Increasing Transparency for Flow-Based Market Coupling in European Electricity Trading

Barriers, Solutions, and Key Indicators

FINAL REPORT

Authors:	Angela Holzmann
	Lukas Zwieb
	Karina Knaus
	Alexander Harrucksteiner
	Altan Sahin

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Mariahilfer Straße 136, 1150 Vienna, Austria, Phone +43 (1) 586 15 24, Fax +43 (1) 586 15 24–340
Email: office@energyagency.at | Internet: www.energyagency.at
Responsible for the content: Peter Traupmann | Project management: Karina Knaus |
Copy editing, Layout, Translation: Bao An Phan Quoc
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Executive Summary

Single Day-Ahead Coupling matches over 200 million euros worth of trades every day across Europe and ensures that 1,500 TWh of electricity are coupled every year in one market solution. The resulting prices are *the* main market signal for producers, suppliers, electricity traders, and consumers. *Flow-based* Market Coupling, currently implemented in Central Western Europe (CWE: Austria, Belgium, France, Germany/Luxembourg and Netherlands), is to be gradually expanded to other regions and markets (intraday) in Europe.

Comprehension of processes and results takes unreasonable effort ⏩ high search and transaction costs

It is therefore an urgent necessity to remove existing barriers that continue to restrict market transparency to this day. For the most part, these barriers do *not* result from the fact that information and data are not available, but are a consequence of a lack of usability leading in turn to disproportionately high search and transaction costs (keyword: pseudo-transparency). This has a negative impact on participants trust in the market, competition, as-well as market efficiency. Moreover, the impact is most severe for smaller or new market participants, as they inherently face greater challenges to provide the considerable resources currently required to search and process information related to Flow-Based Market Coupling compared to larger competitors or incumbents. Considering that many documents are legally binding documents, the lack of transparency is even more severe.

Smaller or new stakeholders at a disadvantage ⏩ no level playing field

In addition, not only market participants, but also regulators, political decision-makers, market observers, research institutions, and even transmission system operators are affected by disproportionately high search and transaction costs. Especially for stakeholders who do not have considerable financial and/or human resources, the lack of transparency results in asymmetric information and a general disadvantage that appears difficult to justify given the importance of FBMC for the entire electricity market. Consequently, this also applies to the countries covered by Flow-Based Market Coupling: smaller and, often, less experienced countries tend to be at a disadvantage. Thus for FBMC, as a process with an extremely high level of complexity and importance, impeccable standards for transparency are a pre-requisite to ensure a level playing field. This also includes a target group-specific development of user concepts for information and data in order to reduce pseudo-transparency.

More resources for improved transparency ultimately lower overall economic costs

Contrary to the perspective that measures for increased transparency would lead to higher costs, it can be argued that from an economic point of view, that centralised of state-of-the-art document and data management substantially more efficient than thousands of users across Europe replicating the same efforts by constantly searching, naming, sorting, or consolidating the exact same documents and data sets.

The socialisation of costs for an improved, centralised and comparably cheap "transparency solution" into total system costs increases overall market efficiency and thereby corresponds exactly to the intentions of implementing EUPHEMIA in the first place, namely to maximise welfare in Europe as a whole. Finally, yet importantly, this would render visible and economically quantifiable this part of transaction costs, which can then be included in the comparative welfare analysis of different market systems.

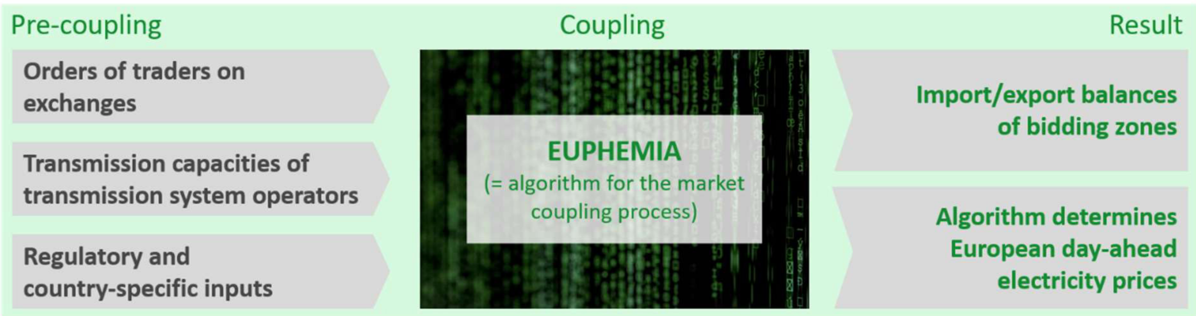
Since May 2015, Flow-Based Market Coupling (FBMC) has been used in the day-ahead markets of Belgium, the Netherlands, France, Germany/Luxembourg, and Austria (CWE) for cross-border capacity allocation. With the split of Austria and Germany into two bidding zones (1 October 2018), Austria now forms a separate bidding zone. The aim is to make the best possible use of the available transmission capacity for electricity trading.

Basic principle of Flow-Based Market Coupling

Flow-Based Market Coupling goes further than conventional systems for capacity calculation (NTC method or ATC model): in order to achieve the greatest possible approximation to the load flows actually occurring on the individual network elements, critical network elements – i.e. those specifically affected by cross-border trade – are identified. Available capacities of these critical network elements are determined by transmission system operators (TSOs) in a comprehensive and complex process ("**pre-coupling"**).

Market coupling

…is the process of efficiently using limited transmission capacities between different bidding zones. Transmission system operators and electricity exchanges jointly organise the market coupling process.



The result of the pre-coupling process defines the solution space for the actual market coupling process ("**coupling"**). The **EUPHEMIA**[1] algorithm summarises both orders traded on the electricity exchanges and available transmission capacities, and calculates – with the objective of maximising welfare in all of Europe[2] – the optimal fulfilment of orders. This enables the simultaneous (implicit) allocation of electricity and transmission capacity on the European day-ahead market. In addition to the capacity constraint, EUPHEMIA also takes into account numerous complex physical, regulatory, and country-specific framework conditions.

Programmed by a private company, EUPHEMIA is owned by the European electricity exchanges. The code itself is not publicly accessible; a documentation with the basic properties has been published.

EUPHEMIA maximises welfare only within the boundaries set exogenously.

Costs not defined in the algorithm but directly related to the allocation of capacity, such as congestion management costs, are not considered when calculating the optimal allocation of the scarce transmission capacities.

Additionally, EUPHEMIA only optimises within the day-ahead market. Economically speaking, however, a welfare assessment is not limited in time; and, because of the objective of maximising the overall economic welfare, it should reflect the entire electricity market (congestion management costs, long-term capacity allocation, intra-

[1] EU Pan-European Hybrid Electricity Market Integration Algorithm
[2] Sum of consumer surplus, producer surplus, and congestion income

day market, balancing markets). Other economic cost factors, such as search and transaction costs, differ in various systems (e.g. between flow-based and ATC-based capacity allocation). These costs are difficult to quantify and are also not taken into account by EUPHEMIA.

The result is thus largely determined by the given framework. The algorithm can in no way replace the necessary political and regulatory discussion about the market design itself. However, framework conditions can be established that eliminate the weaknesses of EUPHEMIA. This essentially includes reducing search and transaction costs through increased transparency in FBMC.

Transmission system operators take part in the Flow-Based Market Coupling process in various roles at key points in time.

The Flow-Based Market Coupling process in its entirety is characterised by a series of complex algorithms and workflows, in which numerous actors (transmission system operators, exchanges, regulators, electricity traders) exercise influence at different points. In addition, transmission system operators make decisions on congestion management methods after the market coupling process ("**post-coupling**"). They have therefore a dual function: on the one hand as an essential data provider in the pre-coupling process, and on the other hand as an economic player in the context of cross-border capacity management and long-term investment decisions. As a result, transmission system operators are affected by both costs and proceeds from congestion management. This is one of the reasons for demanding more transparency in FBMC.

Due to the complexity of the entire process, appeals for more transparency have been made since the conception of FBMC:

> *Market parties […] need to perform price forecasting/market analysis for much longer periods.*
> *Can the full Common Grid Model be made public?*
> *(Market participant, May 2013[3])*

Comprehension of processes and results takes unreasonable effort ⏩ high search and transaction costs.

The comprehensive analysis of public documentation and data sets, as well as surveys, workshops with market participants, and inquiries from relevant stakeholders again show significant barriers in 2020 with regard to transparency in Flow-Based Market Coupling. Due to the historically grown methodology of European market coupling, a large number of platforms currently provide information and data. This also results in a major obstacle in terms of transparency in the market coupling process:

Latest versions of essential documents can only be found with disproportionately high search and transaction costs.

This is due to numerous platforms/websites with similar information, and a lack of search and/or overview functions on these platforms. The naming and structure of the documents, versioning, information on relevance, etc. also show great potential for improvement and do not meet current standards. Together with the lack of consolidated versions of important documents, this represents a significant restriction on transparency.

Relevant data at times not publicly available.

Important data sets generally are published in good time and in sufficient quality. Nevertheless, some data that would be necessary to assess the market or the market result (e.g. input into the common grid model or remedial

[3] ForumExport.pdf available at https://www.jao.eu/support/resourcecenter/overview?parameters=%7B%22IsCWEFBMCRelevant-Documaentation%22%3A%22True%22%7D

actions) are not publicly available. Data formats and interfaces only partially correspond to the state of the art and best practices with regard to data provision, documentation, and metadata. Even within a central platform for FBMC, such as the JAO (Joint Allocation Office), not all data are available at *one* access point.

