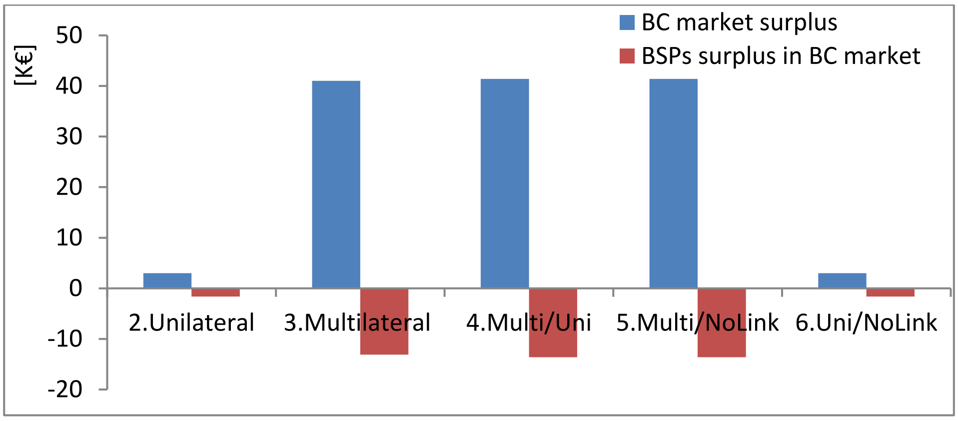

Figure 25: Total DE+NL buyer and seller surpluses in BCM with congested BZB

Uncongested BZB between DE and NL:

Figure 26 shows the total cost of fulfilling demand for both DE and NL case studies where there is no congestion on their BZB. The trend of decreasing the cost due to linking between bids in the DAM and BCMs and increasing the cost due to no link between these two markets can also be observed here. Figure 27 and Figure 28 show the total buyer and seller surpluses in BCMs and DAMs, respectively. Same as in the congested situation, the increase in the DAM surplus is higher in options 2, 3, and 4 with linking of bids between BCMs and the DAMs. Consequently, there is a higher decrease in the sellers' surplus in the DAMs at these three options. Also same as in the congested situation, the surplus of the BCMs increases with linking-of-bid compared to no linking, as shown in Figure 28. Accordingly, BSPs' surpluses decrease in the BCMs with linking.

In short, the results of this subsection show that with connecting two zones – with or without congestion – through the BZB, different linking bid options can lead to a change in the total cost of fulfilling demands and distribution of surpluses among buyers and sellers in BCMs and in DAMs although the trend can differ from the cases where the two zones are isolated.

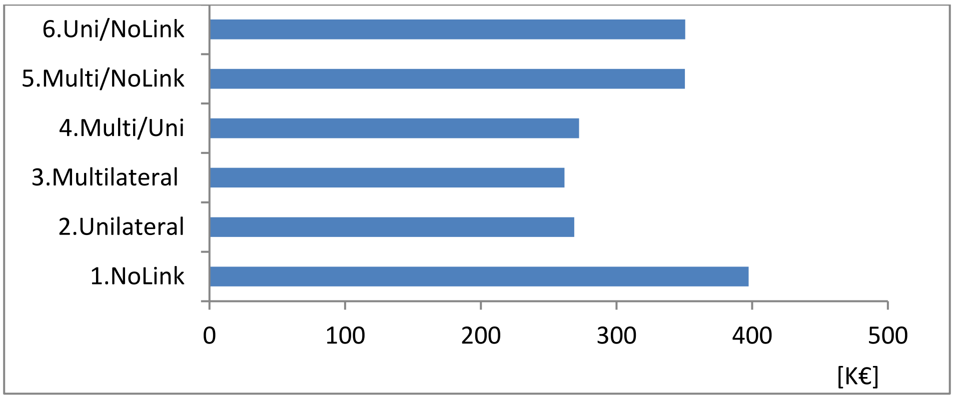

Figure 26: Total DE+NL cost of fulfilling demand with an uncongested BZB

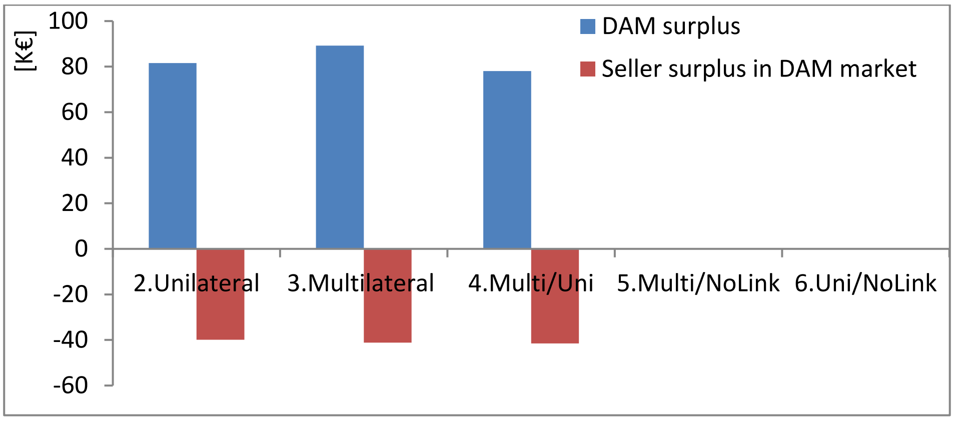

Figure 27: Total DE+NL buyer and seller surpluses in DAM with uncongested BZB

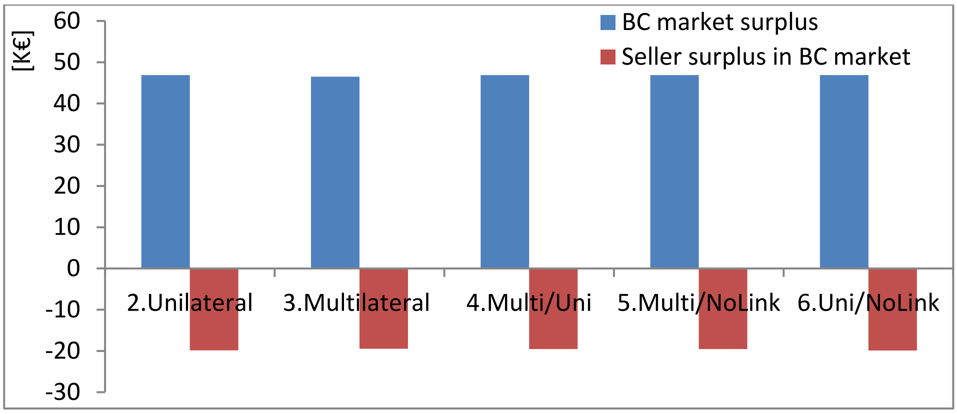

Figure 28: Total DE+NL buyer and seller surpluses in BCM with uncongested BZB

5.4 Summary and Conclusions

This chapter, along with conclusions in chapter 4, tries to give an exemplary overview of how cross-product linking of bids leads to a significant change in welfare gains and welfare distributions among MPs. The results show that with different linking of bids options, there is a difference in economic surplus for demand and supply: For both case studies of DE and NL, multilateral and unilateral cross-product linking of bids between BCMs and DAMs leads to an increase in welfare compared to no linking, although with slightly different ratios. Moreover, with cross-product linking between BCMs and the DAMs, for both case studies of DE and NL, there is an increase in the surplus of buyers and a decrease in the surplus of sellers. With the artificial linking it is observed that cross-product linking between DAM and BCMs has a higher effect on results than linking only between different BC products. Lastly, it is shown that cross-product linking in presence of CZC between two bidding zones can still affect significantly welfare gains and distributions among MPs.

Drawing conclusions about actual market performance requires a more profound assessment taking into account network information and bids in collaboration with MPs to have correct input data concerning linked bids.

6 Feasibility of Linking Balancing Capacity and Day-Ahead Energy Bids

6.1 Introduction

This chapter introduces linking of bids between BCMs and DAMs in the co-optimisation domain. As demonstrated in chapter 5, it is expected that it has a positive welfare impact.

The next section considers the processual implementation of linking of bids between DAM and BCMs as this provides the major challenge for the optimisation methodology. It does not consider linking between and within individual BCMs or linking within DAMs. Four bid submission linking options are explained, how linking of bids can be enabled between BCMs and the DAM from an operational perspective. Subsequently, types of bid submission linking are explained before combinations of co-optimisation implementation options and cross-product linking options are used to assess the performance of their joint implementation. The analysis is based on the study "Co-optimisation of CZC allocations – Feasibility of Linking Balancing Capacity and Day-Ahead Energy Bids" conducted by Artelys.

6.2 Pre-processing of Linked Bids

Bids are currently provided for DAM purposes or for BCM purposes. DAM bids are provided to NEMOs. BCM bids are provided to TSOs. By linking BCM bids and DAM bids it needs to be defined who is the responsible addressee of linked bids.

The Artelys study proposes four organisational options how linked bids could be submitted in the pre-processing step of co-optimisation.[16]

Option 1: No linking at the pre-processing stage

No linking of bids means no linking between DAM and BCM bids. It does not exclude linking within DAMs and it does not exclude linking within or between BCMs. If no linking takes place at the pre-processing stage, the trading and balancing processes are performed separately. Thus, all DAM bids are separately collected by NEMOs and processed in the trading process without any indication of possible cross-product linking. All aFRR, all mFRR and all RR BC bids are separately collected and processed by TSOs in the BC process.

Option 2: External linking

In the external linking case, participants submit their BC bids to their TSO and their DAM bids to their NEMO at the pre-processing stage but can in addition indicate, if BC and DAM bids are linked by using a specific feature (e.g. code) during bid submission. In order to create this linking, an

[16] More details are provided in the Artelys study.

external reference such as a unique id from another platform is needed. Therefore, this linking option is called external.

Option 3: Internal linking

In contrast to external linking, participants submit a complete set of linked BCM and DAM bids to their NEMO or their TSO in the internal linking case. This means that participants have the liberty to submit DAM bids in the balancing process when they are linked to BC bids and BC bids in the trading process when they are linked to DAM bids.

Option 4: Integrated process

In the integrated process, all bids are submitted to one entity or platform (e.g. NEMOs) which will subsequently process the bids. The balancing process is only responsible for processing the TSO BC demands including volume sensitivity due to bid indivisibility, substitution of reserves and sharing of reserves.

6.3 Linking of Bids in the Optimisation Process

Linking of bids comprises different approaches how accepting or not accepting one bid affects the acceptability of other bids. For reasons of completeness, four bid submission linking options shall be explained in the following as discussed in the Artelys study:

Linking possibility 1: No linking of bids

No linking of bids means that bids are considered by the CZCAOF, the CPOF and the SDAC algorithm as independent from each other.

Linking possibility 2: Exclusive groups of block orders only

Exclusive groups enable the selection of individual bids out of a group of bids provided by one BSP/MP. This is illustrated by the following figure:

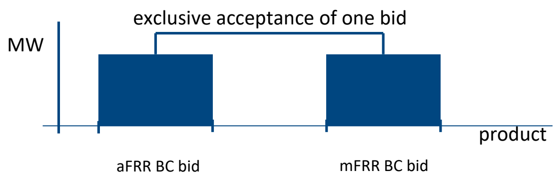

Figure 29: Illustration of exclusive groups

With bid divisibility, bids have a continuous acceptance ratio between 0 and 1, with the sum not exceeding 1 in the exclusive group. With indivisibility, the exclusive group models have an "exclusive or" condition of acceptance. Bids in the exclusive group can be aFRR and mFRR BC bids but should have identical other features (size, price, MTUs). A bid in the exclusive group can be an intertemporal linked bid.

The optimisation algorithm can select one or more bids out of the exclusive group if the acceptance ratio is below 1. E.g., only one of orders A and B can be executed i.e. A or B (not both). All orders are of the same importance, i.e., no preference is possible. In co-optimisation, exclusive groups are applicable for linking products of the same and of different quality. Two block orders covering several MTUs may not be executed simultaneously in case of overlaps of the set of MTUs involved.

Concerning the processing of exclusive groups: If the CZCAOF determines a block bid more favourable for DAM purposes, the bid is provided to the SDAC. In contrast, if it favours it for a BCM, the bid is provided to the CPOF. There is no possibility of changing the results.

Linking possibility 3: Linking families of block orders only

Linking families enable the modelling of "if" or "only if" conditions. E.g., if order A (parent) is executed, then order B (child) can be executed, otherwise not. The optimisation algorithm selects bids considering parent child constraints. This is illustrated in the following figure:

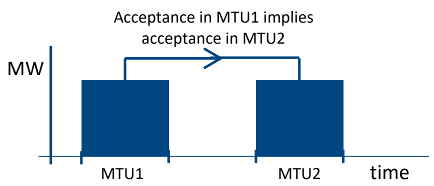

Figure 30: Illustration of linking families

Linked bids may have different prices and volumes and may be intertemporal bids. As in linking option 2, all block orders are in competition and the acceptance results for the block orders of a linking family are final.

Linking option 4: All block orders

The last configuration offers the possibility of linking BC and DAM bids using linking families of block orders or with exclusive groups of block orders.

6.4 Impact Assessment

To assess the different bid submission linking options for the co-optimisation process and to measure the impact of linkage between DAMs and BCMs, the Artelys study defines 35 Key Performance Indicators (KPIs).[17] The main objective of these KPIs is to assess quantitatively which changes are induced by a specific linking option on future operational processes, the market structure and on the governance of DAMs and BCMs. In total eleven linking options can be identified of which five are evaluated in detail (see Table 2).

[17] A list of all KPIs with a detailed description of each indicator can be found in the Artelys study.

		Linking options at the pre-processing stage			
		No linking	External linking	Internal linking	Integrated process
Linking options at the optimisation process stage	No linking	1			2
	Exclusive group only		3	x	x
	Linking family only		x	4	x
	All block orders		x	x	5

Table 2: Summary of the linking of bids options in the original co-optimisation process

Key findings of the analysis are the following:

(1) Base case: No linking of bids

The base case represents the co-optimisation process without any possibilities of linking DA and BC bids. This case has been determined as benchmark. Nevertheless, the base case constitutes an evolution compared to the current situation as BCMs are harmonised and optimised jointly for all control areas. DA and BC bids require a joint format to meet the CZCAOF requirements. As EUPHEMIA currently only deals with DAMs, the base case already requires an expansion of the algorithm scope and increases complexity compared to the current market situation without co-optimisation. On the other hand, the allocation of CZC for both BCM and DAM purposes is expected to increase economic surplus compared to the status quo.

(2) linking of bids at process level

The second option consists of the integrated process linking at the pre-processing stage. In this case, all bids are submitted to the trading process, i.e., to NEMOs, which simplifies the submission process for participants and reduces operational risks in terms of platform failure and data transfers. The use of only one platform for the pre-processing also supports future efforts to integrate linking of bids structures and should lead to an overall cost decrease for the development and operation of the bid processing platform. On the other hand, the implementation of fallback procedures for the balancing process will be more complex and evolutions of the balancing process require close coordination with NEMOs as TSOs are not involved in the pre-processing stage.

In summary, linking option 2 performs equally well or better compared to the base case in terms of market structure and operational processes but governance issues and independences of TSOs and NEMOs are reduced.

(3) linking of bids by exclusive groups of block orders

The third assessed option is the linkage of bids by exclusive groups of block orders with external links in the pre-processing stage. This means that BSPs/MPs can link DAM bids with BC bids with exclusive groups of block orders and submit their offers to NEMOs and to TSOs. From a procedural perspective the linking is implemented by an external reference. Pre-processing is done separately by NEMOs and TSOs and bids are then provided to the CZCAOF. The CZC allocation and the SDAC are optimised jointly and, subsequently, the CPOF is conducted.

While linked bids can be provided which reduces BSPs'/MPs' uncertainty, exclusive group linking increases the complexity of the operational processes. In addition, the integrated process requires clearly specified responsibilities and greater implementation efforts. In terms of market structure, an improvement is achieved mainly due to an increase of BCM liquidity and a better product adequacy.

Compared to no linking of bids, linking in the sense of exclusive groups performs better than the benchmark in terms of market structure but remains below the benchmark in terms of governance and operational processes.

(4) linking of bids only by linking of families of block orders

The introduction of linking families is comparable to the introduction of exclusive groups with respect to welfare. In contrast to external linking, the considered example assumes internal linking. This facilitates the processing for BSPs/MPs as they can provide their linked bids either to TSOs or to NEMOs but not to both (in comparison to external linking). While NEMOs have already implemented the required process for preparing linking families to the joint SDAC process, such a process needs to be installed at TSOs. Both, NEMOs and TSOs provide their pre-processed bids to the CZCAOF for CZC allocation in combination with the SDAC. CPOF is then implemented based on the outcomes of CZC allocation and SDAC. The key challenge for the CPOF is the consideration of the SDAC outcome with regard to the linked bids.

Thus, linking families are expected to increase economic surplus and support market liquidity. Potential downsides are in particular the introduction of required processes at TSOs for pre-processing linked bids in line with internal linking.

(5) linking of bids with all block orders

This bid submission linking option considers the combination of exclusive groups and linking families in an integrated process. BSPs and MPs provide their bids (also BC bids without linking) to NEMOs for pre-processing. This reduces complexity and, thus, uncertainty for BSPs/MPs as they do not need to decide whether to offer their production capacities to DA or to BCMs. The remaining process is as before with CZCAOF running together with the SDAC and CPOF thereafter.

Also, here an increase in economic surplus is expected in comparison to no linking. An identified downside is the required additional exchange between NEMOs and TSOs for fallback solutions in particular for TSOs.

6.5 Summary and Conclusion

This chapter has analysed linking of bids both from a processual perspective and with respect to options for bid submission of linked bids. By combining both dimensions, scenarios have been analysed how implementation and set-up of cross-product linking will affect economic surplus, implementation complexity and governance.

It has been assessed how different set-ups for linking between BCMs and DAM from a bid submission perspective could work. However, it requires the installation or review of processes in particular on TSO-side as TSOs have no structure to deal with linked bids yet. Beyond, linking of bids requires a closer collaboration between TSOs and NEMOs as linking affects both BCMs and DAM.

7 Flow-Based Compatibility Study

7.1 Introduction

During Phase 1 of the IIA, the implementation of co-optimisation in the flow-based domain has been analysed. Within multiple CCRs' control zones/blocks, CZCs are determined by applying flow-based capacity calculation. Flow-based capacity calculation determines CZCs under the assumption that they are fully used for actual energy flows when they are allocated/reserved. Accordingly, since flows will be expected as a result of DAM trades, trades/schedules can be netted and clearing of trades on a particular BZB might relief or burden other BZB to allow for more or less trades respectively.

With allocation of CZC to the exchange of BC or sharing of reserves, a resulting flow of balancing energy is not guaranteed. This depends on actual physical imbalances at real-time and the prices of balancing energy offered at the balancing energy platforms. Consequently, an allocation of CZC to BC is not straight forward, since BC trades cannot be netted and only the burdening effects (positive PTDFs) on other borders should be taken into account, not the relieving effects.

This requires a different approach how to securely allocate CZC to BC. This shall be assessed in this chapter. It discusses how CZC allocated for BC purposes without guaranteed corresponding activation of balancing energy affects the volumes which can be exchanged in the SDAC and how the issue can be solved from a processual perspective. The results provided in this chapter are based on the study "CZC Allocation with Co-Optimisation". A more detailed mathematical analysis of the challenge is provided there.

7.2 Impact of Balancing Capacity on CZC Allocation for Energy

Let us start the consideration with a simple flow-based example. Assume a three-line model with a capacity of 1000 MW of each line in both directions and equal impedance assumptions of the lines.

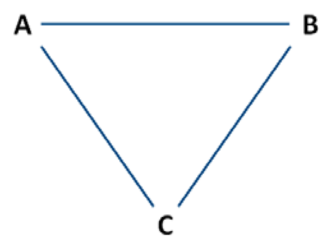

Figure 31: Graphical outline of the explanation of the flow-based capacity calculation

With a total scheduled capacity of 600 MW from A to B, flow-based capacity calculation e.g., allows for a maximum capacity allocation of 1800 MW from C to A. However, this allocation requires the actual flow of 600 MW from A to B.[18] If the allocated 600 MW is not used, only 1500 MW could be allocated from C to A.

The actual flow is most critical when applying co-optimisation to the flow-based domain. Without exchanging BC or sharing of reserves, capacity calculation in the flow-based domain has been conducted for energy market purposes only. Consequently, the allocated CZC is always used for an actual energy flow.

Co-optimisation in the flow-based domain must take into account that CZC is not necessarily used for an actual energy flow. In consequence, first, more CZC is available in real-time in the direction of the CZC allocation for BC purposes. Second, less CZC is available in real-time in the opposite direction of the CZC allocation for BC purposes. This does not only have an impact on the capacity usage of the direct link between two nodes. It also affects capacity usage of links between other nodes.

At the point in time of the CZCAOF, it is unclear if the allocated CZC for BC purposes is connected with a balancing energy flow or not. It may also be the case that it is not continuously used over a total MTU or that it is not completely used for a balancing energy flow. Applying co-optimisation in the flow-based domain therefore requires a condition which reduces the total optimisation space after CZC allocation for BC purposes. In the remaining subset, CZC for BC must not be considered when optimising the usage of allocated CZC for energy market purposes.[19]

7.3 Flow-based Implementation Solutions to Meet the Balancing Capacity Activation Issue

This subsection discusses how the co-optimisation process can be implemented in the flow-based domain. Two major computational set-ups, the one-step computational co-optimisation process and the two-step computational co-optimisation processes, are presented which disentangle the complexity of CZC allocation and the optimisation of CZC usage.

[18] With equal impedance, two thirds of 600 MW flow directly from A to B, one third from A to C and from C to B. Thus, at most 1200 MW could flow directly from C to A and 600 MW from C to B and from B to A.

[19] This discussion explains the key challenge of applying co-optimisation in the flow-based domain. Chapter 5 of the N-Side/ AFRY study explains more comprehensive corner solutions and potential obstacles which can occur in the particular constellation of co-optimisation in the flow-based domain.

7.3.1 One-Step Computational Co-Optimisation Process

The one-step computational solution solves the following tasks at once:

- SDAC for the DAMs (as currently implemented in EUPHEMIA)
- Matching of BC bids with demand
- CZC allocation optimisation

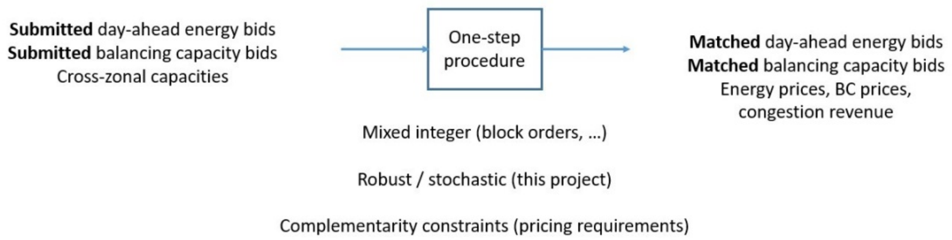

Figure 32: One step co-optimisation process

Following the N-SIDE/AFRY study, the one-step computational co-optimisation process might not necessarily become computationally tractable.

7.3.2 Two-Step Computational Co-Optimisation Process

The two-step computational solution solves the following tasks in a sequence:

- Step one: CZC allocation optimisation in close coordination with SDAC in preparation of BC procurement.
- Step two: BC procurement optimisation

Alternatively, the first step can also be performed with the BC process, namely:

- Step one: CZC allocation optimisation in close coordination with BC procurement in preparation of SDAC
- Step two: SDAC.

In both options, SDAC would be as currently implemented in EUPHEMIA, but EUPHEMIA would need to be adapted to meet cross-product linking.[20]

[20] The question of technical feasibility is addressed in Chapter 9.

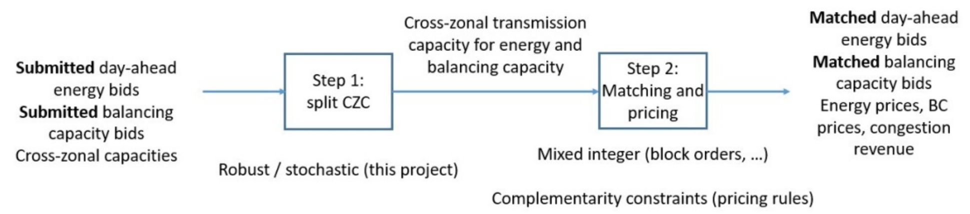

Figure 33: 2-step co-optimisation process

Step one determines the amount of CZC allocated to BC. Assumption is that the required CZC for potential cross-border activation of balancing energy as a result of cross-border procurement of balancing capacity must not be taken for energy market purposes. Therefore, Step 1 is split into two subsequent stages:

Stage 1: This stage determines the amount of CZC allocated for both markets. This is done by calculating the market welfare for the transportation of energy and for BC.

Stage 2: This stage anticipates the clearing of Balancing Markets. The most challenging possible imbalance realizations are considered and activation of required BCs is assumed. Under these assumptions the maximum available CZC for DA trade can be supported.

As a result, this computational set-up provides the CZC allocation which maximizes economic surplus for DAMs under the condition that the highest imbalance situation in the system can be tackled by TSOs employing cross-border activation of balancing energy.

Step two conducts the SDAC and the allocation of BC procurement between control areas. Step two seeks to allow as much energy market trade as possible given the maximum required CZC allocation for balancing market purposes. Step two also allows for cross-product linking between BCMs and Energy Markets.

This two-step computational set-up disentangles the CZC allocation from the subsequent market clearing optimisation: Step one determines the optimal CZC for BC purposes and for energy market purposes. Step two is dedicated to the market clearing in the energy market (SDAC) and the procurement of BC (CPOF) in which prices and volumes of the markets are determined independently.

As price-related constraints cannot be considered in Step one, the optimisation outcomes in Step two need not meet the results of Step one. In consequence, the maximum allocated volumes per market in Step one must be considered as upper boundaries for the Step two optimisation.

A more detailed description including the mathematical reasoning is provided in chapter 4 of the N-SIDE/AFRY study.

A more detailed description of the one-step and the two-step computational solutions can be found in Chapter 8.

7.4 Multistep Computational Set-Up

A multistep computation comprises more than two computational steps:

1. Step one optimises CZC allocation to BCMs and DAM. Revised PTDFs are provided to EUPHEMIA and to the CPOF

2. In Step two, EUPHEMIA is run to determine the SDAC. Revised BC order books are provided to the CPOF.

3. Step three is the run of the CPOF.

In contrast to the two-step computation the CZC allocation is determined independent from the market optimisations. As there is no market clearing foreseen together with the CZC allocation, PTDFs are not revised. This is expected to result in unused CZCs. Although PTDFs could be revised after the SDAC and the CPOF, process steps are not connected and revised PTDFs could not be taken into account in neither of the market optimisations.

Therefore, a multistep computation is not seen as an implementable set-up.

7.5 Hard and Soft Boundaries

In the previous sections of this chapter, sufficient CZC availability for any Balancing Energy activation up to the contracted BC volume has been assumed. This has been analysed in the N-SIDE/AFRY study as the deterministic approach. Thus, always the required CZC has been reserved for very likely to almost unlikely activation of balancing energy up to the volume of BC. The deterministic approach therefore determines hard boundaries as CZC utilisation is assumed to be equal, be it that the allocated CZC is allocated for very likely or very unlikely cross-border activation of balancing energy.

In contrast, the probabilistic approach connects CZC allocation with the probability of cross-border activation of balancing energy up to the volume of XB BC procurement. The probabilistic approach – in comparison to the deterministic approach – can increase economic welfare in multiple cases/for multiple reasons such as

1. CZC allocation between control areas/blocks with the requirement of "last resort" BC and little probability of cross-border activation in an MTU.

2. Cross-border over-procurement of BC (with rarely a need for activation) as supply from home market is too little in the TSO's view.

The threshold of accepted probability depends on TSOs' individual level of accepting potential situations with less balancing energy available. The risk of insufficient balancing energy available can be reduced by different measures such as elastic TSO BC demand, participation in a national and the international balancing energy market, individual approaches such as "last resort" of reserve for fast or time-based activation.

7.6 Summary and Conclusion

While allocated CZC is completely used for energy flows in DAM, CZC usage after the BC process is not necessarily foreseen, but subject to actual system imbalances and prices of balancing energy. Consequently, when allocating CZC to DAMs under flow-based, CZC allocated to BC must be considered differently by respecting only the burdening effects on other borders, not including the relieving effects.

In this chapter, three computational set-ups have been discussed how co-optimisation can be implemented with flow-based. In the one-step computation, the CZC allocation optimisation, the BC procurement and the SDAC are jointly optimised. In the two-step computation either BC procurement or SDAC are jointly optimised with the CZC allocation optimisation and subsequently SDAC or BCMs, respectively, are optimised based on revised PTDFs and revised order books. The multistep computation assumes a sequential optimisation of BCMs and DAM after CZC allocation optimisation. However, this would result in an inefficient usage of CZC.

While CZC allocation has been discussed in the past always under the assumption of hard boundaries in a deterministic setting, this condition has some downsides. In particular, CZC is always assumed to have the same value for BCMs – even, if CZC is used with high certainty for balancing energy or not. A probabilistic approach with soft boundaries provides a probability value to the usage. But this could result in an under-allocation of CZC to BCMs in rare situations, but an economic surplus increase compared to the deterministic approach in many cases.

8 Implementation Options of Co-Optimisation

8.1 Introduction

After conducting the flow-based compatibility study and the linking of bids study, it is concluded that an efficient allocation of CZC (performed by the CZCAOF) without allocating the same CZC twice and avoiding non-allocation of scarce CZC can be achieved by clearing at least one market (DAM or BCM) when CZC is allocated by the CZCAOF.

Consequently, all TSOs have chosen to discontinue the investigation of a possible 3-step co-optimisation. This implies that in the remainder of this assessment, the IIA report shall not focus on a co-optimisation process in which the allocation of CZC, the clearing of the DAM and clearing of the BCMs are performed by three clearly separated processes.

Therefore, this chapter describes four feasible options for implementing co-optimisation which shall be assessed in the remainder of this report.

- **Implementation option 1 [CZCAOF&SDAC]:** a 1-step co-optimisation with a fully integrated optimisation of CZCAOF, SDAC and CPOF.
- **Implementation option 2 [CZCAOF&CPOF]:** a 2-step co-optimisation where the CZCAOF is implemented together with the CPOF for clearing BCMs and subsequent provision of revised PTDFs for DAM and revised DAM order books to (current) EUPHEMIA for SDAC.
- **Implementation option 3 [CZCAOF→←SDAC]:** a 2-step co-optimisation with the CZCAOF using a standalone algorithm based on simplified mathematical equations for SDAC, and subsequent provision of revised PTDFs for DAM to EUPHEMIA. Subsequently, EUPHEMIA clears DAM and provides back the SDAC outcome to CZCAOF. In the second step, the CZCAOF re-optimises based on SDAC (EUPHEMIA) results and provides revised PTDFs for BCMs and revised BCM order books to CPOFs.
- **Implementation option 4 [CZCAOF←→SDAC]:** a 2-step co-optimisation with CZCAOF using (some) EUPHEMIA features interactively to allocate CZCs with an independent full operation of EUPHEMIA and subsequent provision of revised PTDFs for BCMs and revised order books from CZCAOF to CPOFs to clear the BCMs.

The 1-step co-optimisation defines co-optimisation as an integral process in which the CZCAOF, the DAM clearing and the virtual clearing of the BCMs are integrated as much as possible.

With the 2-step co-optimisation and all its related implementation options, only one market is cleared together with the CZCAOF, the other market shall use the remaining CZC and clears after the CZCAOF sub-process. In general, either the CPOF is conducted jointly with the CZCAOF and DAM clearing is implemented by EUPHEMIA using the outcome of the first step, or SDAC is optimised jointly with the CZCAOF and CPOF follows based on the outcome of step 1 of the CZCAOF.

In the following paragraphs the four different co-optimisation implementation options are elaborated. Some of the prior process steps are identical:

Processes 1 & 2: DACC and Bid Collection

Each co-optimisation approach starts at 12:00 pm on D-1 by collecting the final DA capacity calculation results to be used for the DAM/co-optimisation process.

All BSPs submit their bids to the TSOs. DAM bids are provided to NEMOs.

Process 3: Bid preparation

TSOs and NEMOs pseudonymise the provided bids, make them format-compatible and forward them as order books including links and indivisibility constraints to the CZCAOF.

TSOs provide the final flow-based domain and CZC allocation constraints to CZCAOF.

TSOs provide BC requirements and tolerance bands for sharing of reserves and substitution of reserves, demand per control zone and minimum local reserve requirements to the CZCAOF.

Linking of bids provides an additional task to TSOs and NEMOs as linked bids need to have a unique identification which brings them together in the different optimisation functions. To avoid double consideration of one and the same linked bids or miss linked bids, a responsibility rule is required. This responsibility rule determines whether TSOs provide BSPs' bids to NEMOs or whether NEMOs provide MPs' bids to TSOs in a pseudonymised form. NEMOs or TSOs, respectively, add the corresponding bids to the bids provided directly to them, determine the order books for DAMs and BCMs and provide them to the corresponding optimisation functions (CZCAOF, SDAC and CPOFs). The responsibility rule depends on the particular implementation option.

8.2 Implementation Option 1: 1-Step Co-Optimisation

In the 1-step co-optimisation implementation, CZC shall be allocated for all BCMs and for the DAM, and meanwhile the DAM shall be cleared and prices for the DAM are made firm on all BZBs. This requires a fully integrated optimisation of CZCAOF, SDAC and CPOF.

TSOs prepare and provide pseudonymised BC bids to the CZCAOF and the CPOF. NEMOs prepare and provide pseudonymised DAM bids to EUPHEMIA. EUPHEMIA exchanges linked bids received from NEMOs with the CZCAOF. The CZCAOF exchanges linked bids from TSOs with EUPHEMIA and linked bids from EUPHEMIA with the CPOFs.[21]

[21] In principle, TSOs could take over the coordinating role. But as the number of DAM bids exceeds the number of BC bids, additional effort would be much higher for TSOs as the additional effort would be for NEMOs.

Process 4 & 5: Cross-zonal Capacity Allocation, Procurement and Market Clearing

The allocated volumes of CZC for BCMs are used by a central or decentral CPOF of the applications for the exchange of BC and/or sharing of reserves. Also, information on cross-product linked bids is taken into account to determine the prices and volumes of BC by the CPOF and clear the BCMs.

Communication paths in the 1-step co-optimisation are explained in the following graph:

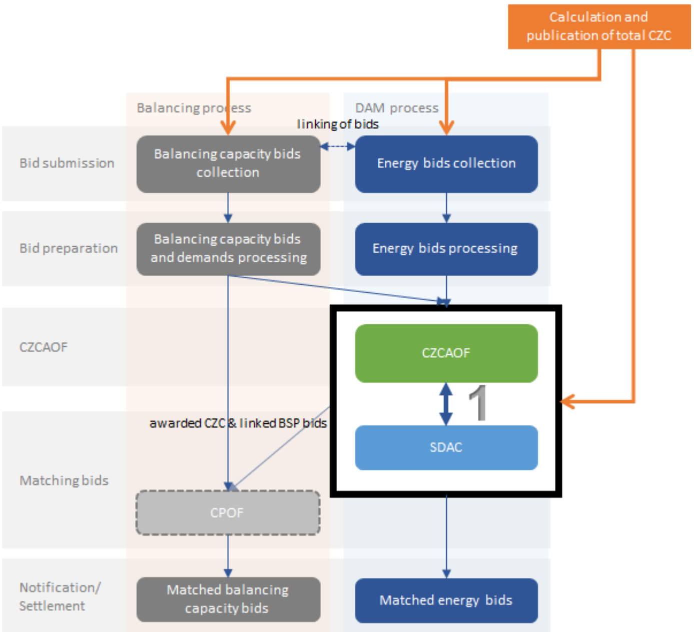

Figure 34: Communication paths in the 1-step co-optimisation option

The graph shows the one-step window around CZCAOF and SDAC (EUPHEMIA) only. The CZCAOF takes into account all BC bids. Therefore, it implicitly comprises the optimisation functionalities of the CPOF. As the CZCAOF is closely connected with EUPHEMIA, the iterative optimisation process provides the first-best solution for CZC allocation from an economic surplus perspective. It enables multilateral cross-product linking in the sense of exclusive group linking, linking families and combinations of them between DAM and BCMs.

On the other hand, full integration comes along with some implementation obstacles:

- Implementing an integrated co-optimisation of three separate optimisation functions is highly complex.
- Due to the iterative approach, co-optimisation might require a shift of subsequent procedures as optimisation with different kinds of linking might become time-consuming.
- Due to the combination of three optimisation functions within one step, it becomes less visible how bids are selected or rejected, and the price formation may not be intuitive.

This might result in a high level of intransparency for MPs and BSPs if introduced in a big bang.

8.3 Implementation Option 2: 2-Step Co-Optimisation: CZCAOF together with CPOF [CZCAOF&CPOF]

In contrast to the 1-step co-optimisation, this 2-step co-optimisation assumes the BCMs to be jointly optimised with the CZC allocation whereas the SDAC follows based on revised PTDFs or ATCs from the CZCAOF.

NEMOs provide MPs' pseudonymised cross-product linked bids to TSOs. TSOs bring these bids together with bids received from BSPs and provide all pseudonymised bids (including all linked bids) to the CZCAOF and the CPOFs. NEMOs provide the pseudonymised bids without links received from MPs to the CZCAOF and to EUPHEMIA.

<u>Process 4 & 5: Cross-zonal Capacity Allocation, Procurement and Market Clearing</u>

The hierarchy of the three optimisation functions is demonstrated in the following figure.

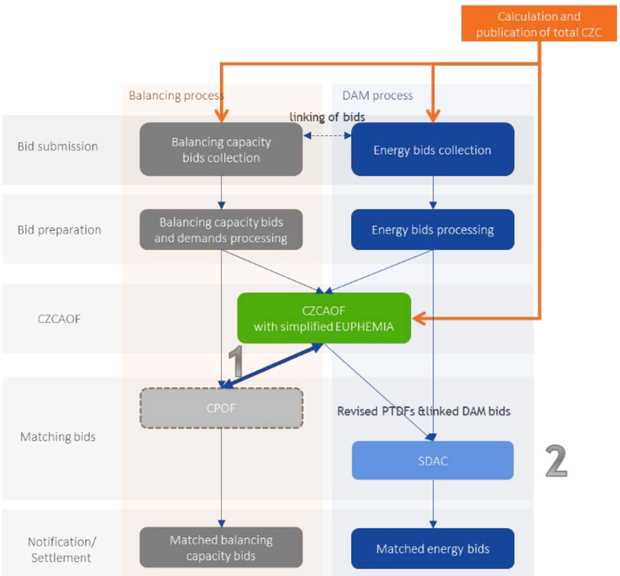

Figure 35: Communication paths in the 2-step co-optimisation CZCAOF together with CPOF

<u>Process 4 & 5: Cross-zonal Capacity Allocation, Procurement and Market Clearing</u>

Co-optimisation Step 1: This implementation option assumes the CZCAOF to be an individual optimisation function outside EUPHEMIA interacting with the CPOFs of all applications applying co-optimisation for the exchange of BC and/or sharing of reserves.

A simplified representation of the DAM clearing function is within the CZCAOF and communicates interactively with the CPOFs on available CZC for all BCMs and available bids in case of cross-product linking. After the CPOFs have determined the final use of CZC and bids of BC, the CZCAOF provides the available CZC and available cross-product linked bids to the Market Coupling Operator (MCO) of DAM such that the DAM in a next step can be cleared.

In this co-optimisation step 1, only the BCMs are cleared and prices and volumes of BC are made firm. Prices and volumes for the DAM are only calculated for an optimal allocation of CZC by the CZCAOF. Revised PTDFs are provided to the MCO operating EUPHEMIA.

Co-optimisation Step 2: Based on the revised PTDFs and/or ATCs, EUPHEMIA clears the DAM and determines prices and volumes for DAM.

This implementation option with BCMs cleared before DAM enables multilateral linking between BCMs and between DAM and unilateral cross-product linking from BCMs to DAM in the sense of exclusive group linking and some types of linking families but not in the opposite direction. As iteration steps are lower than in the 1-step co-optimisation, also optimisation time is expected to be lower.

Key advantages of this approach are:

- Implementation is possible without changing the existing EUPHEMIA procedures and modules as EUPHEMIA just receives revised PTDFs and/or ATCs instead of original PTDFs and/or ATCs while changes to PTDFs are applied before in co-optimisation step 2.
- The co-optimisation step 1 run is expected to be shorter in comparison to the implementation approaches described in 8.4 and 8.5 as only BCMs are taken into account with smaller volumes than DAM.
- EUPHEMIA procedures need not be changed but a simplified EUPHEMIA algorithm needs to be developed for the CZCAOF.

8.4 Implementation Option 3: 2-Step Co-Optimisation: CZCAOF together with SDAC [CZCAOF→←SDAC]

This implementation option optimises CZC allocation together with the SDAC. The CPOFs follow in the second step.

TSOs provide pseudonymised cross-product linked bids to NEMOs. NEMOs bring them together with the DAM bids and provide all pseudonymised bids to the CZCAOF and EUPHEMIA. TSOs provide the pseudonymised not-linked BC bids to the CZCAOF and the corresponding CPOFs.

The detailed process is explained in the following figure.

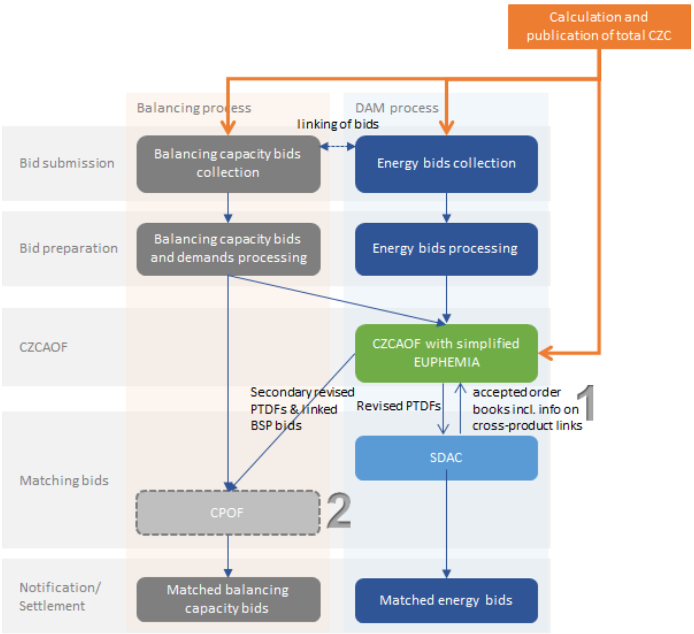

Figure 36: Communication paths in the 2-step co-optimisation CZCAOF together with SDAC [CZCAOF→←SDAC]

Co-optimisation Step 1: For ease of implementation and reduced calculation time, the CZCAOF uses a standalone simplified copy of EUPHEMIA (based on simplified EUPHEMIA requirements) for determining the optimal allocation of CZC to DAMs and BCMs. Thus, the CZCAOF comprises the total BCM optimisation and a solution which meets already a high level of accuracy for DAM bid allocation. With this simplified optimisation approach the CZCAOF determines CZC allocation to DAMs and BCMs but ignores more complex DAM bids as optimisation time exponentially increases in DAM bid complexity.[22,23] The outcome of this first CZCAOF run are revised PTDFs and/or ATCs provided to EUPHEMIA for the SDAC.