Smaller or new market participants at a disadvantage ⏩ no level playing field

Communication of important information, such as changes in processes or the data system, does not reach all market participants to the desired extent. The necessary build-up and maintenance of expertise as well as high search and transaction costs continually cause considerable burdens for market participants, but also for regulators, transmission system operators, market observers, etc. This results in a competitive disadvantage or entry barrier oftentimes insurmountable for smaller or new market participants.

Quality of the EUPHEMIA solution not verifiable on a daily basis.

A regular assessment of the quality of the solution calculated by EUPHEMIA is also not possible with the information currently available.

Barriers have a negative impact on market trust, competition, and market efficiency.

Transparency means that the traceability of both the input parameters and the results of market coupling must be guaranteed. The mere (unstructured) provision of information only creates **pseudo-transparency**. Information and data must be prepared in such a way that understanding the market processes, input parameters, and the market result is feasible with the lowest possible search and transaction costs. This is necessary in a system as complex as FBMC in order to improve market trust, market efficiency, and systemic efficiency.

Transparency is crucial for...

- **Market trust:** ensured comprehensibility of processes and results
- **Market efficiency and competition:** level playing field between small, large, new, established market participants
- **Systemic efficiency:** minimised search and transaction costs as part of overall welfare

Best practice instead of pseudo-transparency.

Transparency barriers and **pseudo-transparency** can be significantly reduced with the application of scientific standards and the implementation of solutions based on best practice examples. Most of these are improvements in information preparation, document structure, and data provision. At best, this should permit the target group a low-threshold and comprehensible access to the necessary information and minimise search and transaction costs.

Transparency means...

- **Information transfer:** documents and data available and findable
- **Usability:** access and usage concepts for relevant target groups
- **Knowledge transfer and interaction:** feedback culture, knowledge exchange, communication channels, etc.

Standardised document publication in compliance with current standards.

The standardised publication of documents, if possible on a platform, makes it easier to find documents, especially in the latest version. The possibility of retracing all steps of the development is guaranteed by appropriate archiving and versioning. In addition, modifications in terms of document structure, file format, naming convention, or attachment management are crucial.

FBMC transparency requirements

Documents	Goal: Possibility to find documents easily, retrace seamlessly all steps of the development, determine topicality – with the lowest possible search and transaction costs
Requirement	
Standardised document structure	Author and contact, date of preparation, date of beginning of validity, effective for which region, version number...
File format	Documents must be available in common file formats (HTML, PDF)
Attachments accessible	Attachments mentioned must be findable in the document, via cross-reference or digital object identifier
Naming convention	File names must be consistent, intelligible, and include a preceding date format and the version number
Indexing in popular search engines	
Systematic storage (one platform)	Findability of documents, traceability of changes through archiving and versioning

Central data provision and documentation.

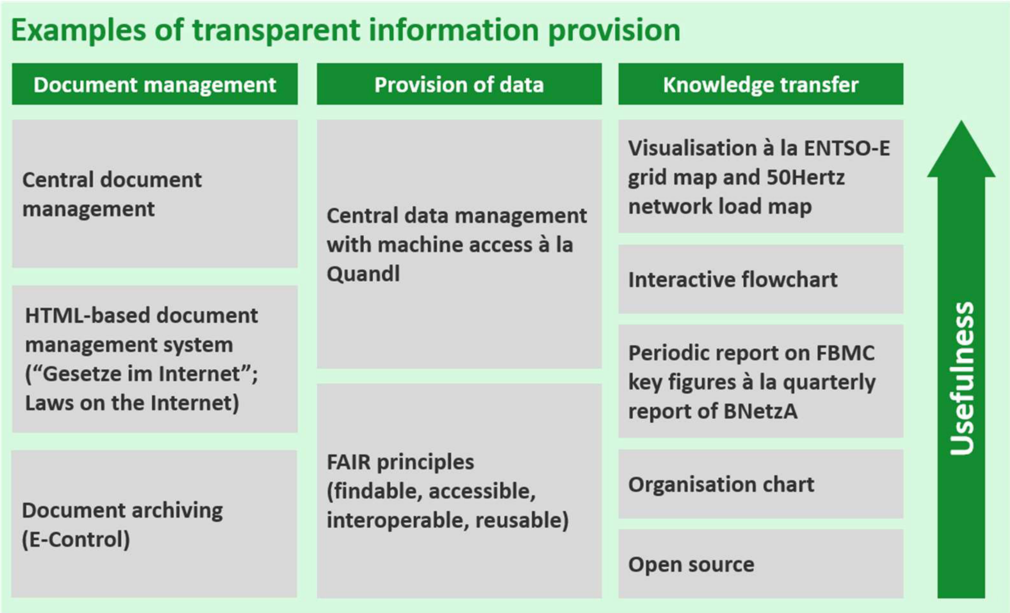
Data must also be stored systematically and at as few access points as possible. The data sets must be comprehensible and documented in relation to current methodology descriptions. Sources and contacts must also be provided. The smooth functionality and availability of the corresponding tools must be ensured.

FBMC transparency requirements

Data (JAO utility tool)	Goal: Low-threshold and comprehensible access to necessary data sets with minimised search and transaction costs
Requirement	
Sources and contacts	Sources of individual data sets should be identifiable in the utility tool. Contacts should be available in case of problems of understanding or questions about the data.
Up-to-date and relevant documentation of the utility tool	Data sets must be intelligible and defined in relation to current methodology descriptions (including cross-references); updates must be communicated; versioning must be comprehensible
Availability, completeness, and accessibility of data	Mostly given by utility tool; further data should not be spread, for example, on the message board of the JAO website, but collected at a single access point
Higher performance of the utility tool	Smooth functionality and availability must be ensured; definition of performance standard and monitoring
Usability of web service	See examples, e.g. time stamp and documentation

In addition to these minimum scientific standards, further usage concepts for the preparation, provision, and communication of information tailored to the target group are required to avoid **pseudo-transparency**.

In practice, there are already numerous examples from many disciplines for the transparent provision of information. Adapted to the needs of the electricity market, these can be used to create a concept for transparent information preparation within the framework of Flow-Based Market Coupling.



One-stop shop as the best solution.

The most suitable step to promote transparency is to set up a one-stop shop, i.e. a central contact point that gives market participants access to all FBMC-relevant documents and data.

Documents should be available as HTML, with the option to download in PDF format, as is usually the case with all legally binding documents (national and at EU level). Above all, documents – also in the future CORE FBMC – should be presented in consolidated versions and in a manner so that their gradual development is traceable.

Filters and search options should be provided for both data and documents. Data should not only be available in Excel format with a time stamp, but also machine-readable with the appropriate documentation.

A flowchart, linked to the HTML-based description, is suitable for representing the process flows. To transfer knowledge, a visualisation of the data, similarly to the network map of ENTSO-E with a zoom function and cross-references to the data sets, would also be ideal.

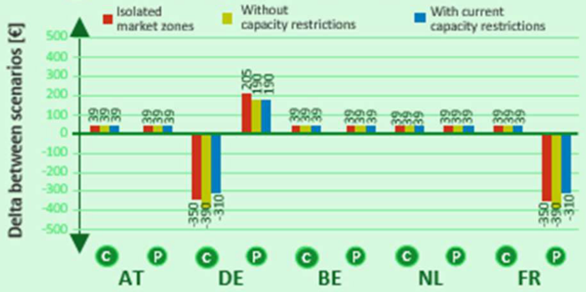
Key performance indicators (KPI) for a quick and intuitive market overview.

In addition to removing existing barriers, key indicators further increase transparency in FBMC and strengthen market trust. Developing and daily publishing KPIs gives market participants, regulators, decision-makers, and market observers a quick overview of the current situation and acute abnormalities. The proposed indicators are intended to (1) validate FBMC as a market organisation process, (2) evaluate the performance of the market coupling algorithm EUPHEMIA, and (3) provide overview information for market participants on the FBMC data.

Validation of FBMC

Winners/losers of welfare optimisation

Consumer surplus/Producer surplus in 1,000€, Σ 24 hours



Price convergence

Convergence in hours

	AT	DE	BE	NL	FR
AT		XX%	XX%	XX%	XX%
DE	XX%		XX%	XX%	XX%
BE	XX%	XX%		XX%	XX%
NL	XX%	XX%	XX%		XX%
FR	XX%	XX%	XX%	XX%	

- Description of legend
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Performance of EUPHEMIA

Computing time

in minutes

First valid solution

XX

Final solution

XX

Improvement of the solution

Increase in welfare per iteration step

Paradoxically rejected orders

Total of 24 hours

	Number	TWh
AT		
DE		
BE		
NL		
FR		

Information for the market

Descriptive evaluation of critical network elements (CBCOs)

	Number CBCO (Ø 24 hours)	Min (number)	Max (number)	Costs (in 1,000€)
AT				
DE				
BE				
NL				
FR				

Often limiting CBCOs (top 5 of the month)

1. XXXXXX (COUNTRY)
2. XXXXXX (COUNTRY)
3. XXXXXX (COUNTRY)
4. XXXXXX (COUNTRY)
5. XXXXXX (COUNTRY)

Available capacity in day-ahead trading

24-hour average

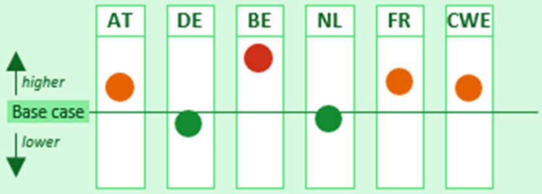
	RAM/F_{max}
AT	
DE	
BE	
NL	
FR	

Implicit remedial actions

24-hour average

	FAV/F_{max}	FAV/RAM
AT		
DE		
BE		
NL		
FR		

Accuracy of the base case (MAPE)



Price divergence (1 to 5)

AT	1 | none
DE	5 | very high
BE	3 | medium
NL	4 | high
FR	2 | low

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1 Introduction

The aim of market coupling is a coherent European single market for electricity. Ideally, price differences should be prevented, or at least reduced, in order to maximise welfare throughout Europe. Limiting elements for the coupling of electricity markets are available transmission capacities in the European electricity network.

(FB)MC determines the Austrian and European electricity prices. Due to the complexity and extensive input data, an analysis of the transparency requirements from a trade perspective is necessary.

With the price coupling of regions (PCR), the European electricity exchanges[4] started an initiative to implement the harmonisation of electricity markets in Europe with the objective to make the best possible use of limited transmission capacities available. Since the start of the PCR in February 2014, the coupled area has been expanded several times; it now covers 95% of the electricity consumption in Europe. The core of the PCR system is the algorithm EUPHEMIA (EU Pan-European Hybrid Electricity Market Integration Algorithm). EUPHEMIA enables the consideration of various systems for capacity allocation (flow-based, ATC[5]) and diverse orders traded on the electricity exchanges (aggregated hourly orders, complex orders, block orders). This means that as part of market coupling, transmission capacity and electricity are allocated at the same time (implicit allocation).

In order to make effective use of transmission capacities, Flow-Based Market Coupling (FBMC) in the Central West European day-ahead markets (Belgium, the Netherlands, France, Germany/Luxembourg, and Austria) has been used since 20 May 2015 for cross-border capacity allocation. With the split of Austria and Germany into two bidding zones in October 2018, Austria now forms a separate bidding zone in this system.

Available cross-border transmission capacities have a significant impact on electricity prices on the day-ahead market. In order to create accurate price forecasts, facilitate efficient trading on the long and short-term electricity market, and make useful investment and operating decisions, it is essential for market participants to be able to understand fundamentally and retrace as seamlessly as possible all processes of market coupling. In this sense, the CACM Guideline (EU 2015/1222) identifies "**ensuring and enhancing the transparency and reliability of information**" as one of the goals of cooperation in capacity allocation and congestion management.

Transparency does not only mean simply making information available, but preparing it in such a way that comprehensively understanding the processes is feasible with the lowest possible search and transaction costs.

Improved transparency has numerous advantages, such as increased trust of market participants in the market coupling process, the possibility for better forecasts as a basis for data-driven decisions, and reduced risk on the part of market participants, while the risk for transmission system operators remains the same. In addition, simplified access to information leads to easier market access for smaller companies (keyword: level playing field).

However, transparency (see Figure 1) in terms of enhancing the traceability of both the input parameters and the results of market coupling does not only imply the mere provision of information (1). Moreover, information must be prepared in such a way that market participants can understand the processes comprehensively with the lowest possible search and transaction costs (2). This includes usage concepts for information preparation,

[4] PCR is an initiative of the electricity exchanges EPEX SPOT, GME, HEnEx, Nord Pool, OMIE, OPCOM, OTE, and TGE.
[5] Average transfer capacity

information provision and communication, which are tailored to the target group (3). This is imperative in order to avoid so-called pseudo-transparency – namely that information is published such that it cannot be found or processed by interested users or only with disproportionately high effort. Due to the low level of user-friendliness, pseudo-transparency can significantly limit the usability of data and information.[6]

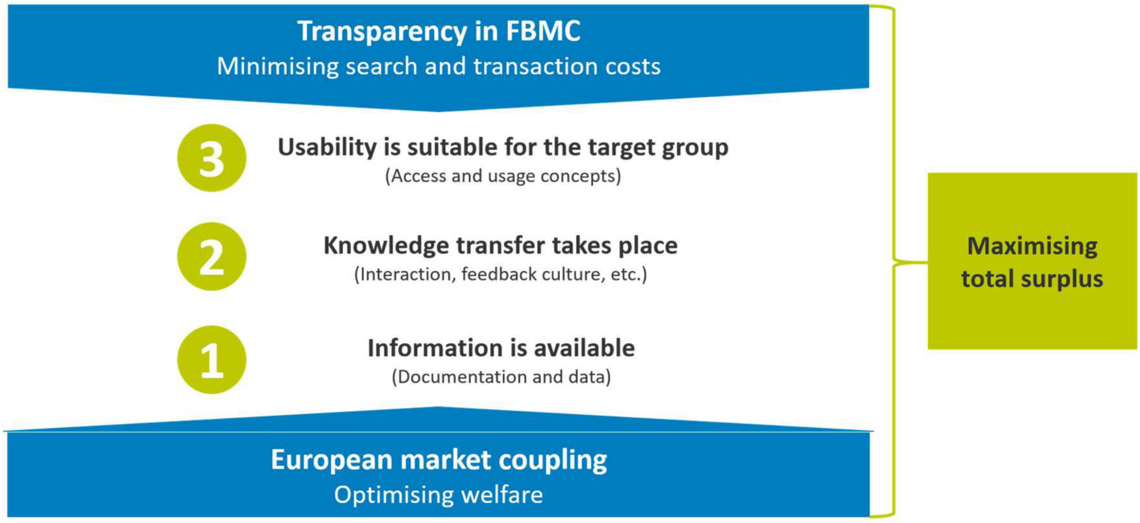


Figure 1: Building blocks of transparency in FBMC; source: own representation

Transparency in the Flow-Based Market Coupling process is not only necessary for the current CWE-DA trade. It is generally gaining in importance, as on the one hand, this trade is to be extended to the CORE region and on the other hand, the FBMC concept is to be expanded for intraday trading.

The present study provides an analysis of information transparency and key indicators in Flow-Based Market Coupling in the CWE region. The content is developed in a two-stage process. The Austrian Energy Agency provides – based on publicly and freely accessible information – the scientific external perspective on transparency in the Flow-Based Market Coupling process, whereas the market participants contribute their experience and competence in the daily handling of the process of day-ahead electricity trading. The subject is thus highlighted from two different angles: on the one hand, there is a systematic screening of the available information, and on the other hand, the experience of the market participants is included into the investigation.

While criticism at European level[7] is concerned with the specifics of the data sets and, above all, demand detailed and additional evaluations, the aim of this study is: (1) to analyse the findability, traceability, and consistency of existing information and data, as well as – based on this – to present recommendations for increasing transparency; and (2) to present indicators for a holistic monitoring of the mode of operation of FBMC (Figure 2).

[6] Cf. Agora Energiewende „Transparente Strommarktdaten als Basis für einen funktionierenden Strommarkt 2.0“ (August 2015) https://www.bmwi.de/Redaktion/DE/Downloads/Stellungnahmen/Stellungnahmen-Weissbuch/Organisationen/150824-agora-energiewende.pdf?__blob=publicationFile&v (Transparent electricity market data as the basis for a functioning electricity market 2.0; only German); accessed 15 May 2020
[7] See Chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**

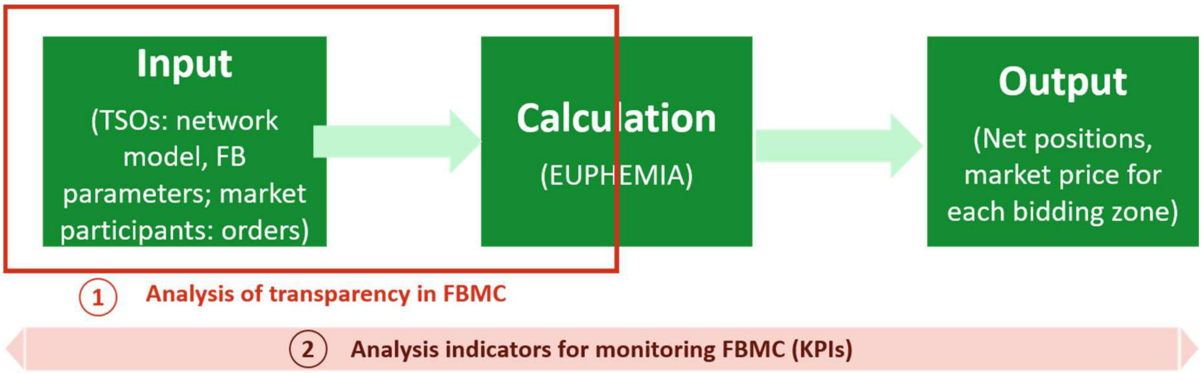


Figure 2: Main objectives of the study; source: own representation

The investigation is divided into three parts:

Chapter 2 deals with the **interdependencies in FBMC**. In theory, the processes and calculation steps underlying FBMC are clearly defined. In practice, however, numerous (local) particularities, processes, and security mechanisms have to be respected. These are not always trivial. A precise and shared understanding of the CWE-FBMC process forms the basis for further discussion. Respective data and cash flows are also described and analysed with regard to the resulting incentive structure. The system boundaries of EUPHEMIA are roughly outlined and the objective function with respect to the concept of welfare optimisation through trade maximisation is examined.

Chapter 3 shows barriers and proposed solutions with regard to **transparency in electricity trading**. Problems and barriers are methodically explained and analysed using concrete examples. This study is complemented with the experience of Austrian traders and market participants. On this basis, specific suggestions for solutions are recommended. These are divided, on the one hand, into approaches that should help to meet current scientific standards with regard to information preparation, document structure, and data provision; and on the other hand, into more extensive and complex solution proposals, which are illustrated using concrete application examples.

In **Chapter 4**, recommendations for **indicators** for ongoing performance monitoring of the market coupling algorithm and FBMC are designed. Building on the theoretical examination of both the data flows and process flows of FBMC and the objective function of EUPHEMIA, meaningful key indicators are developed. These indicators are intended to enable an ongoing and simple assessment of the market coupling process.