EUPHEMIA runs the total DAM optimisation based on the revised PTDFs from the first CZCAOF and provides back the accepted order books including information on cross-product links to the CZCAOF.

Based on the outcome of the SDAC, the CZCAOF re-optimises to determine the PTDFs for BCMs and provides the secondary revised PTDFs and the information about linked BSP bids to the CPOFs.

Co-optimisation Step 2: The CPOFs determine the optimal procurement of BC bids.

This implementation option facilitates unilateral cross-product linking (exclusive group linking and linking families) from DAMs to BCMs and multilateral linking between BCMs and between DAMs.

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[22] To what extent the simplified EUPHEMIA requirements consider DAM bids will be further elaborated in chapter 9 - the technical feasibility analysis.

[23] Further analysis is required in the implementation phase to what extent a CZC surcharge should be taken into account for more complex DAM bids and how this should be adjusted across borders and over time.

As more complex bids are ignored in the first CZCAOF run, optimisation complexity and, thus, required optimisation time is expected to be lower than in the 1-step co-optimisation but higher than in the previous implementation option 2 where the CZCAOF is optimised together with the CPOFs. A key advantage here is again that EUPHEMIA procedures need not be changed but a simplified SDAC algorithm needs to be developed for the CZCAOF. There is no risk of unsatisfied BC demand as long as the CZCAOF uses the identical optimisation algorithm as the CPOFs.

8.5 Implementation Option 4: 2-Step Co-Optimisation: CZCAOF together with SDAC [CZCAOF↔SDAC]

This approach optimises CZC allocation together with the SDAC similar as implementation option 3. In contrast to the previous approach, this implementation option requires a close exchange with EUPHEMIA as it does not include a simplified EUPHEMIA algorithm in itself but relies on the simultaneous optimisation of DAM in EUPHEMIA.

TSOs therefore provide pseudonymised cross-product linked bids to NEMOs. NEMOs bring them together with the DAM bids and provide all pseudonymised bids to the CZCAOF and EUPHEMIA. TSOs provide the pseudonymised not-linked BC bids to the CZCAOF and the corresponding CPOFs.

The detailed process is shown in the following figure.

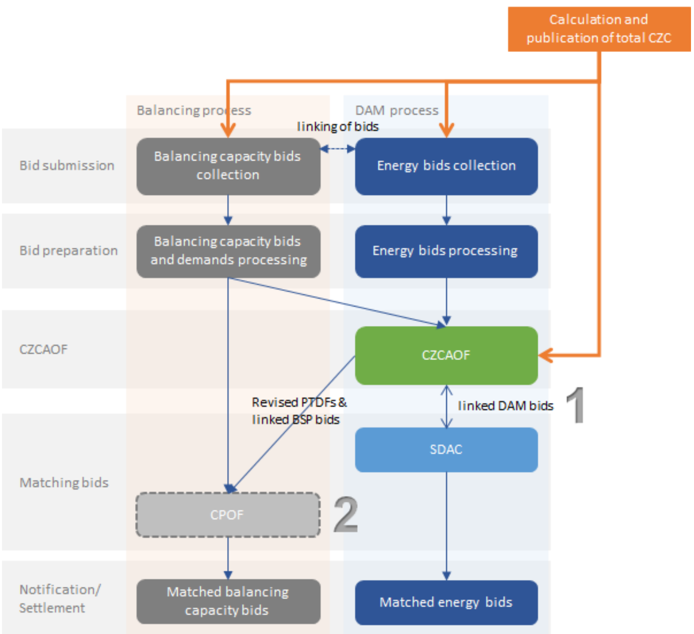

Figure 37: Communication paths in the 2-step co-optimisation CZCAOF together with SDAC [CZCAOF↔SDAC]

Co-optimisation Step 1: The CZCAOF jointly optimises CZC allocation with EUPHEMIA run the SDAC. The CZCAOF comprises the total BCM optimisation except for the actual procurement. Thus, the CZCAOF determines the market values for BCMs whereas the market values for SDAC are derived from EUPHEMIA provisions. In an iterative optimisation process between CZCAOF and

EUPHEMIA the optimal CZC allocation to DAMs is determined. The outcome of this first step are revised PTDFs and linked BSP bids provided from the CZCAOF to the CPOFs.

Co-optimisation Step 2: The CPOFs determine the optimal procurement of BC bids.

This implementation option could enable multilateral cross-product linking (exclusive group linking and linking families) between BCMs, between DAMs and between BCMs and DAMs, subject to the level of functions used from EUPHEMIA. In case the CZCAOF uses a sufficient number of features together with EUPHEMIA, multilateral linking could be applied, but at least theoretically there remains the risk that bids are not cleared due to wrong allocation per market, even though they are in the money in the markets.

The optimisation time is expected to be lower than in the 1-step co-optimisation but higher than in the previous 2-step co-optimisation implementation options due to the full consideration of linked bids also in the CZC allocation sub-process.

The key challenge is the required exchange with EUPHEMIA as this means an adjustment in existing EUPHEMIA procedures or even the CZCAOF integrated as a new module in EUPHEMIA. There is no risk of unsatisfied BC demand as long as the CZCAOF uses the identical optimisation algorithm as the CPOFs.

8.6 Procurement and Settlement

Independent from the implementation options, matched DAM bids and selected BC bids must be further processed. Therefore, the CPOFs provide the selected BC bids to TSOs and EUPHEMIA provides the selected DAM bids to NEMOs. Depending on the pseudonymisation code either TSOs or NEMOs further process the selected bids.

Therefore, in the 2-step co-optimisation implementation option 2, where SDAC is in the second step, NEMOs provide cleared linked bid information to the CZCAOF and this shall be communicated to the CPOFs for TSO usage.

In the 2-step co-optimisation implementation options 3 and 4, where CPOFs are performed in the second step, the CPOFs provide information about accepted linked bids to the CZCAOF.

NEMOs and TSOs re-pseudonymise the selected bids, TSOs continue the procurement and NEMOs and TSOs inform BSPs and MPs about selected bids.

8.7 Requirements of the Functions

In addition to the market and product requirements listed in chapter 3.3 and 3.4, this paragraph lists the non-exhaustive requirements for the function of splitting the CZC, the CZCAOF, and it lists the requirements for the function of the procurement of BC, the CPOF. For each co-optimisation option the requirements are:

1. Always satisfy completely BC demand for each product in case of sufficient local BSP bids

2. In case of unsatisfied local TSO BC demand as a result of insufficient local volumes (bids) offered by BSPs, the TSO surplus is calculated as the difference of the technical price limit of the volume of unsatisfied demand and the marginal price of the importing BSP bids

3. Optimise the BCM by minimising the procurement costs of TSOs (CEP 7(1)(e) / 8(1)(b) / 8(2)(b) and EB Regulation Art. 58.3(a))

4. In case of indeterminacies between DAM and BCMs, according to Art. 40 Methodology (art.9(4)), CZC should be given to the DAM.

5. In case of indeterminacies between the different BC products, the priority is still to be determined at each BZB by respective TSOs.

9 Technical Feasibility of the Implementation[24]

This chapter addresses the technical feasibility of the implementation of a co-optimisation algorithm encompassing all necessary requirements. The specific topics that are addressed in this chapter are described in Section 9.1, along with main takeaways. Section 9.2 describes the features of the target co-optimisation solution. Section 9.3 describes the 1-step co-optimisation option in further details, along with computational variations that could lead to tackling the problem. Section 9.4 discusses the 2-step co-optimisation options that have been presented above in this IIA. Section 9.5 synthesises a comparison of all implementation options in tabular form, consisting of the computational variations of the 1-step co-optimisation and the different 2-step co-optimisation options. Section 9.6 concludes.

A detailed and final algorithmic technical assessment requires actual implementation (in the form of prototyping/mock-up) and testing. An important challenge for such an assessment relates to the definition of precise algorithmic requirements (rather, a set of "orientations/options" have been proposed in the IIA, most of which are yet unambiguously defined). This chapter therefore attempts to progress on this aspect, and to formalise the requirements.[25]

9.1 Introduction

This section discusses the main questions that are addressed in this chapter and provides some summary takeaway points in relation to each question that is raised.

The ensuing discussion considers the "deterministic approach" as explained in section 7.5. Similarly, the analysis considers exchange of BC but not sharing of reserves. Finally, the discussion is based on basic cross-product bid linking models, and the assumption is that links between DAMs and BCMs can be represented in a computationally tractable fashion. Notwithstanding, it is worth mentioning that numerous aspects related to bid linking, especially within a certain product, remain open. In particular, there is no standardised description of bid linking and substitutability. Issues related to the paradoxical acceptance of bids and their interrelation with bid linking also remain open.

[24] The main content behind this chapter has been delivered by N-SIDE.

[25] Notwithstanding, another key challenge to perform a final algorithmic assessment relates to the availability of data. As usual for new software tools, data need to be generated for testing purposes which should include standard and specific situations. For co-optimisation purposes, in particular data for balancing capacity including linking requirements need to be prepared which reflect the effects of cross-border exchange. Beyond, linking with DAMs need to be prepared. Historical data can be used for DAMs. These data are required for the technical performance and accuracy testing of different implementation options. These data need not reflect changes in market structures, liquidity changes and so on.

1. Description of the required adjustments of existing EUPHEMIA processes affected by implementing co-optimisation:

a. **What needs to be additionally implemented within EUPHEMIA for a 1-step co-optimisation? What should additional modules deliver to the existing EUPHEMIA processes?**

The additional requirements that should be implemented within EUPHEMIA relate to

1. the introduction of additional BCM products, and an adaptation of the constraints of the EUPHEMIA model to reflect the linking of these BCM products to DAM products as well as the introduction of additional BC products,
2. a means of coping with the deterministic requirement for flow-based compatibility.

The additional functionalities should deliver, at a minimum, cleared BC bid volumes (supply and demand) and BC prices which are aligned with DAM bid prices (which in turn implies an optimal CZC allocation for each product).

b. **Description of adaptation of existing EUPHEMIA processes to meet the requirements of each implementation option.**

Generally speaking, the IT process of the EUPHEMIA algorithm can remain largely untouched: besides the fact that there are additional inputs and outputs, the workflow can remain similar as in the existing version[26].

The primal formulation of EUPHEMIA should be revisited in order to accommodate BC products and network constraints under the deterministic approach. The dual constraints of the model will also be affected. There are formulations of the model under the 1-step approach, in particular the so-called inscribed boxes approach, that likely allows a tractable generalisation of the existing model at the expense of a somewhat more conservative requirement than the deterministic approach, but one that is computationally tractable. Assuming the inscribed boxes approach can be implemented successfully, the existing EUPHEMIA process would be able to merge the CPOF requirements and the CZCAOF/SDAC functions into one integrated single computation.

c. **What can be reused from existing EUPHEMIA module algorithms for the additional modules?**

The EUPHEMIA algorithm is a branch-and-cut algorithm which relies on fine-tuned branching heuristics and special-purpose cuts for coping with the European market business rules related to the non-paradoxical acceptance of block orders and various other generalizations (PUNs (national single price), MICs (Minimum Income Constraint), and so on). The underlying mathematical program is a mixed integer quadratic program subject to complementarity constraints. It is mixed integer because of non-divisible products such as blocks, and there are complementarity

[26] This statement is actually only valid for the EUPHEMIA algorithm itself, and does not consider other adaptations of the IT infrastructures that are responsible for collecting input or broadcasting output (i.e. PMB and subsequent systems to PMB), which are not analysed in the present chapter.

constraints due to the pricing business rules. Linking of bids makes the problem larger, both in terms of the number of primal and dual variables (matching BC offers, BC prices, implied BC "flows") as well as in terms of constraints but does not affect the fundamental underlying structure. However, the deterministic requirement introduces a more radical effect to the problem, by rendering it a robust/stochastic mixed integer quadratic program subject to complementarity constraints. Although this generalisation of the problem is fundamentally intractable, there likely exists a conservative approximation of the deterministic requirement, which is referred to as the "inscribed boxes approach" in the sequel, which can in principle restore computational tractability. Assuming that the "inscribed boxes approach" can be implemented successfully, the existing EUPHEMIA functionality, which relies on sophisticated cuts and branching heuristics, can be transferred directly to the co-optimisation context.

d. **Provision of an indicative cost estimation for developing the additional modules and their integration with EUPHEMIA (order of magnitude), elaborated in Ch. 14.**

The inscribed boxes approximation would need to be tested, compared with alternative computational variations, and then validated if applicable. A number of important open questions would need to be tackled in order to deploy a full-blown 1-step computational approach:

a) Validation of its alleged property of satisfying the deterministic requirement both in theory as well as through experiments on actual problem instances.

b) Generalisation of the primal problem in order to accommodate BC products, adaptation of network constraints and linking of bids. Duality analysis and development of corresponding dual constraints.

c) Testing of the new model on large-scale instances, in order to ensure computational tractability and to validate that the "inscribed boxes approach" is not overly conservative.

2. Evaluation of the market structures from a technical perspective. For each market structure provide a high-level explanation of technical implementability, required effort and processing time.

The market structures are evaluated in detail in the following sections. There exists a conservative approximation of the 1-step optimisation problem, referred to as the "inscribed boxes approach". This approach can produce coherent DAM and BCM prices and for which the problem remains a mixed integer quadratic program subject to complementarity constraints. This means that the problem could remain no harder in terms of complexity relative to the current formulation (although larger, due to the presence of additional variables and constraints in the model, resulting from the integration of the BCM into the existing model).

3. Comparison of the market structures in terms of process timing and optimisation time. (Explanation of the operation after set-up.)

One should foresee an increase in computation time due to the introduction of new variables and constraints in the market clearing model, as they relate to BC products. However, these could be counter-balanced by an increase in available run time since the BC processes are integrated to

DAM clearing, as well as possible simplifications to the market clearing model which would be game-changing in terms of computational complexity.

4. Identification of a computationally more efficient optimisation approach to the implementation within EUPHEMIA. In case, description how can this be integrated with existing optimisation approaches, and the affect to existing processes including required adjustments.

Any alternative to EUPHEMIA would need to reinvent fundamental innovations related to branching heuristics and special-purpose cuts and would also require significant development effort for proof-testing, against a very demanding set of future requirements (15-minute time resolution, expansion of geographical coverage, new flow-based constraints, and so on).

Section 9.4 discusses different co-optimisation implementation options which attempt to decompose the multi-product auction of a 1-step co-optimisation into multiple steps and keeping EUPHEMIA as the core solution for the DAM clearing. As discussed in the sequel, such configurations depart from the spirit of co-optimisation in the sense of a multi-product auction, most likely result in suboptimal allocations, and in certain cases are not clearly defined.

9.2 Idealised 1-Step Co-Optimisation (CZCAOF & CPOF & DAM)

The 1-step co-optimisation is an integrated co-optimisation of the functions of CZCAOF, SDAC and the full requirements of the CPOFs. In terms of optimisation modelling and algorithmics, there is therefore only one master algorithm which encompasses the three allocation functions (CZCAOF, SDAC, CPOF). This algorithm is represented by the black box in the figure below.

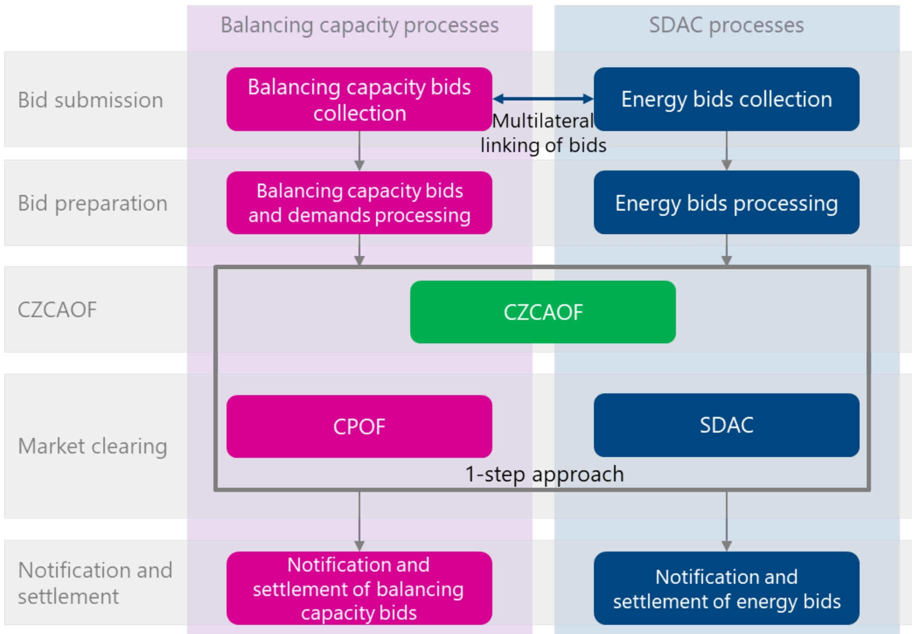

Figure 38: Process diagram of the 1-step co-optimisation

9.2.1 Key Benefits of 1-Step Co-Optimisation

As a general remark, centralising all data into a single calculation optimisation process does, by construction, always provide at least equivalent – and at best superior – solutions, compared to the alternative of splitting the calculation into different sequential steps[27]. For the problem at stake, a computational one-step approach refers to resolving to optimality a single problem fed with a single welfare maximisation objective function. Even if the solutions to this problem are not strictly optimal, due to the combinatorial nature of the problem and limited run time, the properties of the results may nonetheless respect valuable and desirable properties. This is currently the case with EUPHEMIA. Even if a solution is not proven to be optimal, EUPHEMIA provides always output solutions for which, for instance, prices are consistent with congestion patterns. Such properties increase the overall transparency of the co-optimisation options, as they respect coherence between the results of the 3 functions, CZCAOF, SDAC & CPOF.

9.2.2 Key Challenges of 1-Step Co-Optimisation

Experience in real-life complex algorithm developments has shown that it is typically hazardous to guarantee that a given problem can be solved efficiently and within reasonable time only based on expert judgement. Rather, commitments on algorithmic performance can only be ensured upon testing of specific algorithmic approaches over realistic instances, which in turn necessitates the definition of precise requirements. At this stage, such advanced studies are not available insofar as co-optimisation is concerned. It is therefore not possible to unambiguously state what is truly achievable and what is not. This is even more the case given that the current and upcoming EUPHEMIA requirements are already challenging from a performance and scalability standpoint, while the complexity of cross-zonal BC procurement (and in particular the difficulty of real-life instances) is largely unknown.

On the other hand, expert judgement and experience (including from the development of EUPHEMIA) can provide hints and intuitions over alternative options that can be mobilised in case the full set of requirements appears too challenging.

From a high-level perspective, the following three categories can be explored to relief the algorithmic performance to decide for the optimal allocation of CZC:

1. *Simplify/adapt the requirements of SDAC for the CZCAOF*

From the EUPHEMIA algorithm the combinatorial optimisation process structured in four different phases could be simplified:

[27] Refer, for example, to "volume coupling" concepts (as implemented between the CWE and the Nordics, and as contemplated for GB interconnectors – see CEPA, Thema, Ignis, Smart Vision, "Cost Benefit Analysis of Multi-Region Loose Volume Coupling (MRLVC)", April 2021, available at https://consultations.entsoe.eu/markets/cost-benefit-analysis-of-multi-region-loose-volume/consult_view/). In the context of "volume coupling", CZC is allocated independently of the price calculation. This effectively produces only equivalent or inferior solutions, compared to price coupling approaches.

- First, the welfare maximization problem, referred to as Master Problem, is settled,
- then it solves three sub-problems, the Price Determination Sub-Problem,
- the PUN Search Sub-Problem and
- finally, the Volume Indeterminacy Sub-Problem

Such technical details are discussed in Section 9.3.

2. *Simplify/replace (some) DAM bids for the CZCAOF*

Several simplifications of the actual DAM requirements have already been contemplated (notably as part of the "EUPHEMIA Lab R&D program"), and some have been studied quite in depth and/or are being implemented. Bids, bid combinations and existing linking-of-bid types in DAMs, such as complex orders, block orders or merit and pun bids, could be simplified or replaced by a less complex representative.

3. *Change market clearing concepts of SDAC for the CZCAOF*

E.g., during the CZCAOF, the SDAC representation could be used in combination with non-uniform pricing for faster CZC split results.

9.2.3 Mathematical Formulation

The following model is largely stylised, and ignores a number of realistic features, but (1) it lays out the fundamental concept of a 1-step co-optimisation model in the sense of EB Regulation Art. 40, and (2) it illustrates the "inscribed boxes" approximation for satisfying the deterministic requirement. This basic model can then be generalised in a number of directions, as also indicated in the N-SIDE/AFRY co-optimisation study. Generalisations include multiple types of BC products (aFRR, mFRR, RR), upward as well as downward BC products, more complex product types (block orders, scalable complex orders), hybrid network models (i.e., transportation and flow-based formulations), and so on.

Inputs

The inputs of the model can be described as follows:

Sets
Z: set of zones
I: set of offers (includes energy and balancing capacity offers)
K: set of critical branches

Parameters
Q_i: quantity of offer i
P_i: price of offer i
QR_i: quantity of balancing capacity offer i
PR_i: price of balancing capacity offer i
RAM_k: remaining available margin of critical branch k
$PTDF_{z,k}$: power transfer distribution factor from zone z to branch k

Note that – in this simplified notation – all bids are mutually exclusive continuous BCM & DAM bids (although QR or Q may have a zero value, in which case they act as either a DAM-only or a BCM-only bid). The bid linking constraints considered here are thus continuous and allow for allocation of the same physical capacity can be used for either DAM purposes or as BC (equation (8) below).