2 Market Coupling

The aim of market coupling is a coherent European single market for electricity. Ideally, price differences should be prevented, or at least reduced, in order to maximise welfare throughout Europe. Available transmission capacities between the various markets must be adequately taken into account and assigned accordingly to the market participants. Currently, there are different methods for capacity calculation and allocation, which are used on electricity markets, such as available transfer capacity-based methods (ATC) or Flow-Based Market Coupling (FBMC). The latter is the focus of this report. The following section explains the functioning principles of FBMC, economic incentives in the allocation of cross-border capacities, and the optimisation algorithm EUPHEMIA used for day-ahead market coupling. The chapter forms the basis for the further discussion.

2.1 Functioning principles of FBMC

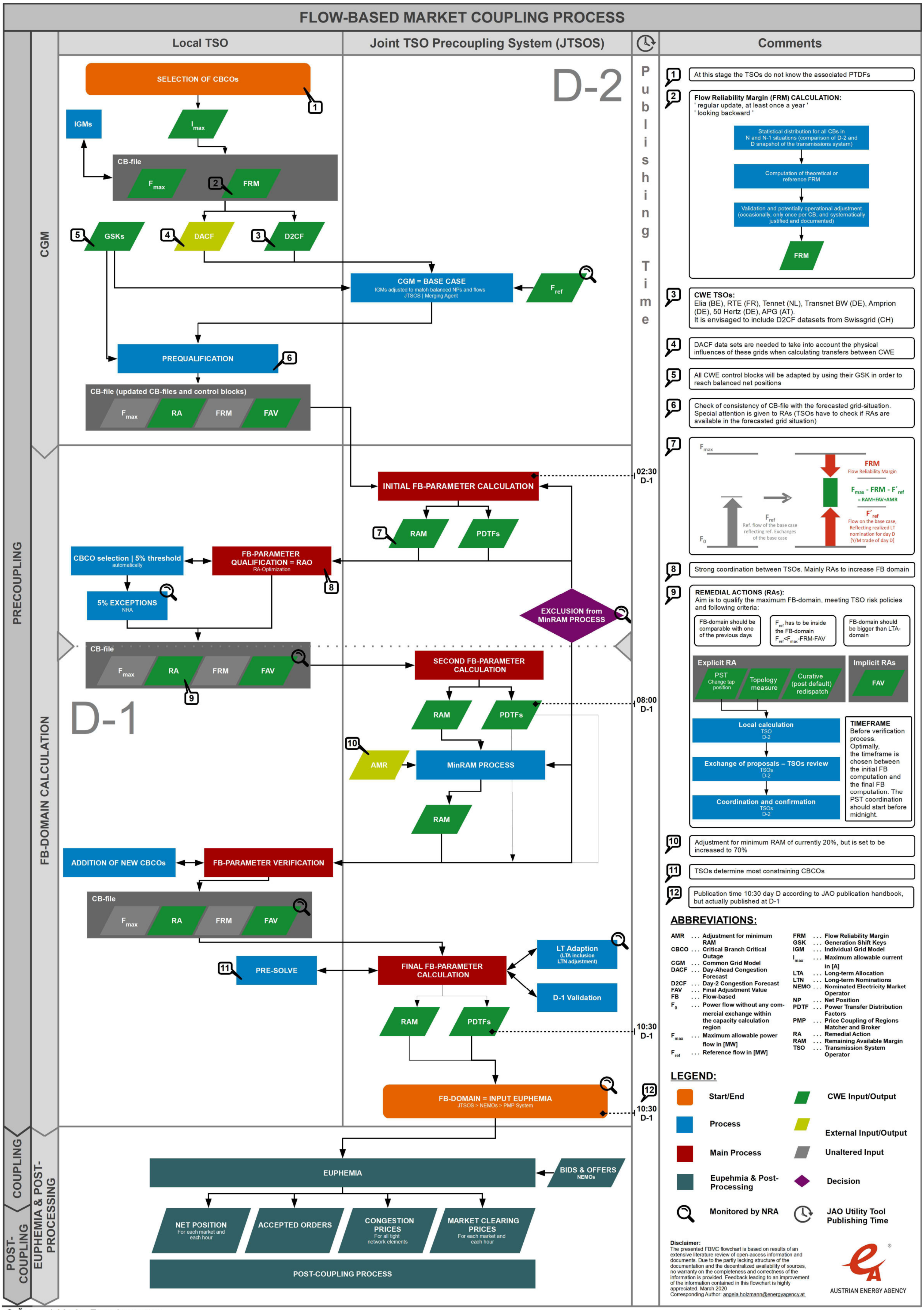
Since 20 May 2015, Flow-Based Market Coupling (FBMC) has been used in Central West European day-ahead markets (Belgium, Netherlands, France, Germany/Luxembourg, and Austria) for cross-border capacity allocation. With the split of Austria and Germany into two bidding zones on 1 October 2018, Austria now forms a separate bidding zone in the day-ahead market.

The basic problem in cross-border capacity allocation is that trade flows (i.e. economic transactions) differ from physical flows (i.e. flows through all parallel paths according to Kirchhoff's law). FBMC takes into account the physical conditions of the electricity grid (as in the nodal system), but simplifies them by applying a zonal approach (as in the ATC approach). The goal is to provide a maximum of transmission capacities for short-term electricity trading (day-ahead and intraday). The entire pre-coupling process aims at creating the so-called flow-based domain (FB domain), i.e. the final solution space of transmission capacities that are available for market coupling.

This chapter provides a basic overview of FBMC, its process, and the most significant parameters and stakeholders.

2.1.1 FBMC | Process flow and parameters

FBMC is not a single process, but an extensive process chain in which various actors exert influence and various tools are used. The following flowchart shows a graphic representation of these processes within FBMC. Based on this, questions within the extensive process chain can be identified and discussed more easily.



FLOW-BASED MARKET COUPLING PROCESS
Local TSO
Joint TSO Precoupling System (JTSOS)
Comments
PRECOUPLING
CGM
FB-DOMAIN CALCULATION
COUPLING
EUPHEMIA & POST-PROCESSING
POST-COUPLING
D-2
D-1
Publishing Time
SELECTION OF CBCOs
IGMs
Imax
CB-file
Fmax
FRM
GSKs
DACF
D2CF
CGM = BASE CASE
IGMs adjusted to match balanced NPs and flows
JTSOS | Merging Agent
Fref
PREQUALIFICATION
CB-file (updated CB-files and control blocks)
Fmax
RA
FRM
FAV
02:30 D-1
INITIAL FB-PARAMETER CALCULATION
RAM
PDTFs
CBCO selection | 5% threshold
automatically
FB-PARAMETER QUALIFICATION = RAO
RA-Optimization
5% EXCEPTIONS
NRA
EXCLUSION from MinRAM PROCESS
CB-file
Fmax
RA
FRM
FAV
SECOND FB-PARAMETER CALCULATION
08:00 D-1
RAM
PDTFs
AMR
MinRAM PROCESS
RAM
ADDITION OF NEW CBCOs
FB-PARAMETER VERIFICATION
CB-file
Fmax
RA
FRM
FAV
LT Adaption
(LTA inclusion LTN adjustment)
PRE-SOLVE
FINAL FB-PARAMETER CALCULATION
D-1 Validation
RAM
PDTFs
10:30 D-1
FB-DOMAIN = INPUT EUPHEMIA
JTSOS > NEMOs > PMP System
10:30 D-1
EUPHEMIA
BIDS & OFFERS
NEMOs
NET POSITION
For each market and each hour
ACCEPTED ORDERS
CONGESTION PRICES
For all tight network elements
MARKET CLEARING PRICES
For each market and each hour
POST-COUPLING PROCESS
1 At this stage the TSOs do not know the associated PTDFs
2 Flow Reliability Margin (FRM) CALCULATION:
' regular update, at least once a year '
' looking backward '
Statistical distribution for all CBs in N and N-1 situations (comparison of D-2 and D snapshot of the transmission system)
Computation of theoretical or reference FRM
Validation and potentially operational adjustment (occasionally, only once per CB, and systematically justified and documented)
FRM
3 CWE TSOs:
Elia (BE), RTE (FR), Tennet (NL), Transnet BW (DE), Amprion (DE), 50 Hertz (DE), APG (AT).
It is envisaged to include D2CF datasets from Swissgrid (CH)
4 DACF data sets are needed to take into account the physical influences of these grids when calculating transfers between CWE
5 All CWE control blocks will be adapted by using their GSK in order to reach balanced net positions
6 Check of consistency of CB-file with the forecasted grid-situation. Special attention is given to RAs (TSOs have to check if RAs are available in the forecasted grid situation)
7 Fmax
FRM
Flow Reliability Margin
Fmax - FRM - F'ref
= RAM+FAV+AMR
F'ref
Flow on the base case, Reflecting realized LT nomination for day D [Y/M trade of day D]
Fref
Ref. flow of the base case reflecting ref. Exchanges of the base case
F0
8 Strong coordination between TSOs. Mainly RAs to increase FB domain
9 REMEDIAL ACTIONS (RAs):
Aim is to qualify the maximum FB-domain, meeting TSO risk policies and following criteria:
FB-domain should be comparable with one of the previous days
Fref has to be inside the FB-domain F'ref<Fmax-FRM-FAV
FB-domain should be bigger than LTA-domain
Explicit RA
PST
Change tap position
Topology measure
Curative (post default) redispatch
Implicit RAs
FAV
Local calculation
TSO D-2
Exchange of proposals – TSOs review
TSOs D-2
Coordination and confirmation
TSOs D-2
TIMEFRAME
Before verification process. Optimally, the timeframe is chosen between the initial FB computation and the final FB computation. The PST coordination should start before midnight.
10 Adjustment for minimum RAM of currently 20%, but is set to be increased to 70%
11 TSOs determine most constraining CBCOs
12 Publication time 10:30 day D according to JAO publication handbook, but actually published at D-1
ABBREVIATIONS:
AMR ... Adjustment for minimum RAM
CBCO ... Critical Branch Critical Outage
CGM ... Common Grid Model
DACF ... Day-Ahead Congestion Forecast
D2CF ... Day-2 Congestion Forecast
FAV ... Final Adjustment Value
FB ... Flow-based
F0 ... Power flow without any commercial exchange within the capacity calculation region
Fmax ... Maximum allowable power flow in [MW]
Fref ... Reference flow in [MW]
FRM ... Flow Reliability Margin
GSK ... Generation Shift Keys
IGM ... Individual Grid Model
Imax ... Maximum allowable current in [A]
LTA ... Long-term Allocation
LTN ... Long-term Nominations
NEMO ... Nominated Electricity Market Operator
NP ... Net Position
PDTF ... Power Transfer Distribution Factors
PMP ... Price Coupling of Regions Matcher and Broker
RA ... Remedial Action
RAM ... Remaining Available Margin
TSO ... Transmission System Operator
LEGEND:
Start/End
CWE Input/Output
Process
External Input/Output
Main Process
Unaltered Input
Euphemia & Post-Processing
Decision
Monitored by NRA
JAO Utility Tool Publishing Time
Disclaimer:
The presented FBMC flowchart is based on results of an extensive literature review of open-access information and documents. Due to the partly lacking structure of the documentation and the decentralized availability of sources, no warranty on the completeness and correctness of the information is provided. Feedback leading to an improvement of the information contained in this flowchart is highly appreciated. March 2020
Corresponding Author: angela.holzmann@energyagency.at
AUSTRIAN ENERGY AGENCY

The FBMC process can be roughly divided into the pre-coupling, the coupling, and the post-coupling phase. The pre-coupling phase describes the process *before* the actual market coupling (coupling) and is the focus of this chapter. The result of this phase is the so-called FB domain, i.e. the possible solution space for the subsequent market coupling. This solution space is described by the parameters "remaining available margin" (RAM) and "power transfer distribution factors" (PTDFs) (see below), which are determined for each critical network element (CBCO, critical branch/critical outage), and uses these parameters to set the free capacities available for market coupling. These parameters are determined by the respective transmission system operators (TSOs) in a complex, coordinated process.

For the present study, the pre-coupling phase was further divided into the creation of the base case (CGM, common grid model; in the flowchart) and the calculation of the FB parameters (FB domain calculation).

The FBMC parameter calculation is started two days before delivery (i.e. D-2) and completed in the morning day-ahead (D-1), so that the FB domain is available for day-ahead market clearing. A precise schedule, in the sense of a clear timeline or a plan of procedure, for the individual process steps was not found in publicly available documents. However, a detailed schedule would be convenient and very helpful, especially for assessing the publication times of the individual data sets.

A recurring feature of the entire FBMC process is the mutual interaction between the individual transmission system operators and the joint TSO pre-coupling system (JTSOS). This close coordination is necessary, on the one hand, to integrate the expertise of the individual transmission system operators, and on the other hand, to enable a coordinated European process. A disadvantage of this necessary coordination effort is the limited traceability for market participants (keyword transparency).

Joint TSO pre-coupling system (JTSOS)

...is responsible for determining the FB parameters. The system is operated alternately (on a weekly basis) by the participating TSOs.

In the JAO utility tool, numerous data sets of Flow-Based Market Coupling are published (for details on the utility tool, see Chapter 3). The publication times shown in the corresponding documentation (Joint Allocation Office, 2019) can be found in the flowchart on the right underneath "Publishing Time". The specified time for the publication of the final FB domain (10:30, D) does not match the experience of the authors (10:30, D-1). The actual publication time was inserted in the flowchart.

2.1.1.1 Creating the possible solution space in pre-coupling (FB Domain)

The aim of the entire pre-coupling process is to create the so-called FB domain, i.e. the possible solution space for the subsequent market coupling. For each critical network element, a set of FB parameters (RAM and PTDFs) is created with hourly resolution (24 sets per CBCO).

Remaining available margin (RAM)

RAM describes the capacity of the network elements available for DA trading; it is clearly defined by the following formula:

$$RAM_i = F_{max,i} - F_{ref,i} - FAV_i - FRM_i - AMR_i \qquad \forall i = CBCO$$

$F_{max,i}$ ... maximum flow per critical network element *i*

$F_{ref,i}$ ... reference flow per critical network element *i*

FAV_i … final adjustment value per critical network element *i*

FRM_i … flow reliability margin per critical network element *i*

AMR_i … adjustment for minimum RAM per critical network element *i*

A detailed explanation of the individual parameters is included in the process description below.

Power transfer distribution factors (PTDFs)

In addition to RAM, PTDFs are the second group of parameters for determining the FB domain. PTDFs show how the flow on a critical element changes when the net position of a bidding zone changes. PTDFs are therefore illustrated as a matrix for each critical element and bidding zone (see example in Table 1).

Table 1: Exemplary matrix PTDFs per critical network element (CBCO) and bidding zone; source: own representation

Critical network element /bidding zone	AT	BE	DE	FR	NL
CBCO 1	$PTDF_{CBCO\ 1,\ AT}$	$PTDF_{CBCO\ 1,\ BE}$	$PTDF_{CBCO\ 1,\ DE}$	$PTDF_{CBCO\ 1,\ FR}$	$PTDF_{CBCO\ 1,\ NL}$
CBCO 2	$PTDF_{CBCO\ 2,\ AT}$	$PTDF_{CBCO\ 2,\ BE}$	$PTDF_{CBCO\ 2,\ DE}$	$PTDF_{CBCO\ 2,\ FR}$	$PTDF_{CBCO\ 2,\ NL}$
CBCO 3	$PTDF_{CBCO\ 3,\ AT}$	$PTDF_{CBCO\ 3,\ BE}$	$PTDF_{CBCO\ 3,\ DE}$	$PTDF_{CBCO\ 3,\ FR}$	$PTDF_{CBCO\ 3,\ NL}$
…	…	…	…	…	…

PTDFs are calculated based on sensitivity analyses of the base case and converted from nodal PTDFs to zonal PTDFs using so-called generation shift keys (GSKs).

Generation shift keys (GSKs) describe the relationship between the change in the net position of a bidding zone and the change in the performance of each generation unit within the same bidding zone. GSKs include power plants that are market-oriented and flexible in changing electrical power (gas, oil, water, storage/pumped storage, and coal). In Austria, storage/pumped storage and thermal power plants are included. GSKs can vary per hour; they are indicated in dimensionless units. A value of e.g. 0.05 for a generation unit means that 5% of the change in the net position of the bidding zone is executed by this power plant. If possible, the GSK values are assigned to the generation units in the common grid model.

> **Generation shift keys (GSKs)**
>
> … describe the relationship between the change in the net position of a bidding zone and the change in the output of each generation unit within the same bidding zone.

Each transmission system operator calculates the GSKs using individual methods for their balancing zone, taking into account the properties of their system. The aim is to provide the best forecast of the effects of a net position change on critical network elements.

Selection of the critical elements (CBCOs)

Critical network elements (CBCOs, critical branch/critical outage)[8] are network elements that are severely affected by cross-border trade and are monitored under certain conditions. Critical network elements are defined (1) by a network element (line, transformer,...) that is significantly affected by cross-border trade, and (2) by an operational situation (normal N or contingency cases N-1, N-2; depending on the TSO's risk policies). The critical network elements are selected by the respective transmission network operators in the context of the FB parameter calculation. In addition, there is an automated process as part of the FB parameter qualification phase, which suggests network elements whose PTDFs exceed a certain threshold as critical. Transmission system operators make the first selection of critical network elements when the joint network model is created, based on the TSOs' experience. This selection is executed with regard to two aspects: on the one hand, critical elements are selected that must be monitored when setting remedial actions (see Chapter 2.1.1.3); on the other hand, elements are selected that are relevant for cross-border trade. If both directions of a line are to be monitored, two critical network elements must be defined.

A critical network element (CB, CBCO)

... is a network element that is severely affected by cross-border trade and is monitored under certain conditions. Critical network elements are determined by each TSO for their own networks and are defined (1) by a network element (line, transformer,...) that is significantly affected by cross-border trade, and (2) by an operational situation (e.g. N-1, N-2,...).

As part of the FB parameter qualification phase, critical network elements are automatically preselected using a 5% threshold. This 5% threshold is based on the so-called zone-to-zone PTDFs. While zone-to-slack PTDFs describe the influence of the change in the net position of *one* bidding zone on the respective critical element (the opposite change can occur anywhere in the network and is not further defined) [9], the zone-to-zone PTDFs take into account the change in net positions of two bidding zones on the critical network element. For example, if the net position of bidding zone A changes by 100 MW, this would have an impact on CBCO 1 of 2 MW (zone-to-slack PTDF 2%). The opposite change in the net position of bidding zone B by -100 MW changes the flow on the CBCO by 4 MW (zone-to-slack-PTDF -4%). Although both changes in net position would not reach the threshold, the zone-to-zone PTDF exceeds the threshold by 1%. As part of the expansion of FBMC to the CORE region, an analysis of this 5% threshold including a possible adjustment is planned (Amprion, et al., no date). The respective transmission system operators can add or remove critical network elements based on their experience.

As part of the presolving process, redundant network elements are removed after the final FB parameter calculation (see Chapter 2.1.1.3) (there are other critical network elements that restrict the solution space more).