Objective and constraints

The primal model can be described as follows.

$$
\begin{aligned}
& \max_{x,xR,n,nR} \left(\sum_{i\in I} P_i \cdot Q_i \cdot x_i + \sum_{i\in I} PR_i \cdot QR_i \cdot xR_i\right) && (1)\\
(\rho_z): \quad & n_z + \sum_{i\in I_z} Q_i \cdot x_i = 0, z \in Z && (2)\\
(\phi): \quad & \sum_{z\in Z} n_z = 0 && (3)\\
(\rho_z^{R,s}): \quad & nR_{z,s} + \sum_{i\in I_z:QR_i<0} QR_i \cdot xR_i = 0, z \in Z && (4)\\
(\rho_z^{R,d}): \quad & nR_{z,d} + \sum_{i\in I_z:QR_i>0} QR_i \cdot xR_i = 0, z \in Z && (5)\\
(\phi^R): \quad & \sum_{z\in Z} (nR_{z,s} - nR_{z,d}) = 0 && (6)\\
(\lambda_k): \quad & \sum_{z\in Z} PTDF_{z,k} \cdot n_z + \sum_{z\in Z} PTDF_{z,k}^{+} \cdot nR_{z,s} \\
& + \sum_{z\in Z} (-PTDF_{z,k})^{+} \cdot nR_{z,d} \leq RM_k, k \in K && (7)\\
(\mu_i): \quad & x_i + \frac{QR_i}{Q_i} \cdot xR_i \leq 1, i \in I : Q_i \neq 0 && (8)\\
(\gamma_i): \quad & x_i \leq 1, i \in I && (9)\\
(\gamma_i^R): \quad & xR_i \leq 1, i \in I && (10)\\
& x \geq 0, xR \geq 0 && (11)
\end{aligned}
$$

Equation (1) maximises the total welfare, which consists of the economic welfare that is generated by the matching of DAM and BCM bids.

Equation (2) defines the net injection of energy, n_z, at each zone, and equation (3) imposes energy balance in the system.

Equations (4), (5) and (6) are the corresponding expressions for BC. Equations (4) and (5) define injections of BC supply and demand respectively, and these need to be treated differently due to the asymmetrical role of BC demand in the model. More specifically, BC demand may materialise in real time at any intermediate level between zero and its fully matched volume, which reflects the deterministic requirement, and which is why it is a separate decision variable from BC supply. Equation (6) then requires that total BC trades equilibrate.

Equation (7) implements the “inscribed boxes approximation” of the deterministic requirement. The full detail of this derivation is described in section 9.3.3. The constraint implies that a firm flow-based on matched DAM bids and an uncertain flow following an accepted BC offer are such that the CNEC limits are respected.

Equation (8) is a basic representation of multilateral linking. It requires that a given amount of asset capacity is not double counted in the model: if a certain amount of supply capacity is used for DAM purposes, it cannot also be used for covering BC.

Constraint (9) requires that a DAM order cannot be matched beyond 100% of its offered volume. Constraint (10) provides the corresponding expression for BCM orders.

Max welfare vs. BC cost minimisation

It is important to point out that the model above can trivially handle strictly inelastic BC demands, by considering them as right-hand side parameters of equation (5). Such BC demands should be served with top priority. However, if BC demands are modelled as strictly inelastic, the model obviously becomes infeasible if there is a lack of sufficient BC offered in the system to cover these balancing demands.

As a fallback, therefore, the valuation of such price-inelastic BC demands can be placed at the ceiling of the BCM bid price (i.e., price-taking BC bids). Equation (1) of the co-optimisation model measures total welfare, which is the sum of the welfare generated by the exchange of both BC and matched DAM bids. This implies that the model will, by design, allocate production capacity to that demand which creates highest market value, and the resulting economic signals generated by the model will be coherent with that allocation. Specifically, if the price cap of BC is above the price cap of DAM, then the welfare optimisation criterion will allocate a linked bid to the BCM with a higher capacity than to the DAM. In addition, the treatment of scarcity in BCM offers can be handled separately – as is currently the case for DAMs in the so-called "adequacy patch".

Further, in case of price indeterminacies (i.e., matching at vertical segments), EUPHEMIA currently implements a mid-point rule for DAM products. However, for inelastic BC demands modelled with price-taking demands, a mid-point rule may be inappropriate, as the resulting prices may be influenced by the maximum prices – which should be considered as a technical parameter. However, since price indeterminacy rules are treated independently from the welfare maximisation, implementing different pricing rules for DAM and BCM products in the case of price indeterminacy is technically straightforward. Specifically, the price indeterminacy rules can be set such that the mid-price is targeted for DAM and the lowest price is targeted for BCMs.

A key benefit of the model presented above is that it avoids unnecessary binary variables (at least when compared to the model proposed in the appendix).

In conclusion of the above, a welfare maximisation function as objective function of all co-optimisation functions (CZCOF, SADC & CPOF, for each implementation option, being it either the computational variation of the 1-step co-optimisation option or each 2-step co-optimisation option) is clearly preferable.

Outputs

The outputs of the model include primal variables (matchings, flows), and dual variables (prices). They can be described in detail as follows.

Primal variables
x_i: accepted fraction of offer i
n_z: net injection of zone z
xR_i: accepted fraction of reserve offer i
nR_z: net injection of balancing capacity in zone z
xR_i: activated fraction of reserve offer i
nR_z: net injection of balancing capacity in zone z

Dual variables
ρ_z: energy price of zone z
ϕ: energy price of a virtual slack node
$\rho_z^{R,s/d}$: balancing capacity price at zone z
ϕ^R: balancing capacity price of a virtual slack node
λ_k: price of flowgate k
μ_i: surplus of linked order i
γ_i: energy surplus of energy-only order i
γ_i^R: balancing capacity surplus of balancing capacity-only order i

Fundamental economic properties of a co-optimisation model

The (non-trivial) Karush-Kuhn-Tucker conditions of the problem can be described as follows.

$$
\begin{aligned}
& 0 \leq \lambda_k \perp RAM_k - \sum_{z \in Z} PTDF_{z,k} \cdot n_z - \sum_{z \in Z} PTDF^+_{z,k} \cdot nR_{z,s} \\
& - \sum_{z \in Z} (-PTDF_{z,k})^+ \cdot nR_{z,d} \geq 0, k \in K && (12) \\
& 0 \leq \mu_i \perp 1 - x_i - \frac{QR_i}{Q_i} \cdot xR_i \geq 0, i \in I : Q_i \neq 0 && (13) \\
& 0 \leq \gamma_i \perp 1 - x_i \geq 0, i \in I && (14) \\
& 0 \leq \gamma_i^R \perp 1 - xR_i \geq 0, i \in I && (15) \\
& 0 \leq x_i \perp -P_i \cdot Q_i + Q_i \cdot \rho_{z(i)} + \mu_i + \gamma_i \geq 0, i \in I && (16) \\
& 0 \leq xR_i \perp -PR_i \cdot QR_i + QR_i \cdot \rho_z^{R,s/d} \\
& + \frac{QR_i}{Q_i} \cdot \mu_i + \gamma_i^R \geq 0, i \in I && (17) \\
(n_z): \quad & \rho_z - \phi + \sum_{k \in K} PTDF_{z,k} \cdot \lambda_k = 0, z \in Z && (18) \\
(n_z^{R,s}): \quad & \rho_z^{R,s} - \phi^R + \sum_{k \in K} PTDF^+_{z,k} \cdot \lambda_k = 0, z \in Z && (19) \\
(n_z^{R,d}): \quad & \rho_{z(i)}^{R,d} + \phi^R + \sum_{k \in K} (-PTDF_{z,k})^+ \cdot \lambda_k = 0, z \in Z && (20)
\end{aligned}
$$

These optimality conditions indicate a number of fundamental properties that should be satisfied by an economically consistent co-optimisation model in the sense of EB Regulation Art. 40. For instance, consider an order which is partially accepted in DAMs (0 < x < 1) and in BCMs (0 < xR < 1). Standard arguments using the optimality conditions above result in the following for the price at the node of an order which is splitting its capacity between the DAM and a BCM:

$$P_i - \rho_{z(i)} = PR_i - \rho^{R,s}_{z(i)} \tag{21}$$

This condition is entirely intuitive, and states that if a bid is linked, then the only way in which the BSP/MP is willing to split its capacity between DAM and a BCM is if its profit margin is equal in both markets. Note that this condition implements marginal pricing in a computationally tractable fashion (as a natural property of a welfare maximisation program, without the need to use any binary variable). This condition also ensures consistency between DAM and BCMs as intended in a co-optimisation context (which is more than what can be said for the 2-step co-optimisation options, for which such no-arbitrage conditions are in general not satisfied, and would thus lead to possible market design and gaming concerns, as discussed further in section 9.4).

Note that the mathematical conditions above clarify why the problem in its genuine form cannot fundamentally be broken into three fully independent/separate boxes: DAM-related and BCM-related decisions are interdependent, and the market prices are also fundamentally interdependent. The following bullet points describe some instances of this fundamental interdependence in the primal and dual conditions of the problem:

- **Interdependence of DAM and CZC in the primal**: constraint (2) which describes the net injection of energy to the network implies that energy flows depend on matched DAM bids and, thus, implies the use of transmission capacity along every link of the network.
- **Interdependence of BCMs and CZC in the primal**: constraint (4) which describes the net injection of BC to the network implies that BC depends on the use the network. Every MW of accepted BC bids implies a (possible) increase in the use of the transmission network for covering possible activation of balancing energy as a result of cross-border procurement.
- **Interdependence of DAMs and BCMs in the dual**: condition (21) describes a connection between the DAM bid price at a certain location and the BC price at the same location. If this location has an order that is splitting its MWs between DAM and BCMs voluntarily, then this order must be earning the same profit margin in both markets. This means that DAM bid prices and BC bid prices depend on each other.
- **Interdependence of matchings and prices**: Condition (16) states that if a non-zero volume of an order is matched ($x > 0$), then the price in the zone of the order is at least as high as the price of the order. Thus, prices depend on how matched orders are selected. These optimality conditions effectively implement the first principles of marginal pricing. Note that these principles embed the notion of transfer of surplus between linked orders, thanks to the dual variable of constraint (8).

These observations can be summarised in the following figure. This figure conveys the message that everything is interdependent in co-optimisation: primal variables (market matches) depend on dual variables (market prices), and DAM depends on BCMs which depends on CZCs. **Any break from these relations would only be justified on the basis of technological/algorithmic dead-ends, which have not yet been clearly identified and are further discussed in section 9.3.**

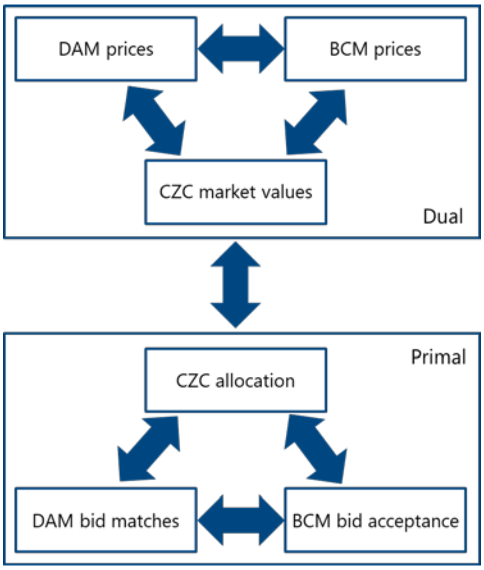

Figure 39: The interdependence of DAMs, BCMs and CZC allocation, and the interdependence of matched volumes and clearing prices are an essential requirement of co-optimisation, which should only be disregarded in case of proven algorithmic dead-ends

What is new/different compared to current EUPHEMIA?

It is crucial to point out that the model above achieves to satisfy the deterministic requirement by delivering a conservative approximation through constraint (7), but without creating a significant departure from the existing algorithmic infrastructure. This is a crucial observation insofar as computational scalability of co-optimisation is concerned.

Challenges to existing algorithmic infrastructure

The aforementioned market clearing model has new variables for BC orders (QR and PR), and it has new constraints (for instance, constraints (4) - (6) insofar as BC products and possible flows of balancing energy as a results of BC exchanges are concerned, and constraints (8) insofar as linking of bids is concerned). This implies additional dual variables (for instance, BC prices and the surplus of BC offers), as well as new dual constraints (for instance, constraints (19) and (20) that link BC prices and the value of the network). This implies a larger problem, and therefore a more challenging computational task.

The good news

A crucial observation of the “inscribed boxes” formulation of equations (1) - (11) is that the deterministic requirement is captured without considering explicitly the entire set of combinations of extreme balancing energy activations resulting from cross-border procurement of balancing capacity. This is a game-changing attribute of the formulation because it means that the fundamental structure of the problem remains unchanged: A mixed integer quadratic program subject to complementarity constraints can be continued to deal with a (deterministic, as opposed to stochastic or robust) mixed integer quadratic program subject to complementarity constraints. More specifically, the same fundamental branch and cut strategy can be further employed that constitutes the heart of the EUPHEMIA solution. Powerful commercial solvers (such as CPLEX) can remain the building stones for this branch and cut strategy, and the special-purpose algorithmic heuristics that relate to intelligent branching and node-specific cuts which have been developed for EUPHEMIA remain valid. The newly introduced constraints are linear, the derivations of surplus expressions for linked blocks result from basic duality arguments, and no-PAB requirements (paradoxically accepted bids requirements) continue to be addressed through problem-specific cuts that exploit problem structure.

9.3 Computational Variations of the 1-Step-Co-Optimisation (CZCAOF & Euphemia for CPOF & DAM) – “*Option 1*”

This section provides a (non-exhaustive) list of algorithmic options for resolving the co-optimisation problem. They are only described qualitatively, as no mock-up or other preliminary implementation has yet been developed. As already stated above, it is hard to know at this stage which option performs best – if at all. This can only be assessed upon actual testing, which requires several further steps: precise requirements, developments, realistic datasets, …

The objective of this section is nonetheless to clarify how various algorithmic steps can influence the performance and the properties of the results of the co-optimisation algorithm, and disentangle the question of whether it is appropriate to separate the co-optimisation function into separate functions that deal with CZC allocation, DAM bid matching, and BCM bid acceptance (see also section 7.3).

9.3.1 Computational Variation 1: Robust Optimisation with Simplified Constraint

This computational one-step approach attacks the deterministic requirement by describing it as a stochastic/robust optimisation formulation.

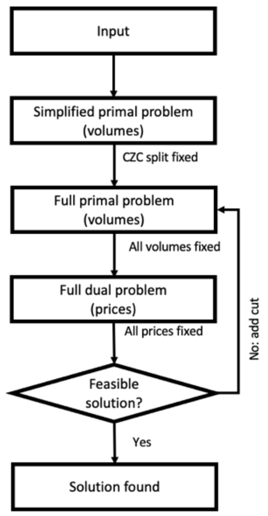

Figure 40: Algorithmic process diagram of computational variation 1 of the 1-step co-optimisation

The idea in this one-step approach is to approximate the problem using a divide-and-conquer strategy, whereby one isolates the deterministic requirement (which is algorithmically a very serious challenge, for the reasons described in the previous paragraph) from the rest of the problem. This is indicated in the process diagram above, where first a simplified primal problem is considered that focuses on the deterministic requirement and simplifies other attributes of the problem (e.g., considers a linear relaxation of blocks, scalable complex orders, and other products), while still representing the linking of bids in this simplified primal problem. The output of this simplified primal problem is the CZC allocation for DAM purposes and for BCM purposes. This allocated CZC is then used as input to a co-optimisation model which is rid of the deterministic requirement. This new co-optimisation problem then seeks to find a solution which respects European uniform pricing rules by looping, if necessary, between this second primal problem and a pricing/dual function.

This procedure is a heuristic approach that attempts to tackle the deterministic requirement. However, the procedure encounters serious computational challenges. These amount to the fact that the first primal problem in the diagram is still a robust optimisation problem subject to decision-dependent uncertainty. This is a class of optimisation problems that remain extremely challenging.[28] One could cast the problem as a stochastic program by enumerating all the possible combinations of ways in which balancing demands could be, but this becomes a problem with a number of scenarios that grows exponentially in the number of BC products (including locations of these products). An alternative is to attack the robust optimisation version of the problem using decomposition methods.[29] Unfortunately, it has been found that such decomposition methods may only find local optima, and also only approximate the requirement, because the range of possible TSO activations of BCs depends on the acceptance of BC bids. This latter feature is called “decision-dependent uncertainty” and is a fundamental computational challenge of the problem which is largely intractable given the existing state of the art in mathematical optimisation. But at least this intractable problem exists only once (in a calculation step which ignores some other complex requirements such as for example binary variables stemming from block bids or uniform pricing rules).

Isolating the deterministic requirement of the problem should not be misunderstood as separating the problem between DAMs, BCMs, and CZC allocation. The procedure described in the diagram above respects EB Regulation Art. 40, since the second primal problem is a co-optimisation model that jointly optimises DAMs, BCMs and CZC allocation, as well as matchings (primal variables) and prices (dual variables). The deterministic requirement is not considered explicitly in this price-matching search, and rather has been tackled in a preceding distinct procedure. However, the model still jointly considers DAMs, BCMs and CZC allocation (though with a fixed apportioning of CZC that can be allocated to each product – which may be a source of suboptimality). It can be

[28] Nohadani, Omid, and Kartikey Sharma. “Optimisation under decision dependent uncertainty”. SIAM Journal on Optimisation, vol. 28, no. 2, pp. 1773-1795, 2018
[29] Bertsimas, Dimitris, et al. "Adaptive robust optimisation for the security constrained unit commitment problem." IEEE transactions on power systems 28.1 (2012): 52-63.

thought of as existing US market clearing models (with a base BC matching) but with uniform pricing on top.

9.3.2 Computational Variation 2: Inscribed Boxes

This one-step approach attacks the deterministic requirement by using the concept of “inscribed boxes”.

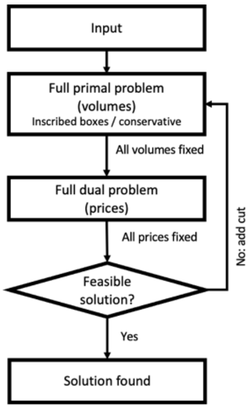

Figure 41: Algorithmic process diagram of computational variation 2 of the 1-step co-optimisation based on inscribed boxes

The market clearing model based on inscribed boxes is described in section 9.2.3 of the present chapter. It amounts to a conservative approximation of the deterministic requirement, but one that is computationally very promising. The algorithmic procedure for tackling the problem is indicated in Figure 42. The idea is to exploit a result of computational geometry which deals with the exponential number of points that define the “box” of possible TSO demand activations in an efficient way by observing that the set of resulting constraints is highly redundant. The implication of this proposition is that the robust optimisation aspect of the problem can be reduced to a set of constraints that is equal to the original number of constraints of the SDAC problem.

What is accomplished relative to computational variation 1 is that this now arrive to a tractable chain of steps, since the primal problem is in principle a computationally viable extension of the existing SDAC model (with BC products, linking of bids, and a conservative version of the deterministic requirement). Even if multiple iterations over the primal problem are required in search of uniform prices, the primal problem is computationally tractable under the “inscribed boxes” approach. Non-uniform pricing would imply that there is no looping required in Figure 42, thus a further acceleration of the algorithmic procedure.

In order to understand why there is a more conservative version of the true deterministic requirement, consider the stylised representation of the feasible region of the problem in the following figure. The green set in the figure is the feasible set of the original problem. The problem is that describing this green set is too complicated, because it lives in a space of very large dimension.

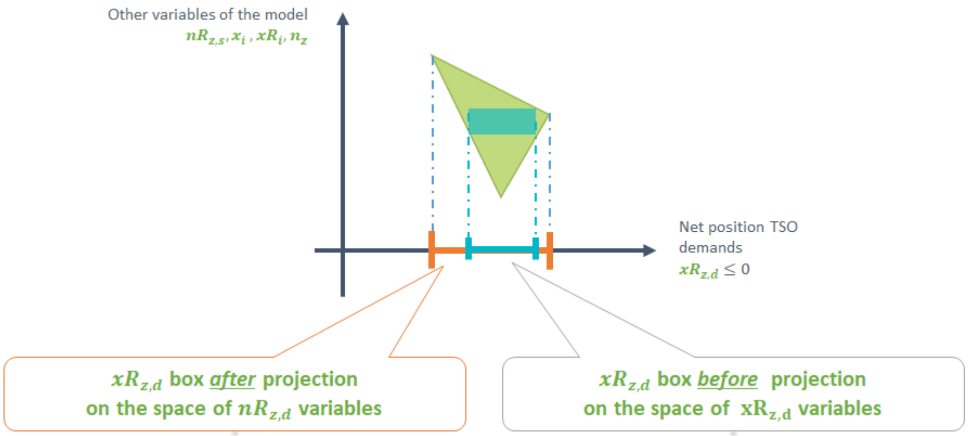

Figure 42: fitting a box in the green triangle and then projecting to the space of TSO demands results in a smaller set (more conservative) than projecting the triangle on the space of TSO demands and then fitting a box to that

In order to bring the problem back to a lower-dimensional space (the dimension that is handled by the existing SDAC model), the possible combination of ways in which the system might react to any possible combination of realised TSO demand should be ignored, and just figured out how matches should be made that make sure that the grid is not put in an impossible position in the balancing market. This is the orange interval in the figure above. Since the green set is intractable to obtain, the orange set which is its projection in the set of feasible TSO demand matchings is also intractable to obtain. The idea of the inscribed boxes approach is to note that the blue box can be easily computed in the figure above, which is a box that is as large as possible while still being in the green triangle, hence the naming of the method. The reason that this is easy to compute is described in [5] and applied in equation (7) of the model of section 9.3.2. Boxes are easy to project, so once the blue box is found, also the blue interval in the figure above can be easily found. Thus, the huge dimensionality of the problem (the y axis in reality is not one dimension as in the figure above, but a number of dimensions which is exponential in the number of areas and reserve products in the market) collapsed to a dimension that we know we can in principle handle in the existing European market clearing platform. This comes along with the effect that the blue interval (the approximation) is smaller than the orange interval (the true and intractable feasible set). The magnitude of this conservatism remains to be tested experimentally. At this point, what can be stated is that it emerges as the most promising computational variation among 1-step co-optimisation options that have been investigated,[30] and merits further consideration as a viable contender for simultaneously meeting the numerous demanding requirements of an efficient co-optimisation model.