While the parameters of the FB domain are quite clearly defined, the process of calculating these parameters is complex and sometimes difficult to follow.Figure 4 gives an overview of the process sections in which the input parameters are set. The individual parameters are explained in detail in the following chapters.

[8] In the current documentation regarding the expansion of FBMC to the CORE region, critical network elements are referred to as CNECs (critical network element and contingencies).

[9] The sum of the net positions must always be zero. If the net position of a bidding zone changes, the same change with the opposite sign must take place somewhere in the network.

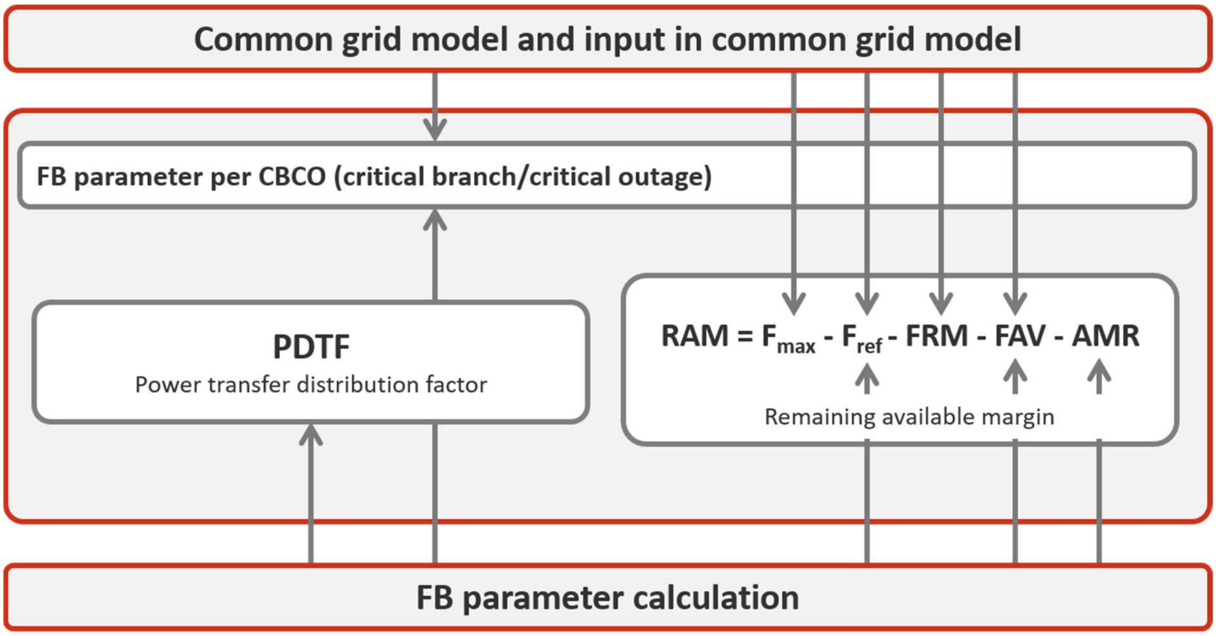


Figure 4: FBMC process, assignment of input parameters to the process sections of the pre-coupling; source: own representation

2.1.1.2 Creating the base scenario for the electricity grid in the common grid model (CGM)

Base scenario in the common grid model (CGM), merged D-2CF

...is a forecast for the state of the electricity grid on day D, which is created two days before delivery (D-2).

The base scenario (base case) or "day-2 congestion forecast" (D-2CF) is a forecast for the state of the electricity grid on day D (i.e. at the time of the actual delivery), two days before the delivery day is created (D-2). The base case is determined in two main steps: first, every transmission system operator estimates the local D-2CF for their network area. This is based on a reference day from the past with similar system conditions (e.g. weekday/weekend, winter/summer), which is then updated with forecasts for renewable generation, load forecasts, performance of the current generation units, and outage planning for generation units and network elements. This step results in an inevitable circularity in the FBMC process: based on expected generation, among other things, TSOs create the possible solution space as input for the following market coupling process. Producers and traders then submit their orders according to their expectations. These expectations are usually fed by available market information, including data provided by TSOs in the FBMC process.

Second, the various local D-2CFs are merged into a common base case, the so-called common grid model (CGM). This process is executed on behalf of transmission system operators by a so-called merging agent. External CWE borders are respected by means of the respective DACFs (day-ahead congestion forecasts).

Input for the CGM: file with critical network elements (CB file)

The respective transmission system operators create the so-called CB file (“file with critical network elements”) as input to the CGM. To do this, transmission system operators must select possible critical network elements two days before delivery and set the parameters determined for them. However, the selection of critical network elements can be modified at various points in the subsequent process. The parameters to be set in the CGM, among others, include:

- **I_{max}**, maximum possible flow, thermal limit in amperes; specified seasonally (weather conditions); not reduced by a safety margin
- **F_{max}**, maximum possible flow in MW
- **FRM**, flow reliability margin; security framework to take into account the simplifications/approximations of the FBMC process. According to the current CWE-FBMC documentation, this security framework is between 5% and 20% (Amprion, et al., 2019) of F_{max} (both positive and negative possible) and is determined with the help of statistical evaluations. Transmission system operators validate this value, which is set automatically, and can adjust it if necessary (a change must be reported to the respective regulatory authority). The FRM is set at least once a year and in the event of unusual occurrences (such as a bidding zone split, the inclusion of a new bidding zone, etc.)

Flow reliability margin (FRM)

...is a security framework to ensure network stability despite possible forecasting errors and uncertainties in the FBMC system.

The zonal FBMC is only an approximation of the real physical properties of the electricity grid. On the one hand, there is a loss of accuracy due to the grouping of nodes into zones. On the other hand, transmission system operators protect themselves against D-2 forecast errors: the use of a linear network model with partially simplifying assumptions about the topology, specific forecasts for the feed-in of renewable energy sources, and unintentional deviations due to load frequency control naturally lead to uncertainties.

Additionally, the GSKs (generation shift keys), with which the nodal PTDFs are converted into zonal ones, are based on forecasts of the market result, since the actual market result at time D-2 is not yet known. There are also simplifying assumptions about transactions that take place beyond the CWE area. These simplifications lead to deviations between the flows calculated as part of FBMC and the actual flows in the network. To compensate for these uncertainties, the transmission capacity available to the market is reduced by a **security framework, the flow reliability margin (FRM)**.

Input for the CGM: external constraints (EC)

External constraints describe limitations of the solution space, which cannot be associated with individual critical network elements or cannot be efficiently represented as maximum flows on the critical network elements. This includes import or export constraints that are necessary to ensure secure network operation. In contrast to the flow reliability margin (FRM), these constraints are not based on analyses of the past, but on evaluations by transmission system operators regarding future possible critical situations that would endanger network security, e.g. voltage drops or stability problems. External constraints are summarised in the published data in the JAO utility tool under the heading “Critical Network Elements”; they are identifiable by the PTDFs, which have the value 0 for all bidding zones and the value -1 or 1 for the bidding zone concerned. The indicated RAM represents the import or export constraints.

External constraints are not set daily (or even hourly), but are constraints that exist regardless of the current operating conditions. In case of an external constraint hampering the market, the respective constraint receives a shadow price. This shadow price is announced to the respective regulator as part of the monitoring. At the time of reporting, the publicly available documentation did not indicate at what point in the pre-coupling process the external constraints were used.

An example of an external constraint is given in the CWE-FBMC documentation from 2011 (Amprion, et al., 2011), where the Belgian transmission system operator Elia sets an import limit of 4,500 MW in order to ensure network security. According to the current CWE-FBMC documentation (Amprion, et al., 2019), APG does not use any external constraints. Germany has not used external constraints since the German/Austrian bidding zone split.

Output of the CGM: reference flow per critical network element (F_{ref})

The reference flow per critical network element for the base case in MW, F_{ref}, describes the current flow of the respective reference day. These commercial transactions can be internal (within a bidding zone) or external (between bidding zones). This flow changes in the course of the capacity calculation process. While the term F_{ref} (partly as F_{ref}' or $F_{ref}*$) is still used throughout the CWE documentation ((Amprion, et al., 2019), (Amprion, et al., 2011)), the distinction in the description of the FBMC method for the CORE region is already clearer and refers to F_i or F_{LTN}. This distinction is helpful for the transparency of the process.

Merging into a common base scenario (common base case) is not a fully automated process, but involves a quality check by individual transmission system operators. As part of this so-called prequalification, transmission system operators can already set remedial actions (RA), also referred to as D-2 remedial actions (for explanations on RAs, see below).

The majority of the parameters relevant to the result are determined and their scales already defined at this point, i.e. when calculating the base case. This allows initial conclusions to be drawn about the high relevance of the base case for the results of market coupling.

2.1.1.3 Process for creating the solution domain of the FB domain

Figure 5 describes the mutual interaction between transmission system operators and the joint TSO pre-coupling system. The latter calculates the FB domain (RAM and PTDFs) and sends the (preliminary) results to participating transmission system operators. They check the results with regard to network security and a possible enlargement of the FB domain, and make adjustments where possible/necessary. The six most important process steps are described in more detail below.

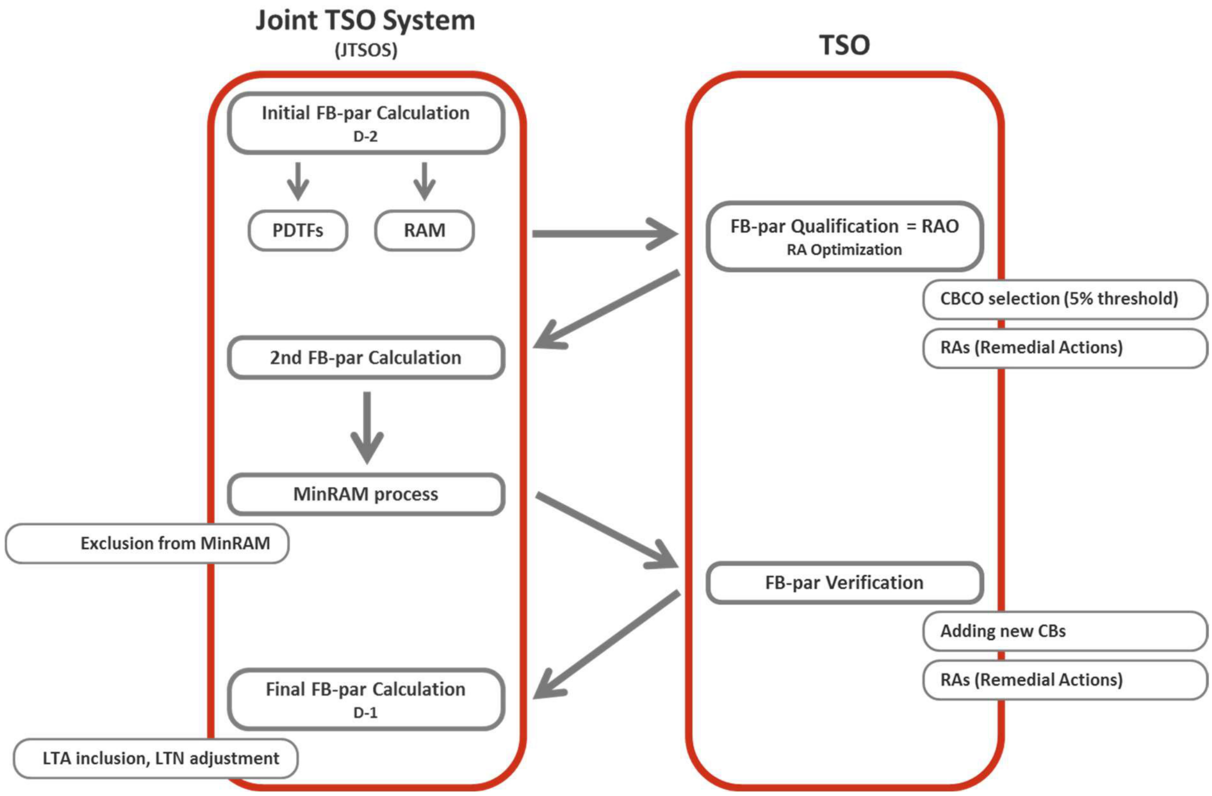


Figure 5: FB parameter calculation process; source: own representation

Phase 1: first FB parameter calculation

Based on the CGM, the first calculation of FB parameters is performed. The output is the first version of PTDFs and the RAM for each critical network element.

Phase 2: optimising the solution space of the FB domain in the qualification phase (remedial action optimisation, RAO)

The aim of the FB parameter qualification phase is, on the one hand, **to update the selected critical network elements**. They are automatically preselected based on a 5% threshold (PTDF of a bidding zone higher than 5%) and can then be adjusted by transmission system operators (by including a network element even if below 5%, or excluding a network element even if over 5%). See Chapter 2.1.1.1 for details.

On the other hand, the qualification phase aims at optimising cross-zonal capacity, i.e. increasing the capacity available for cross-border electricity trading while recognising local/national risk policies. Boosting the capacity is to be achieved through **remedial actions** (RA) on restricting (non-redundant) critical network elements. This process is executed locally by the respective transmission system operators.

According to (Amprion, et al., no date), remedial action optimisation (RAO) is an automated, coordinated, and reproducible optimisation process for the RAs set by individual TSOs. It is a physical property of the energy system that flows can only be re-routed and, therefore, a reduction in the flow on one network element automatically leads to an increase in the flow on one or more other network elements. The aim of the RAO process is to manage this trade-off.

Adjusting the solution space through remedial actions (RA)

Remedial actions describe the process of transmission system operators intervening and modifying the size of the available capacity. On the one hand, remedial actions serve to maintain network security (reduction of RAM, verification phase) and, on the other hand, to enlarge the FB domain (increase in RAM, qualification phase); by nature, there is always a certain trade-off between these two goals. Remedial actions within the FB parameter calculation are divided into explicit RAs and implicit RAs. Regarding the explicit RAs, three different blocks of measures can be set: (1) the position of the phase shifters, which should always be in a neutral position in the base case (exceptions are possible), is determined. (2) Measures relating to the network structure (topology measures), for example the opening or closing of a network element, are specified. (3) Redispatch actions, i.e. measures that either change the use of the power plant or the load pattern, are taken. Measures that cannot be assigned to explicit RAs are referred to as implicit RAs. They are represented as part of the FB process via the so-called **final adjustment value** (FAV) and are set by the respective transmission system operator for individual critical network elements (increase/reduction of RAM by x MW).

Remedial actions (RA)

...describe the process of transmission system operators intervening and modifying the size of the available capacity. They are divided into explicit and implicit remedial actions.

Final adjustment value (FAV)

Implicit remedial actions, i.e. RAs that cannot be assigned to any explicit measures, are represented via the FAV. The FAV has a direct influence on the RAM; this value is published for each CBCO in the JAO utility tool.

While implicit RAs are published in the JAO utility tool via the FAV for each critical network element, it is not obvious from the publicly available documentation whether and to what extent explicit RAs are reported. The documentation also does not clearly indicate which of the FB parameters are influenced by the explicit RAs. The structure of the process suggests that they have an impact on the base case and thus on F_{ref}, but the lack of documentation leaves some questions unanswered. With the possibility of transmission system operators influencing the available capacity and thus the potentially great importance of RAs on the result of market coupling, there is, at any rate, an increased need for information in the sense of transparency of market coupling.

Phase 3: second FB parameter calculation

After considering the changes in the framework conditions in the qualification phase, the FB parameters are recalculated.

Phase 4: adjusting the solution space through the MinRAM process (AMR)

The MinRAM process aims to ensure that a minimum of currently 20% of F_{max} (Amprion, et al., 2019) is provided for cross-border DA trading. An automated check is performed to determine whether the RAM available meets the previously specified value. If the RAM is below this value, it is corrected by the adjustment for minimum RAM value (AMR). Transmission system operators can exclude individual critical network elements in their bidding zone from this process. This can be done before the first FB parameter calculation: during the qualification phase, during the MinRAM process itself, and during the subsequent verification phase.

In June 2019, Directive EU 2019/943, Article 16 (8) stipulated an increase in the minimum RAM value to 70% for all critical network elements from 01.01.2020 (European Parliament and the Council, 2019). The Austrian transmission system operator APG, like other TSOs, has submitted an application for an exemption under Article 16 (9) (CCR Core TSOs' Cooperation, 2019). This application will be decided by national regulatory authorities in coordination with other regulatory authorities concerned. In the event that regulators fail to reach an agreement, the decision is forwarded to the Agency for the Cooperation of Energy Regulators (ACER). This exemption can be granted for one year, in exceptional cases for a maximum of two years. The reason for applying for exemption is mainly the short lead time (June 2019 to January 2020) and the resulting lack of adequately tested calculation tools and processes.

Phase 5: verifying the FB parameters

The aim of the FB parameter verification phase is to check whether network security is ensured with the given FB parameters. The FB domain is usually reduced in size during this phase. The process is executed locally by the respective transmission system operators. They can make changes in the CB file by adding new critical network elements, setting RAs, or reducing F_{max} ((Amprion, et al., 2011); (Amprion, et al., 2019)).

Phase 6: final FB parameter calculation

During the final calculation of FB parameters, the following adjustments take place in the morning D-1:

Extension by long-term capacities (LTA inclusion)

LTA inclusion refers to a step of extending the FB domain using virtual FB parameters in such a way that long-term allocated capacities are covered in any case. This action is implemented automatically at the end of the capacity calculation process (shortly before adjusting to LT nominations, LTN), if some parts of the FB domain are exceeded by long-term allocated capacities. This is to avoid that the realisation of long-term transmission rights would lead to overloads on flow-based critical network elements, and it ensures that the RAM of each critical element remains positive.

Theoretically, this artificial extension of the FB domain contradicts the basic concept of Flow-Based Market Coupling: the FB domain provides the reference in terms of security of supply, and TSOs have a number of measures available within the capacity calculation process to enlarge this domain or counteract congestion on individual network elements. The need in practice for this extension is explained in the annex to the CWE-FBMC documentation, "Annex regarding the LTA inclusion check and domain adjustment" (Amprion; APG; creos; elia; hertz, 50; Rte; TenneT; BW, Transnet, no date), and attributed to the linearity of the flow-based capacity calculation model. Hence, complex operating conditions are not always reproducible. From the traders' point of view, however, long-term capacity products are an important instrument for hedging.

Adjusting the solution space in terms of actual long-term nominations (LTN adjustment)

F_{ref}, the reference flow in the base case, reflects the utilisation of critical network elements based on the selected reference day. This reference flow is adjusted at this point so that only long-term nominations (LTN) actually made are taken into account. Import/export balances are set at the level of the net nominations of long-term products for the boundaries of the bidding zones with physical transmission rights (Amprion, et al., no date). A schematic representation of the effect of this adjustment is given inFigure 6. In addition, external constraints are adjusted so that the boundaries provided for the market coupling mechanism relate to the net positions resulting from LTN.