One final remark is that the inscribed boxes approach brings the model closer to the professional practice in other worldwide markets by avoiding an exponential growth in the dimensionality of the problem. It is not clear that there exist currently any electricity markets in the world that perform market clearing with a deterministic requirement (even if some market clearing models

[30] N-SIDE, AFRY, "CZC allocation with co-optimisation", November 2020 and N-Side, "Co-optimisation of cross-zonal transmission capacity: an alternative proposition to co-optimise energy and balancing capacity within the SDAC algorithm", March 2020.

include security constraints, but N-1 security constraints do not imply an exponential increase in the dimensionality of the problem with respect to number of areas). Although the requirement makes perfect sense operationally, especially in the context of multi-member state coordination, it is extremely challenging computationally. In this respect, the inscribed boxes approach is a promising way forward that may merit further investigation.

9.3.3 Computational Variation 3: Conservative Approach

This computational variation of the 1-step co-optimisation attacks the deterministic requirement by using a highly conservative pre-processing of input data for the co-optimisation model. It is described in section 4.3 of [4].

The idea of the model is to calculate, for each BC demand, the worst possible stress that a matching of this BC demand can exert on the system by being matched to the most unfavourable possible BSP supply. This gives rise to “worst-case PTDFs” which are indexed over BC demands and CNECs, and which quantify how much every matched MW of TSO demand can stress a given CNEC in the worst possible case. The computational appeal of this approach is that these parameters can be precomputed very easily, based on BC offers, and then used as input for populating a tractable co-optimisation market clearing model. Like the model of section 9.3.3, this market clearing model is tractable because it avoids the exponential increase in the dimensionality of the model which is implied by the pure deterministic requirement: the conservative processing of the data implies that there is no need to endogenously represent the possible activation of balancing energy resulting from matched cross-border BC procurement. The downside of the model is that, like the inscribed boxes approach of section 9.3.3, it may cut off parts of the feasible region.

Compared to the "inscribed boxes" approach, this option is considered to be less promising, because of its high conservatism. Concretely, it is argued in [3] that BC demands of zones in well-connected parts of the network can be blocked from accessing BC out of their area because of the possibility that these BC demands might need to be served by BC resources in “edges” of the network. Thus, preliminary reflections on the relative merit of the inscribed boxes approach relative to the conservative approach indicate that the inscribed boxes approach is more straightforwardly deserving of possible consideration for prototyping purposes.

The conservative approach could, however, be further investigated. For example, the conservative approach could be deployed separately for different EU regions, linked via simpler constraints (e.g. SWE region and CWE region calculate a separate “conservative set of CZC constraints”, and these regions are “seamed” together by simplified ATC-like constraints). The conservative approach is therefore worth considering as a potential interim approach in case all EU regions do not abide to a full EU co-optimisation concept at the same pace.

9.4 2-Step Co-Optimisation Implementation Options

This section discusses the 2-step co-optimisation implementation options that have been described in section 7.3.2. Section 9.3 outlines possible computational variations of the 1-step co-optimisation implementation option, at least one of which is deemed to be worthy of investigation for algorithmic viability (even if this requires downgraded requirements such as a conservative approximation of the deterministic requirement or shifts related to non-uniform pricing or simplifications of products). Thus, any separation of the integrated multi-product auction model is expected to downgrade the quality of the solution that can be furnished by a computationally viable one-step approach.

It should be noted that in the 2-step co-optimisation implementation options, the step in which the CZCAOF is solved will include information from both the BCMs and DAM, but some relaxations are introduced in order to make the problem more manageable. These relaxations may include or combine the translation of products into other products easier to handle and deactivation of requirements from DAM or BCMs, depending on the computational variation chosen.

9.4.1 2-Step Co-Optimisation Option CZCAOF together with CPOF [CZCAOF&CPOF]

The Option CZCAOF together with CPOF [CZCAOF&CPOF] procedure approaches the problem as a 2-step process as explained in section 8.3. Algorithmically, the procedure can be depicted as in the figure below. The idea here is that the first step, which iterates over a challenging robust optimisation problem and price search, loops until convergence. After fixing BC matches and corresponding prices, the remaining CZC is provided to the DAM model. Any relevant links between accepted BCM bids and DAM bids are communicated to the DAM. Another iterative price/matching procedure is then launched, based on the current EUPHEMIA implementation, until the DAM portion of this sequential optimisation is completed.

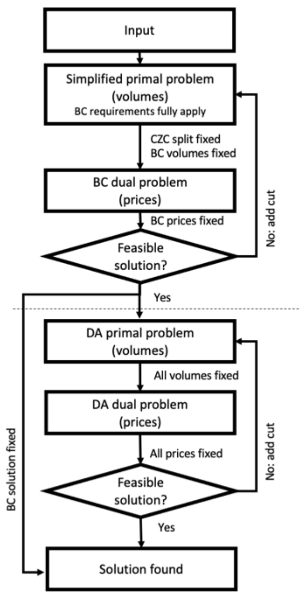

Figure 43: Algorithmic procedure implied by the 2-step Option 2: CZCAOF together with CPOF [CZCAOF&CPOF].

Key gains

- This approach treats the complexity of DAM separately from the remainder of the problem.
- The simplifications of the SDAC representation in the CZCAOF will be done in the way orders are expressed in the first step in a simplified way, conversions of products and deactivation of requirements from DA may be applied to reduce the time required to complete the first step.
- There is an organisational and implementation benefit in the sense that DAM processes are impacted at a minimum level. Specifically, current EUPHEMIA can be embedded in this procedure without significant changes.

Key pains

- The procedure is heuristic and may involve two distinct objective functions that are not traded off against each other in an integrated way. The allocation is therefore expected to be suboptimal, and the outcomes less transparent.
- The prices generated by this procedure are not expected to be coherent. For instance, there is no guaranteed coherence of cross-zonal price differences between BCM and DAM products (which in turn impacts congestion revenues).
- The multilateral linking of BCM and DAM bids is not possible. The dependency is only limited to the direction from BCMs to DAMs.
- The first step of the process is inherently computationally highly challenging, as it iterates between price search and a highly challenging robust optimisation which captures the deterministic requirement. Note that if the computational challenge is addressed by further approximations (such as for example using approaches like "inscribed boxes"), then this procedure is in any case inferior to the equivalent 1-step co-optimisation.
- Simplifications introduced to reduce the time in calculating the first step have impact in reducing coherence in prices and flows sense. The more simplifications added, the greater the impact is.

Key unknowns

- It may be the case that the process gives priority to the trading of BC over the DAM. This may or may not be preferable, depending on the marginal value of CZC for DAM purposes and for BCM purposes.

9.4.2 2-Step Co-Optimisation Option CZCAOF together with SDAC [CZCAOF←→SDAC]

The Option CZCAOF together with SDAC [CZCAOF←→SDAC] procedure approaches the problem as a two-step process (see section 8.5). Algorithmically, the procedure can be depicted as in the figure below. The idea here is that the first step, which iterates over an extremely challenging robust optimisation problem and price search, loops until convergence (which is already technically likely to be extremely challenging). After fixing DAM matches and corresponding prices, another iterative price/matching procedure is launched, until the BC portion of this sequential optimisation is completed.

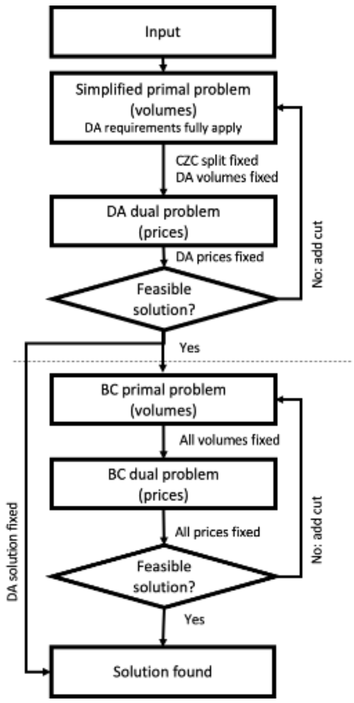

Figure 44: Algorithmic procedure implied by the 2-step Option 3: CZCAOF together with SDAC [CZCAOF&SDAC] process.

Key gains

- This approach treats the complexity of CPOF separately from the remainder of the problem. However, it is unclear if this is the key complexity in the co-optimisation. In particular, BCMs are expected to involve lower volumes than DAMs, as well as less complex products. And these products are already present in step 1 of this procedure.

Key pains

- The procedure is heuristic and may involve two distinct objective functions that are not traded off against each other in an integrated way. The allocation is therefore expected to be suboptimal, and the outcomes less transparent.
- The prices generated by this procedure are not expected to be coherent. For instance, there is no guaranteed coherence of cross-zonal prices between BCM and DAM products.
- The multilateral linking of BCM and DAM bids is not possible. The dependency is only limited to the direction from DAMs to BCMs.
- The first step of the process is inherently computationally intractable, as it iterates between price search and an intractable robust optimisation which captures the deterministic requirement.

Key unknowns

- It may be the case that the process gives priority to the trading of DAMs over BCMs. This may or may not be preferable, depending on the marginal value of CZC in the exchange of energy from DAM bids versus exchange of BC.

Suboptimal outcomes and inexistence of supporting prices

In view of the equivalence, in the convex case, of Welfare Optimality and Market Equilibrium, if the 2-step cases lead to suboptimal allocations, there will not exist market clearing prices that can support the resulting allocation. This means that there will be bids which are sub-optimally cleared, or sub-optimal congestion rents, given the DAM prices and BCM prices.

9.5 Comparing the Computation Variations of the 1-Step and 2-Step Co-Optimisation Options

The following table summarises the different approaches that are considered in this chapter in terms of technical feasibility of the implementation. The options are scored in the range of ++ (best possible score) to -- (worst possible score), with 0 corresponding to a medium score. The criteria that are considered can be summarised as follows:

- **Efficiency**: ability of the market clearing to maximise economic value for DAM purposes and for BCM purposes.
- **Coherent** economic signals: ability of the market clearing to preclude arbitrage opportunities.
- **Expressive ability** of agents: ability of the auction to accommodate adequate requirements in linking bids.
- **Algorithmic scalability**: the extent to which the model can realistically be tackled within the required time limits that are imposed on the clearing algorithm.
- **Communication/information** passing requirements: the extent to which the model requires the communication of data between separated processes. Note that communication in itself uses up time, and it requires an arbitrary partitioning of time between separate sequential processes (as opposed to using a given block of time for tackling an integrated problem).

Note that such a comparison remains based on "educated/expert intuition" and will need to be confirmed empirically before a final decision on the best possible model is made.

Implemen-tation option	**Efficiency**	**Coherent economic signals**	**Expressive ability of agents**	**Algorithmic scalability**	**Comm. requirements**
1-step computational variation 1 (section 9.3.2)	+	++	++	-	++
1-step computational variation 2 (section 9.3.3)	+	++	++	++	++
1-step computational variation 3 (section 9.3.4)	-(-)	0	++	++	++
2-step Option CZCAOF & CPOF (section 9.4.3)	0	0	-	-	-
2-step Option CZCAOF&SDAC (section 9.4.4)	-	-	-	--	-

Table 3: Table comparing the computational variations that are considered in the technical feasibility of the implementation.

It is important to observe that 2-step co-optimisation implementation options are typically dominated in terms of the proposed evaluation criteria by at least one of the computational variations of the 1-step co-optimisation implementation option. In other words, there exists a computational variation of the 1-step co-optimisation implementation option that can perform equally well or better than any 2-step co-optimisation implementation option in terms of the evaluation criteria that are listed in Table 3.

It is further important to note that the most promising computational variation of the 1-step co-optimisation implementation option emerges as more future-proof options and are likely simpler to implement technically. This is due to the fact that no interim complex organisation is required. Promising computational variations of the 1-step co-optimisation implementation option offer the possibility of moving directly to an enduring infrastructure. Nevertheless, it is possible that, under the 1-step co-optimisation, a certain downgrade in requirements (e.g., a level of conservatism that exceeds the deterministic requirement) appears as necessary for algorithmic performance purposes. The advantage of a 1-step co-optimisation nevertheless remains its ability to be able to (re-)upgrade the requirements at a later stage without changing the overall infrastructure.

9.6 Summary and Conclusion

This section summarises some of the main messages of the technical feasibility assessment.

Conclusion 1: The spirit of co-optimisation of DAMs, BCMs, and CZC allocation in the sense of EB Regulation Art. 40 implies that these processes become interdependent. Separating them deviates from optimality and tends to resemble to the approaches described in EB Regulation Art. 41 and 42 (save for the fact that they are run with actual data instead of forecasted data – however with downgraded calculation requirements).

Conclusion 2: The 2-step co-optimisation implementation options described in section 9.3 introduce suboptimal matching outcomes and are expected to create inconsistent prices that could introduce arbitrage opportunities. Implementing a 2-step co-optimisation – where roles and responsibilities of the different functions (CZCAOF, CPOF & SDAC) are split into different systems – creates additional complexity and risks, including the risk that such an approach, even if implemented as an interim solution – persists over time and fails to grasp the full benefits of co-optimisation, even in the long run. Furthermore, 2-step co-optimisation implementation options introduce increased operational risks that originate from the multiplication of processes and data exchanges

Conclusion 3: The deterministic requirement in the existing European market design introduces a serious computational challenge. The existing algorithm, in an attempt to deliver uniform prices, needs to loop over a challenging primal model. The deterministic requirement in its exact sense moves the primal model from “challenging” to “likely intractable”.

Conclusion 4: One promising, but possibly conservative, approximation of the deterministic requirement is based on a concept which is referred to as "inscribed boxes".[31] This approach appears to restore a computationally tractable primal market matching problem, while respecting the deterministic requirement, at the expense of possibly cutting off parts of the solution space. The degree of conservatism of the proposed approach and its computational viability remains to be determined in practice.

Conclusion 5: The introduction of the deterministic requirement and bid linking implies that, if current run time targets are maintained in the future, certain other aspects of the market clearing model may need to be relaxed. The move to 15-minute MTUs, the introduction of BC products and multilateral bid linking, flow-based constraints, and the expansion of the geographical coverage of the auction imply a more challenging problem. Relaxing other attributes of the problem can make a serious dent in restoring computational tractability to the problem.

Conclusion 6: The perspective of efficient linking of bids is seen as a key benefit of the co-optimisation concept, as it enables to offer BC without the need to forecast DAM prices (which in turn increases transparency, reduces risks and thereby improves total welfare). However, such a benefit can only be grasped if BCM bids and DAM bids are matched concurrently. The only option that allows full multilateral linking between BCMs and DAM, where all bids in the money are actually taken, is the 1-step co-optimisation option.

Conclusion 7: While DAM auctions can only be addressed by welfare maximisation programs, BCM products are in principle sourced with "procurement costs minimisation" approaches. In practice however, it is technically preferable to replicate the "procurement costs minimisation" as a welfare maximisation problem, as (1) it ensures feasibility of the problem, (2) avoids the use of unnecessary binary variables and (3) is sufficiently flexible to accommodate customised marginal pricing rules that are suitable to BC procurement.

Final word: Co-optimisation is a promising improvement of the overall DAM and BCM design. Nevertheless, it introduces additional algorithmic complexity, which has been discussed at length in this chapter. At this stage, based on the qualitative-only analysis provided above, it is not possible to guarantee what will ultimately be realistic in terms of precise requirements and computational feasibility. A further quantitative assessment is needed for that. Nevertheless, the clear recommendation from an algorithmic perspective is to implement a 1-step co-optimisation – irrespective of the final set of requirements that will be implemented. This is because any implementation option of the 2-step co-optimisation creates an unnecessary and detrimental separation of calculation steps (and possibly a more complex IT infrastructure), without being able to provide any calculation benefits that cannot be achieved under a 1-step co-optimisation.

[31] Bemporad, Alberto, Carlo Filippi, and Fabio D. Torrisi. "Inner and outer approximations of polytopes using boxes". Computational Geometry 27.2 (2004): 151-178.

10 Governance of the CZC Allocation Optimisation Function

10.1 Introduction

This section assesses the governance of the CZCAOF for the alternative implementation options described in chapter 8. For each of the processes foreseen under each implementation option it will be explained who the responsible entity would be, the **data owner**, the **host or operator** of the platform under which the process would be performed and the **decision body** that would manage any evolution in the process.

It should be noted that at the time of drafting this report, a public consultation on a potential review by ACER of CACM towards a "CACM 2.0" was carried out by the Agency.[32] In accordance with the material provided by the Agency in the framework of that public consultation, it may be the case that under the future CACM 2.0 the function of CZC allocation is assigned to the MCO which at the same time would be a joint responsibility for all TSOs and all NEMOs subject to CACM regulation. This paradigm shift would have some implications in terms of governance of some of the processes described in this section which the TSOs have tried to take into consideration in the assessment performed in this section. However, it should be noted that a more careful analysis is needed, should MCO governance and functions assignment evolve as foreseen in ACER's public consultation.

10.2 The 1-Step Co-Optimisation

The first co-optimisation implementation option can be divided in separate tasks, which are individually analysed in the following table in terms of their governance.

Where not specified, the "Data owner" column refers to input data, process data and output data altogether.

[32] https:/ / documents.acer.europa.eu/ Official_documents/ Public_consultations/ Pages/ PC_2021_E_03.aspx

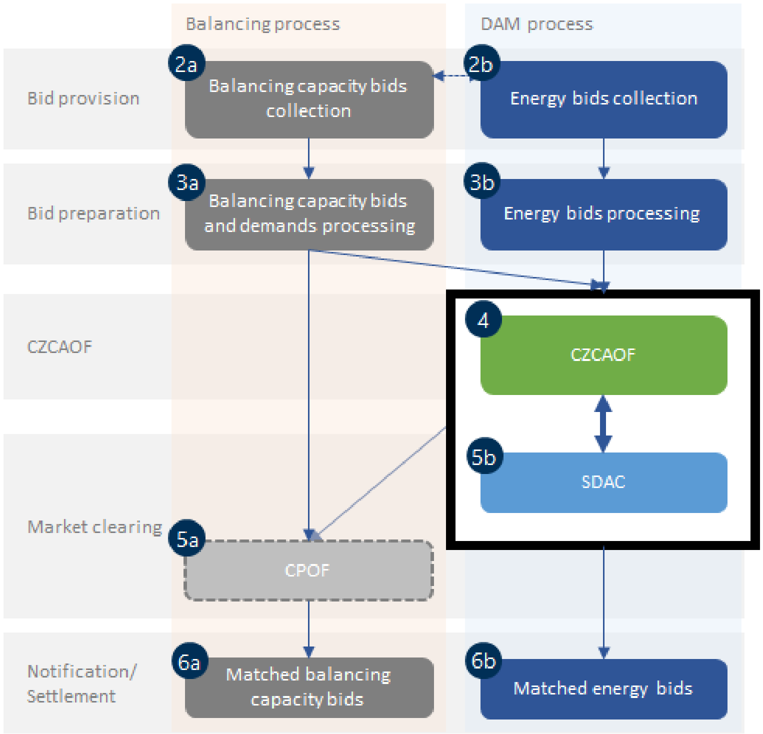

Figure 45: Balancing and DAM processes of the 1-step co-optimisation

Table 4: Governance of the 1-step co-optimisation option

Step	Task description	Responsible entity	Data owner	Platform host or operator	Decision body related
2a	Bid provision for BC • BSPs submit bids to their connecting TSOs (or their delegates), with relevant information for any kind of linking.	TSO, BSPs	TSO and relevant BSPs	TSO	Relevant TSO
2b	Bid submission for energy (SDAC) MP submits bids to **NEMOs**, with relevant information for linking.	NEMO	NEMO and relevant MP	NEMO	Relevant NEMO
3a	Bid preparation and collection of BC bids and demand • **TSOs** (or their delegates) collect BC bids and demands, perform validations and conversions, etc. • **TSOs** (or their delegates) send the anonymised set of BC bids to the CZCAOF and the CPOF.	TSO	TSO	TSO or their delegates	Relevant TSO
3b	Bid collection (SDAC) • **NEMOs** collect bids, perform validations and send them to EUPHEMIA.	NEMO	Input data: see step 2b Process and output data: NEMO	NEMO	Relevant NEMO
4	CZCAOF performs the CZC allocation between the BCMs and the DAMs and EUPHEMIA performs the DAM clearing.	MCO	Input data: See steps 3a and 3b. Process data and output data: MCO (under CACM 2.0 draft proposal)	MCO	MCO (under CACM 2.0) All TSOs & All NEMOs (under current CACM)

	• EUPHEMIA and CZCAOF combine the bid information required for each optimisation step (for CZC allocation and for DAM clearing). • The **CZCAOF** performs the CZC allocation between BCMs and DAMs (no governance issues for CZC allocation and linking) • The **CZCAOF** submits the revised PTDFs to the CPOFs function.		MCO and Relevant TSOs (under current CACM)		
5a	CPOF • **TSOs** (or their delegates), using the information of allocated CZC (per product and direction) coming from the CZCAOF, clear the BCM (i.e. select bids and satisfy need).	TSO	Input data: See step 3a and 4 Process data and output data: TSO	TSO or their delegates	Relevant TSO
5b	EUPHEMIA performs the SDAC.	MCO	Input data: See steps 3b and 4. Process data and output data: MCO	MCO	MCO
6a	Notification & Settlement of accepted BCM bids • **TSOs** notify accepted bids to BSPs; • **TSO-TSO** settlement as DA congestion income • **TSO-BSP** settlement • **TSOs** (or their delegate) publish information according to EB Regulation Art. 12, 3 (h)-(i)	TSO	TSO and relevant BSPs for accepted BC bids Otherwise: TSO	TSO or their delegates	Relevant TSOs for TSO-TSO settlement; Relevant TSO for TSO-BSP notifications and settlement
6b	Notification & Settlement of accepted DAM bids • MCO submits DAM results to NEMOs who communicate them to their TSOs and MPs.	NEMO	NEMO and relevant MPs/TSOs	NEMOs	Relevant NEMO

10.3The 2-Step Co-Optimisation with a Combined CZCAOF and CPOF [CZCAOF&CPOF]

The first 2-step co-optimisation implementation option integrates the CZCAOF with the CPOFs. Individual processes and governance are described in the table below.

Where not specified, the “Data owner” column refers to input data, process data and output data altogether.

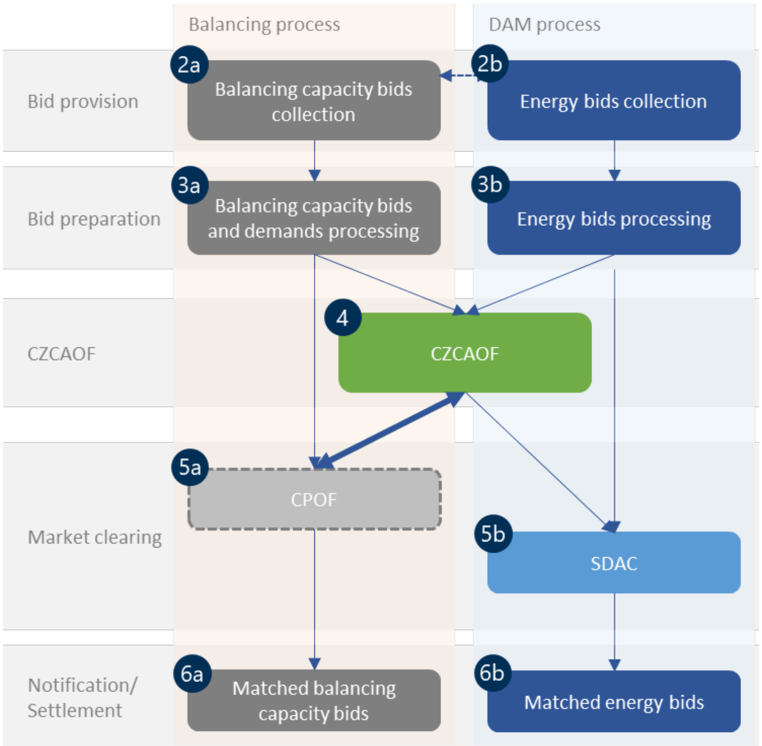

Figure 46: Balancing and DAM processes of the 2-step co-optimisation CZCAOF together with CPOF [CZCAOF&CPOF]

Table 5: Governance of the 2-step co-optimisation CZCAOF together with CPOF [CZCAOF&CPOF]

Step	Task description	Responsible entity	Data owner	Platform host/ operator	Decision body related
2a	Bid provision for BC • BSPs submit bids to their connecting **TSOs** (or their delegates), with relevant information for any kind of linking.	TSO, BSPs	TSO and relevant BSPs	TSO	Relevant TSO
2b	Bid submission for energy (SDAC) • MP submit bids to **NEMOs**, with relevant information for linking.	NEMO	NEMO and relevant MPs	NEMO	Relevant NEMO
3a	Bid preparation and collection (elaboration of BC bids and demand) • **TSOs** (or their delegates) collect BC bids and demands, perform validations and conversions (e.g. from ISP bid to standard product), etc. • **TSOs** (or their delegates) send the anonymised set of BC bids to the CZCAOF and the CPOF.	TSO	TSO	TSO or their delegates	Relevant TSO
3b	Bid collection (SDAC) • **NEMOs** collect bids, perform validations and send them to EUPHEMIA.	NEMO	Input data: See step 2b Process and output data: NEMO	NEMO	Relevant NEMO
4	CZCAOF CZC is allocated between the BCMs and DAMs. The CZCAOF submits the revised PTDFs to the CPOFs. After step 5a, the CZCAOF provides the revised PTDFs to EUPHEMIA.	MCO (under CACM 2.0) Joint TSO-NEMO (under current CACM)	MCO (under CACM 2.0) Joint TSO-NEMO (under current CACM)	MCO (under CACM 2.0) Joint TSO-NEMO (under current CACM)	MCO (under CACM 2.0) All TSOs & All NEMOs (under current CACM)

5a	CPOF TSOs (or their delegates), using the information of allocated CZC (per product and direction) coming from the CZCAOF, clear the BCMs (i.e. select bids and satisfy need) and communicate back to CZCAOF the status of linked bids and the remaining CZC.	TSO	Input data: See step 3a and 4 Process and output data: TSO	TSO or their delegates	Relevant TSO
5b	EUPHEMIA performs the SDAC taking into account revised PTDFs and status of linked bids.	MCO	MCO	MCO	MCO
6a	Notification & Settlement of accepted BCM bids • **TSOs** notify accepted bids to BSPs; • **TSO-TSO** settlement as DA congestion income • **TSO-BSP** settlement • **TSOs** publish information according to EB Regulation Art. 12, 3 (h)-(i)	TSO	Relevant TSOs and relevant BSPs for accepted BC bids Otherwise TSO	TSO or their delegates	Relevant TSOs for TSO-TSO settlement Relevant TSO for TSO-BSP notifications and settlement
6b	Notification & Settlement of accepted DAM bids MCO submits DAM results to NEMOs who communicate them to their TSOs and MPs.	NEMO	NEMO and relevant MPs/ TSOs	NEMOs	Relevant NEMO

10.4 The 2-Step Co-Optimisation with a Combined CZCAOF and SDAC: [CZCAOF→←SDAC] & [CZCAOF↔SDAC]

The two implementation options for the 2-step co-optimisation with integrating CZCAOF and SDAC, differ in the level of integration. They require the same governance structure and are therefore analysed together in this chapter (graph corresponding to [CZCAOF↔SDAC] option).

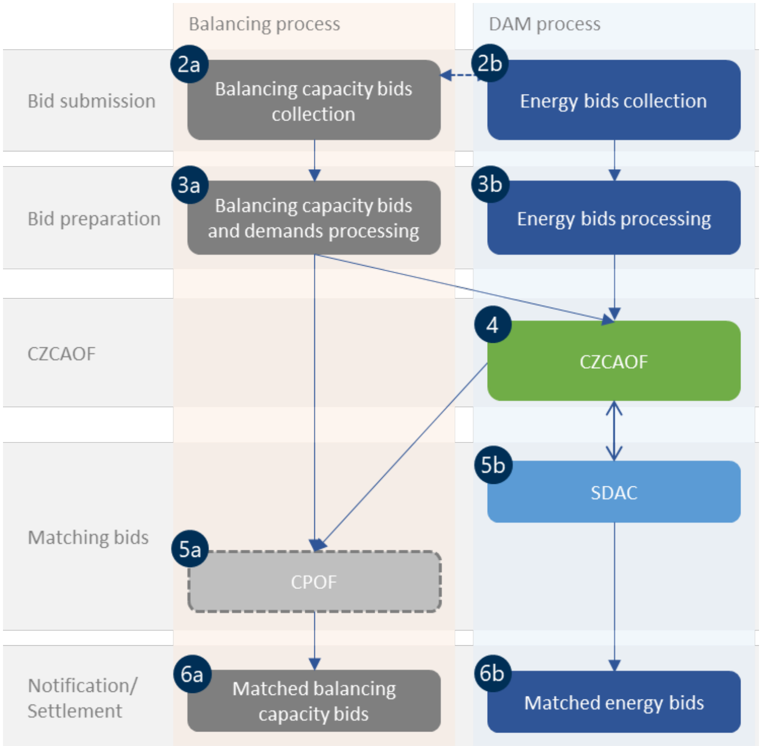

Figure 47: Balancing and DAM processes of the 2-step co-optimisation CZCAOF combined with SDAC [CZCAOF↔SDAC]

Table 6: Governance of the 2-step co-optimisation CZCAOF combined with SDAC [CZCAOF→←SDAC] & [CZCAOF↔SDAC]

Step	Task description	Responsible entity	Data owner	Platform host or operator	Decision body related
2a	Bid provision for BC • BSPs submit bids to their connecting **TSOs** (or their delegates), with relevant information for any kind of linking.	TSO, BSPs	TSO and relevant BSPs	TSO	Relevant TSO
2b	Bid provision for energy (SDAC) • MP submits bids to **NEMOs**, with relevant information for linking.	NEMO	NEMO and relevant MPs	NEMO	Relevant NEMO
3a	Bid preparation and collection (elaboration of BC bids and demand) • TSOs (or their delegates) collect BC bids and demands, perform validations and conversions (e.g. from ISP bid to standard product), etc. • TSOs (or their delegates) send the anonymised set of BC bids to the CZCAOF and the CPOF.	TSO	TSO	TSO or their delegates	Relevant TSO
3b	Bid collection (SDAC) • **NEMOs** collect bids, perform validations and send them to EUPHEMIA.	NEMO	Input data: see step 3 Process and output data: NEMO	NEMO	Relevant NEMO
4	The CZCAOF performs the CZC allocation between the BCMs and the DAMs and determines which linked bids are available for the following processes.	MCO	MCO	MCO	MCO (under CACM 2.0) All NEMOs (under current CACM)

	• To EUPHEMIA: available capacity for SDAC and available linked bids. • To CPOFs (see step 5a): available capacity for balancing and available linked bids. • (after EUPHEMIA, see step 5b) To relevant TSOs: remaining CZC after SDAC, market value of allocated CZCs and available linked bids.				
5a	CPOF • **TSOs** (or their delegates), using the information of allocated CZCs (per product and direction) and status of linked BC bids, clear the BCMs (i.e. select bids and satisfy need).	TSO	Input data: See steps 3a and 4 Process and output data: TSO	TSO or their delegates	Relevant TSO
5b	EUPHEMIA performs the SDAC taking into account PTDFs for the SDAC and communicates back to the CZCAOF the remaining CZC and the status of linked bids.	MCO	MCO	MCO	MCO (under CACM 2.0) All NEMOs (under current CACM)
6a	Notification & Settlement of accepted BCM bids • **TSOs** notify accepted bids to BSPs; • **TSO-TSO** settlement as DA congestion income; • **TSO-BSP** settlement; • TSOs publish information according to EB Regulation Art. 12, 3 (h)-(i).	TSO	TSO and relevant BSPs for accepted bids Otherwise: TSO	TSO or their delegate	Relevant TSOs for TSO-TSO settlement Relevant TSO for TSO-BSP notifications and settlement
6b	Notification & Settlement of accepted energy bids • MCO submits DAM results to NEMOs who communicate them to their TSOs and MPs.	NEMO	NEMO and relevant MPs/ TSOs	NEMOs	Relevant NEMO

10.5 Summary and Conclusion

Following the above assessment, it can be noted that in terms of governance little differences arise between the 1-step co-optimisation and the different implementation options of the 2-step co-optimisation. This would specially be the case should the potential evolution towards CACM 2.0 incorporate the CZCAOF as a MCO functions assignment.

Implementation decisions such as the level of (cross-product) linking of bids are not expected to cause deviations from the analysed governance features.

11 Compatibility of Price Coupling

11.1 Compatibility with Price Coupling Principles

Article 38 of EC Regulation 2015/1222 (CACM) establishes that the price coupling algorithm shall produce results in a manner which:

(a) aims at maximising economic surplus for SDAC for the price-coupled region for the next trading day;

(b) uses the marginal pricing principle according to which all accepted bids will have the same price per bidding zone per MTU;

(c) facilitates efficient price formation;

(d) respects CZC and allocation constraints;

(e) is repeatable and scalable.

The methodology of co-optimised CZC allocation for sharing or exchanging of BC shows full compatibility with the principles set forth for Price Coupling in CACM in the extent it does not modify in any of the above-mentioned co-optimisation options the functioning principles of current price coupling.

The co-optimised CZC allocation for the exchange of BC or sharing of reserves does not impact the SDAC functioning beyond the competition for the CZC use, which is allocated to the competing markets (and related products) according to the principle of economic surplus maximisation.

All options assessed offer different implementation strategies for determining the optimum CZC allocation for DAMs and BCMs, without affecting the compliance of the principles set forth by Article 38 of CACM Regulation by the price coupling.

11.2 Compatibility with Current Price Coupling Methodologies

The “Methodology for the price coupling algorithm, the continuous trading matching algorithm and the intraday auction algorithm” is made of the following documents:

- ACER Decision on Algorithm - Annex I - Algorithm methodology
- ACER Decision on Algorithm - Annex II - DA requirements
- ACER Decision on Algorithm - Annex III - ID requirements
- ACER Decision on Algorithm - Annex IV - DA monitoring
- ACER Decision on Algorithm - Annex V - ID monitoring

The implementation of the co-optimised CZC allocation methodology will take the form of an additional layer to price coupling (be it a previous step as described in the implementation options of the 2-step co-optimisation or an integrated optimisation process as described in the 1-step co-optimisation).

This will require the incorporation of new requirements to the price coupling algorithm, which may vary depending on the choice of the co-optimisation implementation option and will be further analysed and defined when elaborating the list of requirements foreseen in Article 13(3) of Annex I to ACER's Decision No 12/ 2020.

Regarding the existing requirements of the price coupling algorithm, at the time when this IIA report was drafted no change or modification of existing requirements has been identified yet.

Below a high-level description of additional requirements for the DA algorithm is provided for the implementation options.

Option	High-level additional requirements
1-step co-optimisation	• EUPHEMIA shall perform the CZCAOF between the energy market and the BCMs by comparing the respective market values and maximising the total economic surplus; • CZC shall be allocated to each product separately; Bids for each product can be linked (level of linking tbd.); • The current process and timings can remain unchanged (if performances of new algorithm allow it).
2-step co-optimisation CZCAOF&CPOF	Process of CZCAOF and CPOF to be added in the general timings and data flows of DA algorithms.
2-step co-optimisation [CZCAOF→←SDAC] [CZCAOF↔SDAC]	The CZCAOF shall be performed together with EUPHEMIA, with different level of integration between the two functions. Process of CZCAOF and CPOF to be added in the general timings and data flows of the DA algorithms.

Table 7: Overview of additional requirements for EUPHEMIA per implementation option

11.3 Compatibility with the Single Intraday Coupling Algorithms

The allocation of CZC according to EB Regulation Art. 40 DA (but also according to EB Regulation Art. 41 and 42) has an impact on the SIDC.

In both continuous trading and intraday (ID) auctions, TSOs will need to be able to send as an “already allocated capacity” the CZC that was allocated for the exchange of BC or sharing of reserves.

This allocated CZC, which is “reserved” for the exchange of BC or sharing of reserves:

- is not available for the exchange of energy in the SIDC;
- must be sent by TSOs as an already allocated capacity per border and direction, without netting;
- may be released by TSOs, through an update of this information.

For the purpose of the “Methodology for the price coupling algorithm, the continuous trading matching algorithm and the ID auction algorithm”, the new data flow can be considered as part of the information on CZC that TSOs send to the continuous trading matching algorithm and the ID auction algorithm, so **it would not be necessary to amend such methodology nor its Annex III (on ID requirements)**.

11.4 Summary and Conclusion

Generally, the co-optimising CZC allocation for the exchange of BC and sharing of reserves does not introduce any incompatibility with price coupling or SIDC principles or methodologies.

However, new requirements for both SDAC and SIDC will be needed to properly describe the integration of co-optimising CZC allocation with existing markets.

12 Impact on Operational Security

12.1 Introduction

Meeting operational security standards enables the power system to function with a satisfactory level of security and quality of supply, as well efficient utilization of infrastructure and resources. The system is organised to focus on common operational security principles, pan-European operational security, coordination of system operation, and some important aspects for grid users connected to the transmission grid.

Although co-optimisation has only a minor direct relation to operational security, the indirect consequences and similar topics (e.g. capacity calculation and operational planning) will be discussed in this chapter.

12.2 Overview

All currently identified relevant and direct related processes to be considered for a secure operation of co-optimisation are depicted in the graph below.

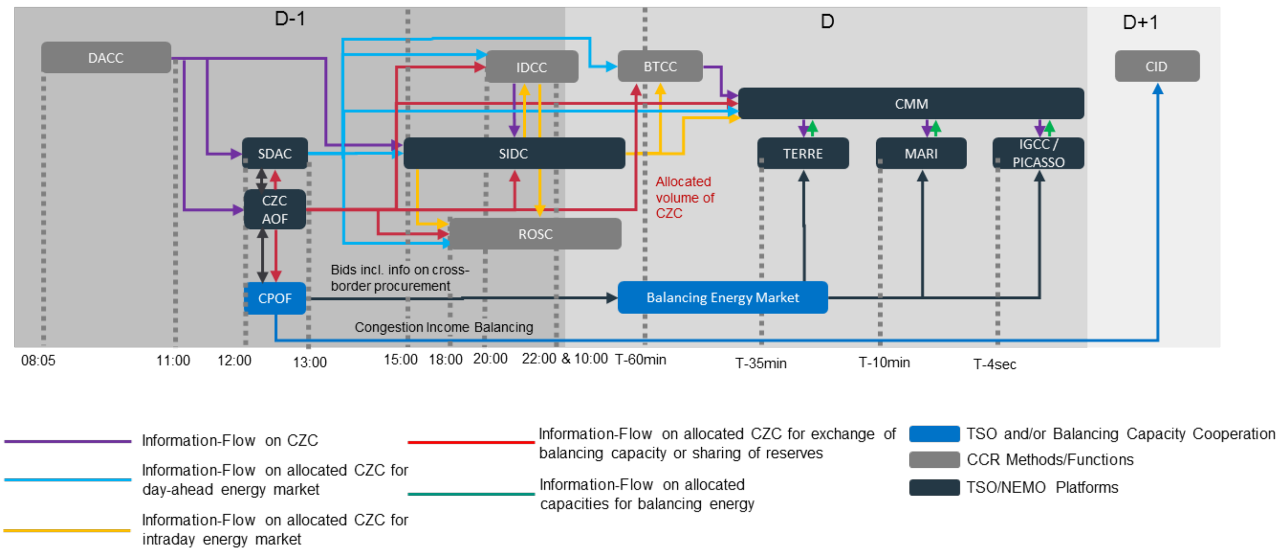

Figure 48: Related processes for a secure operation of co-optimisation

12.3 Detailed Impact

The impact and consequences on the most important processes and systems are described in this section.

12.3.1 DACC

Co-optimisation starts by calculation of the final DA capacity domain.

The allocations from DAM and BC have to be treated differently in the flow-based regime. An allocation for DAM leads to a defined flow and this leads to a decrease or increase of the Remaining Available Margin (RAM). An allocation for BC may lead to a physical flow, however it is also possible that no flow will occur. Therefore, this positive effect of increase in RAM cannot be considered for BC, see also chapter 7. The conservative approach, i.e. the deterministic approach should be followed to determine the influence of activations of balancing energy.

To correctly handle the differences between allocations for DAM and BC, changes in DACC (IT and processes) might be needed. One possible option could be to create an additional flow-based domain for the BC allocations (linked to flow-based domain for DAM) in DACC. This requires changes in DACC.

Also for non-flow-based CZC, the effect noted above has to be considered by DACC.

These CZCs shall be sent to the MCO of SDAC, which runs the CZCAOF in the 1-step co-optimisation. For a 2-step co-optimisation, the final DA capacity domain shall also be sent to the CZCAOF that is organised in a separate module.

The CZC are the upper limit for the exchange of BC and DAM.

The results from DACC are also used for the start of SIDC.

12.3.2 SDAC

The input from DACC may change, as described above and below. This requires changes in IT and processes in SDAC. SDAC shall send the results of the DAM to the affected parties. This information is used in SIDC, Intraday Capacity Calculation (IDCC), Balancing Timeframe Capacity Calculation (BTCC), Regional Operational Security Coordination (ROSC) and Capacity Management Module (CMM) and does not change compared to the process without co-optimisation.

12.3.3 CZCAOF

Within this section, the requirements for the CZCAOF with regard to operational planning are described. Depending on the options for co-optimisation (chapter 8), the CZCAOF may be executed together with other functions in the same systems. Within this chapter, the functions are described separately even if they are in the same system.

The CZCAOF shall allocate the CZCs per market and per BZB.

The sum of capacities for the exchange of BC and for the exchange of energy shall not exceed the DA CZC as calculated by DACC. Therefore, there should be no congestion due to the exchange/sharing of BC by co-optimisation, see also chapter 7. The conservative approach, i.e. the deterministic approach should be followed.

During implementation, processes have to be defined for the execution of CZCAOF. The results of CZCAOF shall be sent to CPOF and SDAC.

The information on the allocated CZC for the exchange of BC and or sharing of reserves (CZC allocation for BC) shall also be sent to IDCC, BTCC, SIDC, ROSC and CMM.

The CZC allocation for BC to IDCC, BTCC, SIDC and ROSC includes:

- the volume of allocated CZC for BC;
- the direction of the allocated CZC;
- the BZB;
- the MTU.

The CZC allocated for BC to CMM includes:

- the volume of allocated CZC;
- the direction of the allocated CZC;
- the product it is allocated for;
- the TSO(s) allocating the CZC;
- the BZB;
- the MTU.

12.3.4 CPOF

Each CPOF of each application for the exchange of balancing capacity shall interact with the CZCAOF on the actual use of CZC that has been allocated for BC. This requires changes in CPOF (IT and processes).

The amounts of awarded bids including the information on sharing/exchanging of reserves are also sent to the balancing energy markets in order to take into account the sharing/exchanging of reserves. The balancing energy markets then send the bids including the information on sharing/exchanging of reserves to Balancing platforms to be able to respect this in the activation of balancing energy.

No changes in CPOF for the introduction of co-optimisation are necessary in case the market-based allocation process of CZC for BC is already applied.

12.3.5 SIDC

SIDC has to take into account the results of co-optimisation.

A possible solution would be to send the information on allocated capacities for BC to SIDC and SIDC has to apply the following rule during the ID allocation: The total CZC including BC and energy market (as calculated by DACC and IDCC) has to be reduced by the allocated capacities for BC (not netted). This requires changes in SIDC (IT and processes).

Therefore, there should be no congestion due to the exchange/sharing of BC by co-optimisation.

SIDC shall send the results of the ID energy market to the affected parties. This information is used in IDCC, BTCC, ROSC and CMM and does not change compared to the process without co-optimisation.

12.3.6 IDCC

With iterative steps, the IDCC calculates available CZC along the auctions/continuous trades of SIDC.

IDCC has to take into account the results of co-optimisation. A possible solution would be to send the information on allocated capacities for BC from CZCAOF to IDCC and IDCC has to apply the following rule: Within its calculation, all possible flows from the allocation for BC according to the deterministic approach have to be taken into account. The resulting CZCs are the sum for allocations for BC and energy market. This requires changes in IDCC (IT and processes).

These CZCs shall be sent to SIDC.

No changes in IDCC for the introduction of co-optimisation might be necessary if the economic efficiency or market-based allocation process of CZC for BC is already applied.

Depending on the data exchanges in the local markets, the information on the location of the reserve units providing the BC may not be known. Therefore, it might not be possible to include the exact locations in the IGMs. This issue might already now exist for a LFC area. But due to the increase of flow caused by the sharing/exchanging of reserves, this problem will increase.

12.3.7 ROSC

ROSC has to take into account the results of co-optimisation. A possible solution would be to send the information on allocated capacities for BC to ROSC and ROSC considers any possible utilization of allocated CZC for BC according to the deterministic approach. This requires changes in ROSC (IT and processes).

No further changes in ROSC for the introduction of co-optimisation might be necessary in case the market-based allocation process of CZC for BC is already applied.

Depending on the data exchanges in the local markets, the information on the location of the reserve units providing the BC may not be known. Therefore, it might not be possible to include the exact locations in the IGMs. This issue might already now exist for an LFC Area. But due to the increase of flow caused by the sharing/exchanging of reserves, this problem will increase.

12.3.8BTCC

There might be a strong overlap between IDCC and BTCC.

Balancing time frame capacity calculation has to take into account the results of co-optimisation. A possible solution would be to send the information on allocated capacities for BC to BTCC and BTCC has to apply the following rule during: Within its calculation, all possible flows from the allocation for BC according to the deterministic approach have to be taken into account. The resulting CZC are the sum for allocations for BC and energy market. This requires consideration in BTCC (IT and processes).

These CZCs shall be sent to CMM.

No changes in BTCC for the introduction of co-optimisation might be necessary if the economic efficiency or market-based allocation process of CZC allocation for BC is already applied.

Depending on the data exchanges in the local markets, the information on the location of the reserve units providing the BC may not be known. Therefore, it might not be possible to include the exact locations in the IGMs. This issue might already now exist for a LFC Area. But due to the increase of flow caused by the sharing/exchanging of reserves, this problem will increase.

12.3.9CMM/Balancing Platforms

CMM and balancing platforms have to take into account the results of co-optimisation.

A possible solution would be that CMM receives all the necessary input: Information on allocated capacities for SDAC and SIDC, the latest CZC from BTCC and the allocated capacities for BCs (CZC allocated for BC). With this information, the cross-zonal capacity limits (CZCLs) are calculated and offered to TERRE, MARI and PICASSO/International Grid Control Cooperation (IGCC). The allocation happens serial, because the 3 balancing platforms run their activation optimisation function (AOF) one after the other: First, the CZCL for TERRE are calculated and sent together with the CZC allocation for TERRE to TERRE. TERRE then runs its AOF and the results are sent to CMM. Second, the CZCL for MARI are calculated and sent together with the CZC allocation for MARI to MARI. MARI then runs its scheduled and direct AOF and the results are sent to CMM. Last the CZCL for PICASSO/IGCC are calculated and sent together with the CZC allocation for PICASSO to PICASSO/IGCC. PICASSO/IGCC then runs its AOF and the results are sent to CMM.

Additionally, the bids including information on sharing/exchanging of reserves are sent from CPOF to balancing platforms. The balancing platforms use this information in their AOF to make sure that the TSO has a prior access to the bids that are situated at another TSO, but were chosen by CPOF to meet the demand of BC of this TSO.

This will require some changes to the balancing platforms and CMM (IT and processes).

12.4Summary and Conclusion

The new functions for the co-optimisation have to be set up and the data exchanges and the processes in DA, ID and balancing energy allocation have to be adopted accordingly to make sure that the capacities as determined by the capacity calculation are not allocated twice, e.g. by BC and energy market.

The main challenge for the consecutive processes is to take correctly into account any possible utilization of allocated CZC for BC in DACC, IDCC, BTCC and ROSC in order to prevent/correctly forecast any congestion caused by the activation of balancing energy. This requires a different handling of allocated capacities for BCs compared to allocated capacities for energy market.

The information exchange also has to be adopted in order to provide all allocation platforms (SDAC, SIDC, balancing platforms) with the necessary information to make sure that the same MW of CZC from capacity calculation is not allocated twice.

Additionally, the balancing platforms have to receive even more information and adopt the AOF in order to grant the TSO applying the exchange/sharing of reserves a prior access to bids which are located at another TSO but were chosen by CPOF to meet the BC demand.

The consequences of the application of co-optimisation described in this chapter are for most of the processes identical to the application of economic efficiency or market-based allocation process of CZC for BC.

Currently no blockers were identified to adopt the processes as described in this chapter. If this is done, no worsening of the operational security or operational planning is expected. However, this requires extensive changes in the process and affected IT systems.

13 Separate Procurement Step

13.1 Introduction

Co-optimisation requires three optimisation functions:

- the CZCAOF determines the optimal allocation of CZC for providing BC cross-border and trading DA energy products between bidding zones. CZC is allocated to DAMs if the marginal value of providing the next MW of CZC to DAMs is higher than the marginal value of providing the MW of CZC to BCMs. Therefore, allocated CZC is firm after the CZCAOF.

- EUPHEMIA determines the welfare maximising DAM clearing given the allocated CZCs to DAMs. Therefore, DAM bids are firm after the SDAC in EUPHEMIA.

- the CPOF determines the welfare maximising procurement of BCs given the allocated CZCs to BCMs. Therefore, BC bids are firm after the CPOF.

EUPHEMIA and, after entry into force of CACM 2.0, the CZCAOF are expected to be run by the MCO (at the time when this co-optimisation IIA report has been provided). The CPOF will be operated by TSOs.

For determining the optimal CZC allocation, BCM bids and DAM bids enter the CZCAOF. As described in chapter 7, the CZCAOF determines the BC part of the flow-based domain which cannot be used for DA energy. Therefore, the CZCAOF also covers the functionalities of allocating BC bids which is also part of the CPOF.

In the following, it will be elaborated why the CPOF is required although the CZCAOF runs similar functionalities as the CPOF.

13.2 Process of the Procurement of Balancing Capacity

13.2.1 Background

Chapter 2 and also chapter 10 describe the responsibilities for the particular processes and tasks in co-optimisation.

TSOs provide the pseudonymised BC bids to the CPOF including information about cross-product linking and indivisibility constraints as well as local reserves constraints and sharing of reserves potential. TSOs also provide information on substitution of reserves. The firm CZC allocation comes from the CZCAOF.

The CPOF determines the welfare maximising procurement of BC in each of the considered control zones for the TSOs running the CPOF jointly. Thus, when the CPOF run is final, all BC bids to be procured by TSOs are determined. BSP information and market information on procured BC bids can be derived directly from the CPOF results.

13.2.2 Reasoning

TSOs are responsible for the procurement of BC for their control zone/ block. This responsibility comes along with liability requirements vis-à-vis BSPs and cooperating TSOs but also in the direction of MPs for linked bids. Thus, TSOs need to secure that BC procurement is based on cost minimisation and in case of CZC allocation it must be welfare maximising to justify the possible welfare loss for the DAM.

This understanding also follows the reasoning of the EB Regulation. The EB Regulation clearly distinguishes the CZCAOF and the CPOF. The CZCAOF shall be an all-TSO process which compares "the actual market value of CZC for the exchange of balancing capacity or sharing of reserves and the actual market value of CZC for the exchange of energy" (EB Regulation Art. 40, 1 and 2). Beyond the EB Regulation explains that it does not need to be one CPOF for all different applications, but that "two or more TSOs exchanging balancing capacity shall develop algorithms to be operated by the CPOFs for the procurement of balancing capacity bids." (EB Regulation Art. 58, 1 (3)). This clearly states that a CPOF is not (necessarily) an all-TSO function. The CPOF only has to respect all decisions made by the CZCAOF in terms of volume allocation of CZC and the according prices and volumes of balancing capacity and congestion income.

13.2.3 Governance and Security

From a business perspective, governance and security of BC procurement are the main topics to keep the CPOF separate from the CZCAOF.

BC secures for each TSO the availability of sufficient balancing energy whenever it is needed to be reserve compliant. TSOs follow deviating assumptions and approaches how they dimension BC which can be explained by the national or regional production situation, generation types of power plants, consumption and the regional grid itself. Despite the undoubted consensus of the requirement of BC for guaranteeing system stability, TSOs apply different types of BC products to similar situations. This is again a matter of availability of generation types, costs and also the individual approach. Therefore, TSOs are responsible to determine which BC bids should be procured to best meet their individual grid situation.

The CZCAOF determines the European welfare maximising allocation of CZC. This is based on economic requirements. By dimensioning, determination of maximum shared reserves etc. TSOs set their boundaries for the CPOF and automatically the CZCAOF. However, the technical responsibility for having the right BC product in sufficient amount whenever needed is with the TSOs. They know the technical capabilities of production units in their control area and to some extent in neighbouring control areas due to procurement rules but also based on continuous exchange with the power plant operators. This secures the required high level of security for the individual control areas.

Consequently, in the foreseeable future, procurement and CPOFs should be organised on a regional basis to best meet TSOs' responsibility and technical requirements and to guarantee regional system security. If TSOs realise that procurement can be further harmonised and integrated, the implementation approach facilitates sufficient flexibility to combine CPOFs in the future.

13.3 Summary and Conclusion

Each optimisation function within the co-optimisation is meant to determine one variable: the CZCAOF verifies the CZC, EUPHEMIA finalises (clears) the DAM bids and the CPOF determines (clears) the BCM bids to be procured by TSOs. Despite the similarity of the functionalities, a separation with different responsible entities (MCO for CZCAOF and TSOs for CPOF) is needed.

The EB Regulation clearly distinguishes between the CZCAOF and the CPOF. It defines the CZCAOF as central process whereas the CPOF is an application function for those TSOs part of a balancing capacity cooperation, which leads to multiple CPOFs for different regions (different applications). By putting the focus on the regional aspect within the CPOF, differences between technology, procurement processes, and grids can be taken into account. Furthermore, each TSO is still responsible for having the right BC product in sufficient amount whenever needed. Therefore, the justification to separate the CZCAOF and the CPOF is provided as long as the CPOF respects the decisions made by the central CZCAOF.

Nevertheless, the implementation approach facilitates sufficient flexibility to combine CPOFs in the future in order to harmonise and integrate the procurement.

14 Cost Estimation, Categorisation and Sharing

The assessment of costs related to the design and implementation of the co-optimisation was not possible with the available information at the point in time when this report was closed. Therefore, the PT Co-optimisation IIA together with the involved NEMO experts recommend a prototype study by N-SIDE, the NEMO IT service provider, to receive more insights into the implementability of the different implementation options of the 1-step and 2-step co-optimisation including the computational variations as described in chapter 8 and chapter 9. Based on the outcomes of this technical feasibility study, which is foreseen by April 2022, the costs will be estimated, further assessed and categorised.

Cost categorisation requires the differentiation of cost estimates into the following categories:

- the implementation of the required optimisation tools and/ or the adjustment of existing tools such as EUPHEMIA
- the required changes in processes
- the setup of new organisational requirements
- the preparation and implementation of legal arrangements.

If it comes to a stepwise implementation of co-optimisation, these cost categories need to be broken down for each implementation step.

Concerning the operational phase, processing costs and maintenance costs need to be estimated for application.

Subsequent sharing of costs needs to differentiate the (potentially stepwise) implementation phase and the operation phase of co-optimisation. If there will be no other cost sharing key provided by regulation[33], cost sharing between NEMOs and TSOs needs to be determined either subject to the economic merits of co-optimisation for DAMs and for BCMs or subject to the cost burden for TSOs and NEMOs.

If the CZCAOF is foreseen to be run by an MCO under CACM 2.0, the cost sharing discussion can be focussed on the costs for:

1. Implementation;
2. Maintenance; and
3. Operation.

[33] CACM 2.0 including the MCO function has been under review at the point in time when this co-optimisation IIA report was finalised.

15 Next Steps

During the IIA, the ENTSO-E Project Team Co-Optimisation IIA and NEMO experts have identified topics which require further analysis reaching beyond the scope of this IIA report. These topics are outlined in the following:

- Prototype analysis: Chapter 9 provides the technical feasibility analysis for implementing co-optimisation. In the course of the preparation of this chapter, a high-level analysis based on qualitative expert statements has been conducted on the foreseen 1-step and 2-step implementation options and technically feasible computational variants in particular for the 1-step implementation option. The provisions of this technical feasibility analysis need to be further detailed by employing a prototype-based analysis of the 1-step implementation option and of a 2-step implementation option. This analysis should provide further insights into the implementability of each implementation option. It is also expected to learn more about calculation requirements, potential obstacles of the handover between the three optimisation functions as well as the calculation time.

- Detailed analysis of economically efficient bid acceptance: The combination of different optimisation procedures requires a careful understanding of the respective bid acceptance procedures. While the CEP postulates cost minimisation of BC procurement also taking into account the possibility of substitution of different BC products, the methodology requires maximisation of economic surplus when determining the CZC allocation. As such definitions might result in diverging optimisation outcomes and, thus, diverging bid acceptance depending on the hierarchy of the optimisation functions, an analysis should be conducted on the impact of the optimisation hierarchy on economic surplus maximisation and cost minimisation for BC procurement. This economic analysis is also required as the order of optimising BCM outcomes defines the options for unilateral linking in 2-step co-optimisation implementation options. It is expected that such a study provides further insights for determining the updated set of requirements and rules for the optimisation procedures.

- Definition of the updated set of requirements: Annex 1 to the algorithm methodology defines a common set of requirements for the price coupling algorithm. This is a first-level set of requirements from already existing functionalities. This set of requirements is to be updated following the IIA. As the prototype analysis is a data-based analysis, it is also expected that the prototype set up provides further information for updating and complementing the set of requirements for implementing co-optimisation. TSOs will determine the updated set of requirements to be provided to NEMOs as service provider for the implementation of co-optimisation in June 2022.

- Fallback procedures: Co-optimisation as a combined and interrelated procedure of three optimisation functions in combination with cross-product linking of bids impose comprehensive requirements during the run of the processes in the direction of BSPs and MPs as well as TSOs. The accurate optimisation run requires the satisfaction of multiple levels of product and bid definitions and provision of bids. These definitions comprise the formatting, the pseudonymisation and the handover of bids between processes and involved TSOs and

NEMOs, deadlines for the handover as well as convexity of the individual and the joint problem set for optimisation. If one of the definitions is not met or if a deadline cannot be met, the overall procedure could be interrupted. To avoid such an incidence in the light of the highly sensitive market time requirements of BCMs, DAMs and subsequent markets, fallback scenarios need to be determined and tested before the Go-Live of co-optimisation. The worst case possible must be the status quo. However, there exist also less critical incidence levels. These incidence levels need to be identified and counter measures and fallback scenarios as well as computational requirements need to be defined to handle these incidence levels. While this is required before the actual Go-Live, continuous training and testing might provide additional incidence cases to be followed up during operation.

16 Appendix

16.1 General Market Clearing Process with Marginal Pricing Scheme

As requested in the EB Regulation, the methodology to determine prices for BC is based on marginal pricing scheme. General speaking, the marginal price represents the price of the last bid that has been selected to cover the demand for a specified zone. The common practice for market clearing process in which the demand is inelastic and the pricing scheme is based on marginal pricing scheme is that a power pool schedules generation by minimising the total offered cost. This can lead to the following optimisation process with the objective function:

$$Minimize \sum_{i=1}^{n} p_i^g q_i^g \quad (16.1)$$

, where p_i^g is the biding price of BSP i and q_i^g is its cleared volume and is the output of this optimisation and g stands for generation. Under marginal pricing and the assumption of perfect competition, BSPs optimal strategy is to bid their marginal costs to guarantee the maximization of their revenue and the efficiency of the market. Consequently, since BC demand is inelastic, the objective function in (16.1) is basically minimising the procurement costs for the aFRR/mFRR BCM.

Note that the objection functions in (16.1) is also applied in a pay-as-bid scheme. It is, therefore, expected that objective function for the marginal pricing scheme to be equal to:

$$Minimize\ \mu \sum_{i=1}^{n} q_i^g \quad (*)$$

, where μ is the uniform market price. However, in a general market clearing process (without cross-product linking of bids), the objective function in (16.1) will lead to same results as if the objective function to be equal to the one in (*). Moreover, the objective function in (16.1) is a linear function compared to the objective in (*). With cross-product linking of bids, however, the objective function in (16.1) cannot necessarily lead to the most optimal solution. This is explained in detail further in section 16.1.2.

Following constraints need to be enforced:

$$\sum_{i} q_i^g = D^{aFRR/\,mFRR} : \ \mu \ (16.2)$$

$$q_i^g \leq q_i^{gmax} \ (16.3)$$

The first constraint belongs to the balance equation in which $D^{aFRR/\,mFRR}$ is the total demand in the aFRR BCM / mFRR BCM. The Dual variable (μ) of this balance equation is the uniform market-clearing price for all the MP. The second constraint limits the output of generators to their technical limits.

Through a similar approach as in (16.1)-(16.3), the market clearing process for the DAM can be implemented. However, since the demand in the DAM is elastic, the objective function in (16.1) becomes:

$$Minimize \sum_{i=1}^{n} p_i^g q_i^g - \sum_{j=1}^{k} p_j^d q_j^d \quad (16.4)$$

Subject to:

$$\sum_{i} q_i^g = \sum_{j} q_j^d \quad (16.5)$$

$$q_i^g \leq q_i^{gmax} \quad (16.6)$$

$$q_j^d \leq q_j^{dmax} \quad (16.7)$$

Where q_j^d is the bidding volume for the consumer j. Constraint (16.5) ensures the balance between supply and demand. Constraints (16.6) and (16.7) limit the outputs of generators and consumers to their technical limits.

16.2 Market Clearing Process in the Multilateral Cross-Product Linking Bids Option

As mentioned earlier in chapter 5 section 5.2, in the multilateral cross-product linking bids option, it is important to define a proper objective function that ensures that the resulting marginal price will end up with the highest welfare. As shown in equations (16.1)-(16.3), the usual objective function in the market-clearing algorithm is maximising the bid price multiplied by the corresponding output of a generator. However, in the multilateral cross-product linking, this objective function may not necessarily guarantee that the marginal price will give the highest welfare. In the following, this problem and its solution are explained.

A simple example in Figure 49 explains this issue. For simplicity, only aFRR and mFRR BCMs are considered. Their demands are inelastic. The capacity for each bid in the aFRR and mFRR BCMs is 10 MW. There is one linked bid coloured blue.

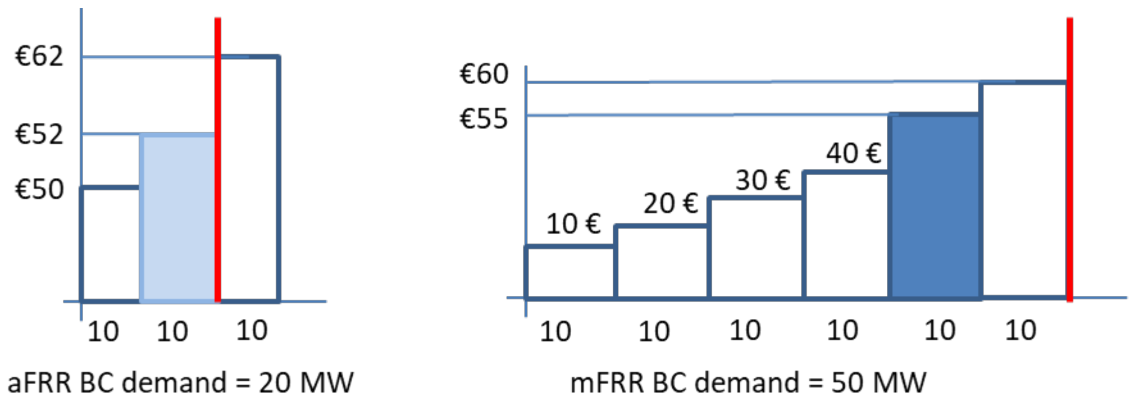

Figure 49: Multilateral cross-product linking

First, the market results based on the market-clearing process shown by (16.1)-(16.3) are calculated. According to the equation in (16.1), the marginal price for the aFRR and mFRR BCMs are 52 €/MW and 60 €/MW, respectively. This means that the linked bid is accepted for aFRR and therefore cannot be present for mFRR. Based on these values for marginal prices, the objective function in (16.1) becomes:

(50 €/MW*10 MW + **52 €/MW***10 MW) + (10 €/MW *10 MW + 20 €/MW *10 MW + 30 €/MW *10 MW + 40 €/MW*10 MW + **60 €/MW** *10 MW) = 2620 €

In other words, the total procurement cost for aFRR and mFRR BCMs is equal to 2620 €. Now the question is whether 52 €/MW and 60 €/MW as the marginal prices of the BCMs lead to the most optimal solution - the least amount of procurement cost. To answer this question, one can consider another solution where the linked bid is cleared in the mFRR BCM, instead. As a result, the marginal price in the aFRR BCM becomes 62 €/MW while the marginal price in the mFRR market becomes 55 €/MW. In this case, the total procurement cost for aFRR and mFRR BCMs based on these values of the marginal prices is:

(50 €/MW*10 MW + **62 €/MW** *10 MW) + (10 €/MW*10 MW + 20 €/MW *10 MW + 30 €/MW *10 MW + 40 €/MW *10 MW + **55 €/MW** *10 MW) = 2670 €

which is higher than 2620 € and, therefore, one can conclude that 52 €/MW and 60 €/MW were the most optimal marginal prices for the aFRR and mFRR BCMs which leads to the lowest amount of procurement costs. Consequently, this means that the linked bid should be cleared in the aFRR BCM.

However, in the marginal pricing scheme, all MPs pay or are paid based on one marginal price. In other words, in practice, the total cost of fulfilling the demands should be calculated which is equal to the marginal price multiplied to the total demand. Back to the example above, the total cost of fulfilling demand in aFRR and mFRR BCMs where the optimal marginal prices are 52 €/MW and 60 €/MW, is, therefore:

52 €/MW*20 MW + **60 €/MW***50 MW = 4040 €

However, in the alternative solution where the linked bid is cleared in the mFRR BCM and the marginal prices are 62 €/MW and 55 €/MW and based on the market-clearing process in (16.1)-(16.3) was shown is not the optimal solution, the total cost of fulfilling the demands in the aFRR and mFRR BCMs is:

62 €/MW*20 MW + **55 €/MW***50 MW = 3990 €

which is less than 4040 €. This means that the most optimal solution in which the total cost of fulfilling demands is minimised is the solution in which the linked bid is cleared in the mFRR BCM, the opposite solution of the market-clearing process in (16.1).

In short, in case there are linked bids between two (or more) markets, the usual way of market-clearing process with the objective function of minimising the total procurement costs – which equals to the summations of bidding price of MPs multiplied to their corresponding MW – cannot lead to the most optimal solution. Instead, the objective function in a cross-product linking of bids problem should be minimising the total cost of fulfilling demands. In other words, the objective is to minimise the hatched area shown in figure 16.5 which is equivalent to the marginal price multiplied with the total demand.

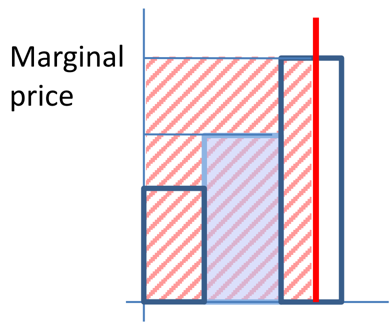

Figure 50: Objective function in multilateral cross-product linking of bids

Therefore, the mathematical formulations of the optimisation problem for the multilateral cross-product inking of the bids between aFRR, mFRR BC and DAMs is as follows:

$$Minimize: \sum_{i=1}^{n} (\mu_i^{aFRR} D^{aFRR} + \mu_i^{mFRR} D^{mFRR} + \mu_i^{DAM} D^{DAM}) \ (16.4)$$

in which μ_i^{aFRR}, μ_i^{mFRR} and μ_i^{DAM} are the marginal price of aFRR, mFRR BC and DAMs, respectively and they are variables and the outputs of the optimisation problem. The D^{aFRR}, D^{aFRR}, D^{aFRR} are the total demands in the aFRR BCM, mFRR BCM and DAM, respectively. The objective function in (16.4) minimises the total cost of fulfilling demands in the BC and DAMs.

The following constraints belong to the objective function in (16.4):

$$\sum_i b_i^{aFRR} * Pg_i^{aFRR} \geq D^{aFRR} \ (16.5)$$

$$\sum_i b_i^{mFRR} * Pg_i^{mFRR} \geq D^{mFRR} \ (16.6)$$

$$\sum_i b_i^{DAM} * Pg_i^{DAM} \geq D^{DAM} \ (16.7)$$

$$\sum_i b_i^{aFRR} * C_i^{aFRR} \leq \ \mu_i^{aFRR} \ (16.8)$$

$$\sum_i b_i^{mFRR} * C_i^{mFRR} \leq \ \mu_i^{mFRR} \ (16.9)$$

$$\sum_i b_i^{DAM} * C_i^{DAM} \leq \ \mu_i^{DAM} \ (16.10)$$

$$\sum_i b_i^{aFRR} + \ b_i^{mFRR} + b_i^{DAM} \leq 1 \ (16.11)$$

Constraints (16.5)-(16.7) show the power balance for aFRR, mFRR BC and DAMs. $\sum_i b_i^{mFRR}$, $\sum_i b_i^{mFRR}$ and $\sum_i b_i^{mFRR}$ are the binary variables presenting whether or not a BSP or a BRP is cleared in the BC or DAMs. Constraints (16.8)-(16.10) limit the marginal prices of aFRR, mFRR and DAM respectively. Lastly, constraint (16.11) enforces that linked bid MPs can only be cleared in the aFRR BC or the mFRR BC or the DAM.

This approach is proposed to be used in the experimentation phase, but it is not the final recommendation of the optimisation problem.

16.3Input Data and Case Studies

This section describes the input data and the case studies applied in this chapter for the study of the different linking bid options. The Netherlands and Germany are considered as two case studies and their bid ladders in aFRR BC, mFRR BC and DAM market data are input data for the analysis in section 5.3.1 and 5.3.2. Figures 16.6 and 16.7 show the bid ladders of aFRR upward BCM, mFRR upward BCM, and DAM per MTU, for the Netherlands and Germany, respectively. Demands in all markets are considered inelastic and for all three markets, price caps are equal to 3000 euro.

In order to pose a linking between bids in three different markets, a random approach has been implemented in such a way that the MPs with linked bids have a more or less similar bid sizes for their bids in different markets. For linking bid options where there is no link between the aFRR, mFRR BC and DAM markets, the size of the bids for mFRR and/or DAM becomes zero.

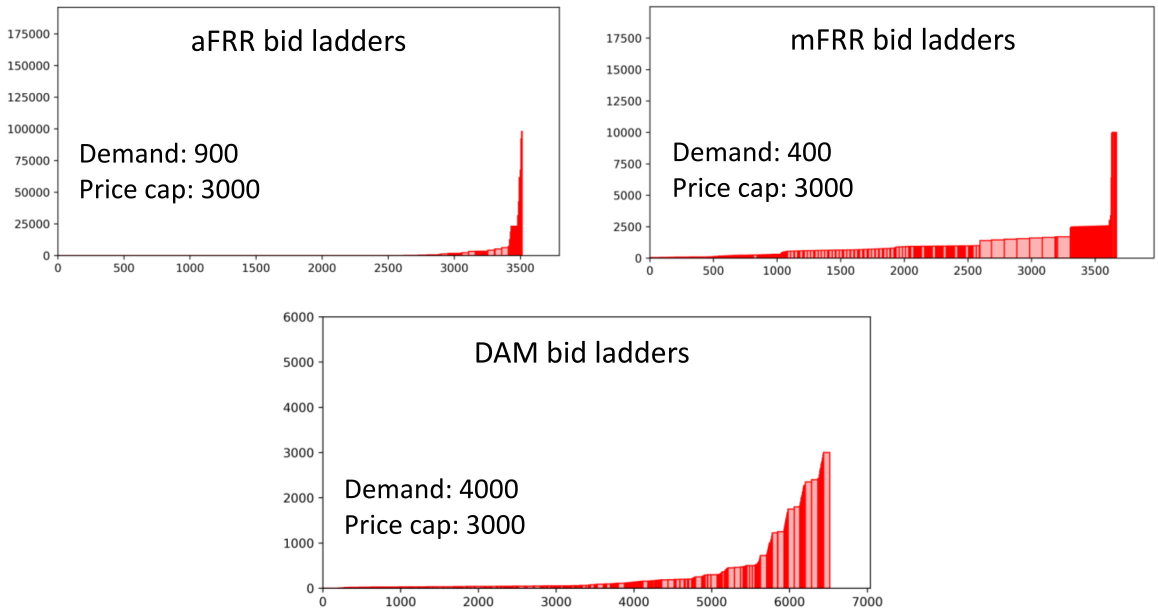

Figure 51: Bids ladders per MTU in BCM and DAM in Germany

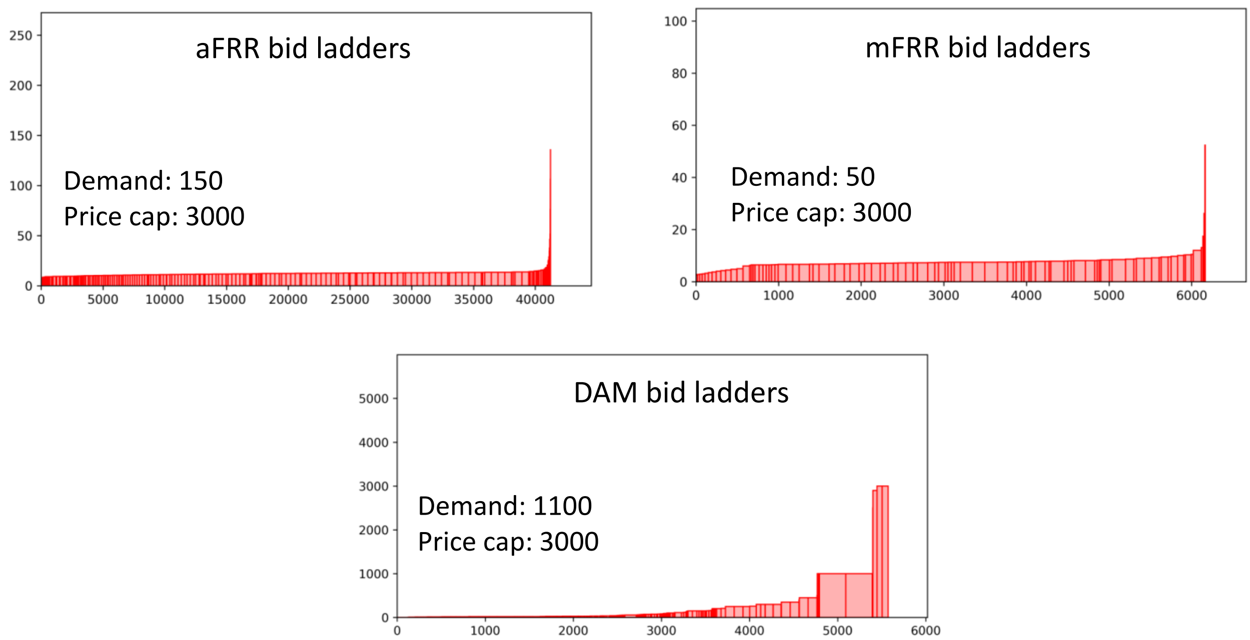

Figure 52: Bids ladders per MTU in BCM and DAM in the Netherlands

For example, for option 1, where there is no link between aFRR and mFRR and DAM bids, the mFRR bid size of those bids which have also participate in the aFRR BCM, become zero and also the DAM bid sizes for those bids which can participate in the aFRR and/or mFRR BCMs, become zero. A same approach is applied for DAM bids in option 5 and 6 where the DAM has no link with the BCM.

16.4 Methodology for the Different Linking Bid Options with CZC

In this section, the methodology applied for taking into account the CZC between two zones with different linking bid options is presented. Depending on which linking bid option is applied, the methodology can differ. Therefore, this section is split into two different parts. In the first part, the methodology belongs to unilateral cross-product linking or no linking including options 1, 2, 6 is explained. In the second part, the methodology belongs to the multilateral cross-product linking in options 3, 4 and 5 is presented.

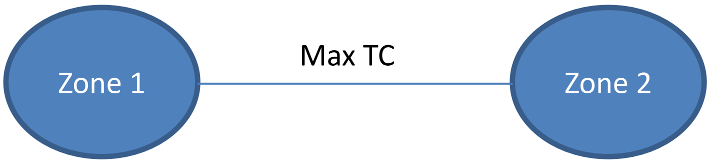

Figure 53: Zone 1 and zone 2 with CZC Max TC

16.4.1 Unilateral Cross-Product Linking and No-linking Options:

As explained in section 5.2, in option 1, 2, and 6, first the aFRR BCM is cleared. Also with CZC between two zones, first aFRR BCM is cleared. *Step 1-3* show how the aFRR BCM with CZC between two zones works:

Step 1. As figure 16.15 shows, there are two zones, zone 1 (z1) and zone 2 (z2), which are connected through a BZB with a maximum transmission capacity, *Max TC*. First, the common merit order list (CMOL) is formed based on all the bids from two zones and total demands of zone 1 and zone 2. The total marginal price is calculated as shown in figure 16.15. Note that MP_{total} cab also be the marginal price at zone 1 and zone 2 when there is no congestion between two zones.

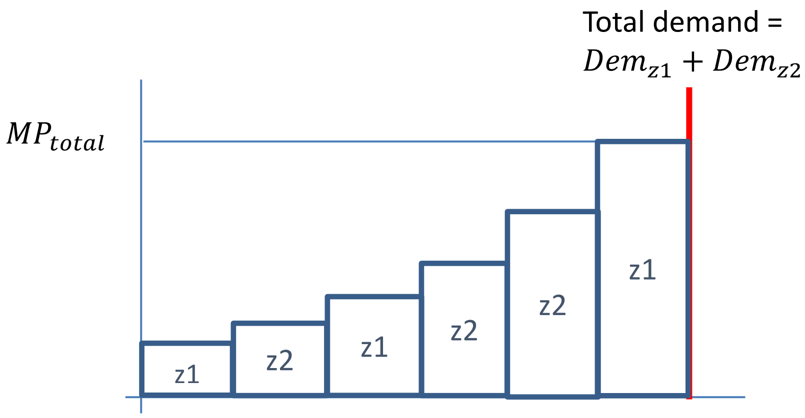

Figure 54: Common merit order list for zone 1 and zone 2

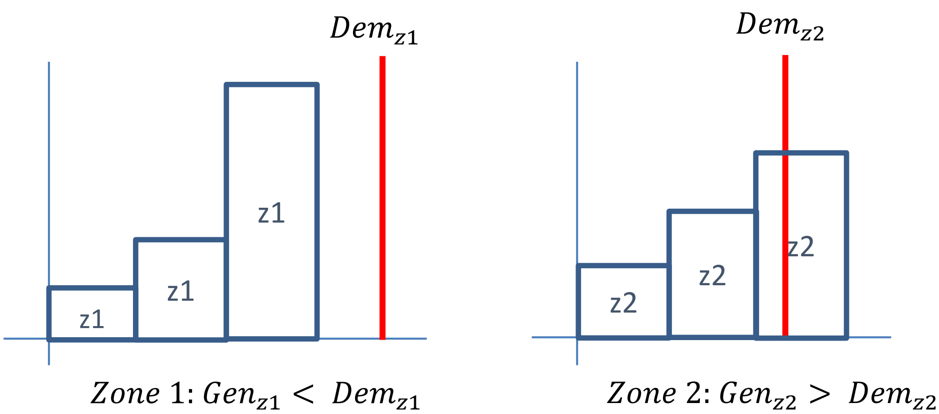

Figure 55: Local merit order list at zone 1 and zone 2 with respect to their local demands

Step 2. According to the accepted bids from zone 1 and zone 2 in step 1, the local merit order list at each zone is formed. Figure 16.16 shows the local merit order list for zone 1 and 2. As figure 16.16 shows, in zone 1, the summation of accepted bids, with respect to the local demand, is lower hence it cannot fulfil the demand. In contrast, in zone 2, the summation of total accepted bids is larger than the local demand, showing that there is an excessive generation in zone 2 which can be exported to zone 1. Therefore, in this step the injected power to the BZB, and its direction becomes calculated as shown in the equation below and in figure 16.17:

$$A = |Gen_{z1} - \ Dem_{z1}| = |Gen_{z2} - \ Dem_{z2}|$$

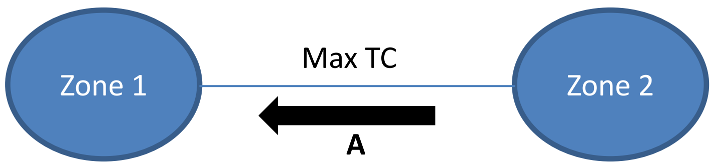

Figure 56: Power flow over the BZB

Step 3. In this step, it is investigated whether or not the injected power to the BZB, A, leads to congestion over the BZB. Then depending on the congested or uncongested BZB, the local market price at each zone can be calculated for each of these two situations:

1) Congested BZB: If $A > Max\ TC$, therefore there is congestion over the BZB. In this situation, the maximum amount that A can have is equal to $Max\ TC$. The local market price at each zone and congestion rent are calculated through following steps:

I. Local demands at zone 1, importer, and zone 2, exporter, will be assumed to be:

$$Zone\ 1\colon\ Dem_{z1}{}' = Dem_{z1} - Max\ TC$$

$$Zone\ 2\colon\ Dem_{z2}{}' = Dem_{z2} + Max\ TC$$

II. based on $Dem_{z1}{}'$ and $Dem_{z2}{}'$, the local market prices at zone 1 and zone 2 are calculated as shown in figure 16.18. Note that due to the congestion between two zones, the local market prices at each zone can be different and equal to MP_{z1} and MP_{z2}.

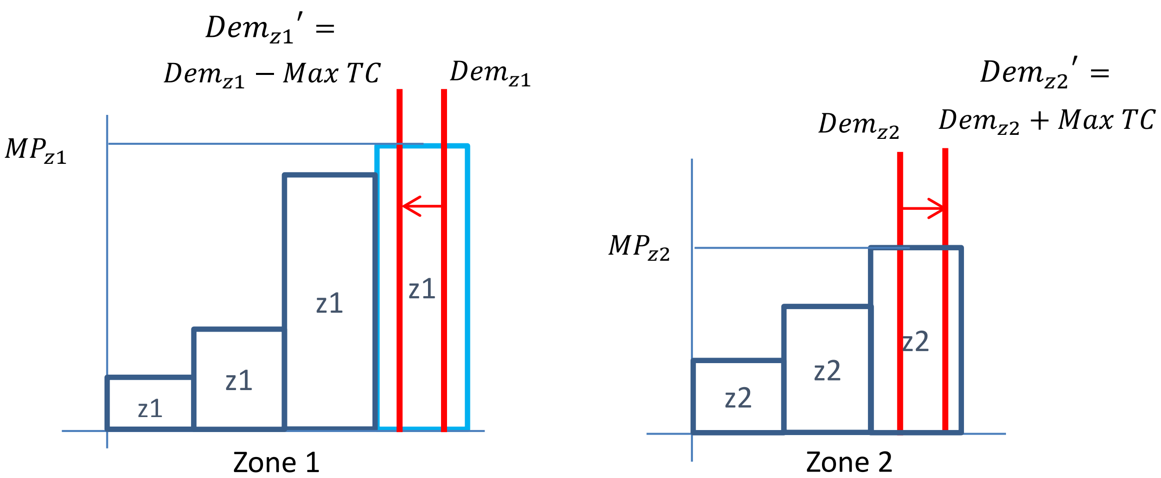

Figure 57: Local market prices in zone 1 and zone 2 with congested BZB

III. Finally, the congestion rent equals to the power flow over the BZB multiplies to the difference of local market prices:

$$Zone\ 1\colon congestion\ (+) = MP_{z1} * Max\ TC$$

$$Zone\ 2\colon congestion\ (-) = -MP_{z2} * Max\ TC$$

$$Congestion\,rent\ =\ (MP_{z1} - MP_{z2}) * Max\ TC$$

2) Uncongested BZB: If $A < Max\ TC$, there is no congestion happened at the CZC and therefore, the market price at both two zones becomes equal to the total marginal price, MP_{total}.

Step 4. Depending on the linking bid option, unilateral or no linking cross-product between aFRR and mFRR BC products, mFRR market is cleared. Therefore, *steps 1-3* are also implemented for the mFRR BCM while taking into account whether or not the bids accepted in the aFRR BCM should be or not be presented in the mFRR BCM, depending on no linking or unilateral cross-product linking between aFRR and mFRR BC bids.

Step 5. Finally, in this step the DAM is cleared. Same as the mFRR BCM in step 4, in this step also depending on whether there is unilateral or no-linking between the DAM and the BCM, the DAM is cleared with a similar approach shown in *step 1-3*.

16.4.2 Multilateral Cross-Product Linking Options:

In the case of multilateral cross-product linking between aFRR, mFRR, and/or DAM products, the BCM and the DAM are cleared through an optimisation process. This optimisation has an objective function equal to the one shown in (16.4). However, there are additional constraints that are related to the cross-border capacity. This objective function and constraints of this optimisation are as follow:

$$Minimize\colon \sum_{i=1}^{n} (\ \mu_i^{aFRR}\, D^{aFRR} + \mu_i^{mFRR} D^{mFRR} + \mu_i^{DAM} D^{DAM})\ (16.12)$$

Subject to:

$$\sum_i b_i^{aFRR} * Pg_i^{aFRR} - D^{aFRR}\ \le Max\ TC^{aFRR}\ (16.13)$$

$$\sum_i b_i^{mFRR} * Pg_i^{mFRR} - D^{mFRR}\ \le\ Max\ TC^{mFRR}\ (16.14)$$

$$\sum_i b_i^{DAM} * Pg_i^{DAM} - D^{DAM}\ \le\ Max\ TC^{DAM}\ (16.15)$$

$$(16.5) - (16.10)\ (16.16)$$

Constraint (16.13)-(16.15) enforce the limits for injected aFRR and mFRR and DAM through the cross-border to their maximum transmission capacity.