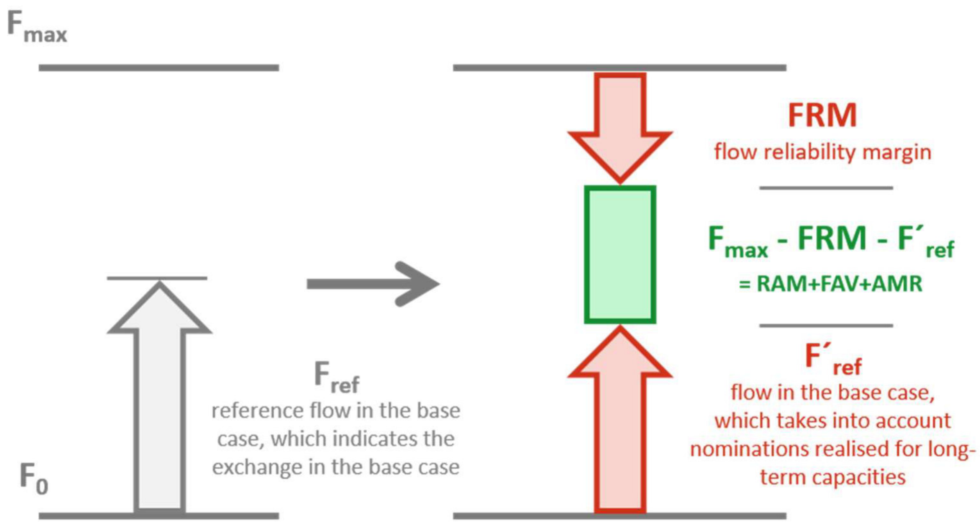


Figure 6: Changing F_{ref} through LT adaptation, schematic representation; source: own representation based on CWE-FBMC documentation 2011 (Amprion, et al., 2011)

Validating FB parameters the day before (D-1)

As stated in the CWE-FBMC documentation 2011 (Amprion, et al., 2011), this is a pure plausibility check (e.g. compliance with the file format). Capacities can no longer be changed at this point.

According to the CORE methodology description (Amprion, et al., no date), both FAVs and ECs can be set as part of the validation. This leads to the calculation of the final FB parameters being performed again.

Removing non-restrictive network elements (presolve)

In this step, non-restrictive network elements are removed in order to reduce the number of constraints for the market coupling algorithm. By adhering to the presolved domain, all other constraints are automatically maintained. This presolving step is also used in earlier phases of the process (FB qualification and FB verification).

2.1.1.4 Representing the final solution space: the FB domain

Figure 7 describes the relationship between various parameters. The x-axis shows the net position of the bidding zone z (NP_z); the y-axis illustrates a selected critical network element i. $F_{max,i}$ describes the maximum possible flow on the selected network element; this is reduced by the safety margins FRM and FAV. F'_{ref} represents the utilisation of the network element through nominated long-term contracts. RAM_i depicts the capacity available for the DA market. The straight line $PTDF_{z,i}$ shows how the utilisation of this capacity of i changes when the net position of z changes.

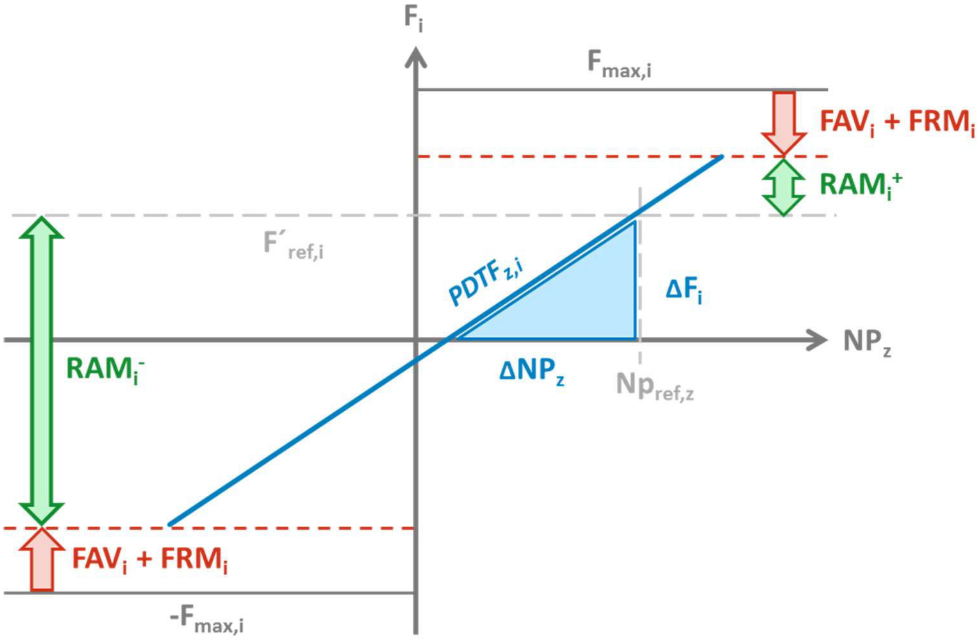


Figure 7: FBMC parameters and their relationships; source: own representation based on (Schönheit, et al., 2020)

The possible solution space for market coupling (FB domain) is defined using FB parameters (RAM and PTDFs). Each limit of this solution space is specified by a critical network element. The permitted commercial export or import between two bidding zones in this solution space is therefore dependent on trade between the other bidding zones.

The two-dimensional example[10] here shows how the FB domain is created.Table 2 illustrates FB parameters for the exemplary bidding zones A and B. For the sake of simplicity, it is assumed that the available RAM on all critical network elements is 100 MW. The specified PTDFs highlight how the flow on a critical element changes when the net position of a bidding zone changes. For instance, if the net position of bidding zone A changes by +1 MW, the utilisation of line A>C changes by 0.67 MW. Assuming that the net position of the other bidding zone is zero, the following applies: to ensure that the RAM, i.e. the capacity of the network element A>C available for DA trading, is not exceeded, the net position of bidding zone A may change by a maximum of 100 MW/0.67=149.25 MW (intersection of line A>C with the y-axis inFigure 8). The net position of bidding zone B may change by 100 MW/0.33=303 MW in order to avoid exceeding the RAM of line A>C (theoretical intersection of line A>C with the x-axis).

The constraints represented inFigure 8 shows the maximum of possible changes in the net position of individual bidding zones [$NP(A)_{max}$=200, $NP(A)_{min}$=-200)] as well as all other possible intersections of critical network elements.

[10] based on (Energinet_DK, et al., no date)

Table 2: Example representation of the FB domain; source: own representation

CBCOs	FB parameter		
	RAM in MW	PTDFs	
		A	B
A>B	100	0.33	-0.33
B>C	100	0.33	0.67
A>C	100	0.67	0.33
B>A	100	-0.33	0.33
C>B	100	-0.33	-0.67
C>A	100	-0.67	-0.33

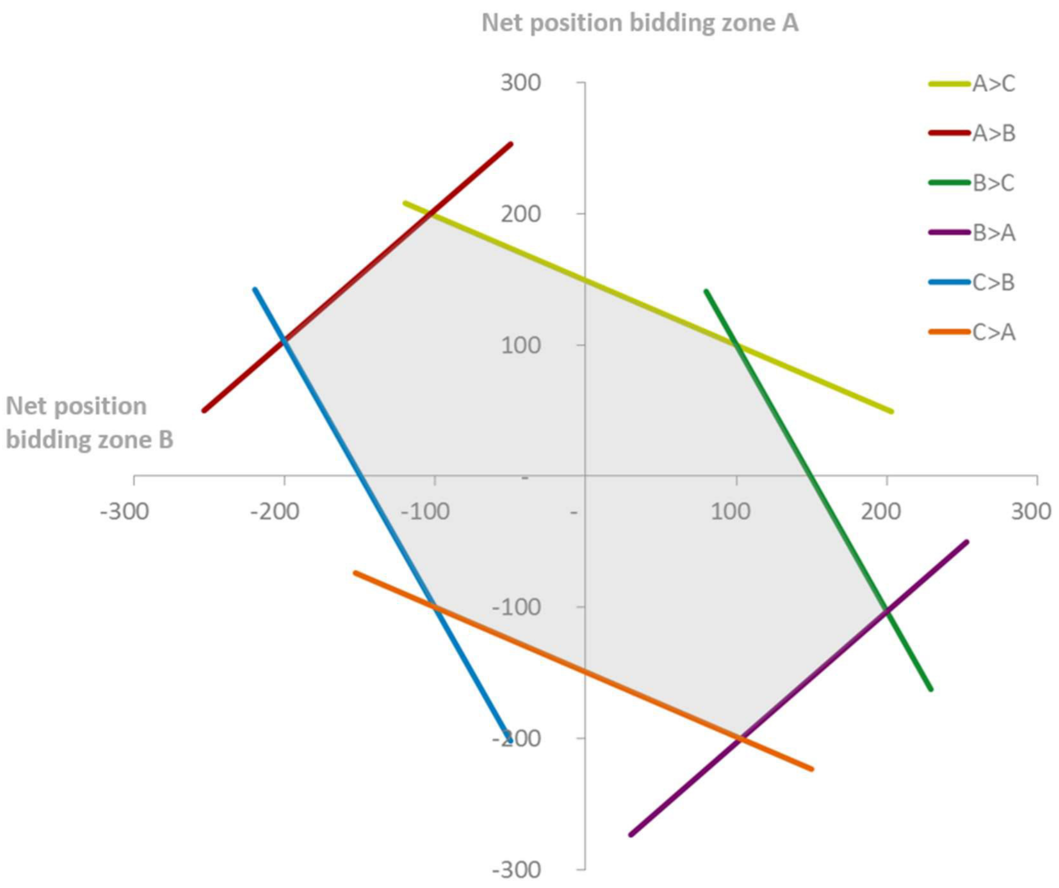


Figure 8: Example representation of the FB domain; source: own representation

2.1.2 Conclusion FBMC

Transparency in the Flow-Based Market Coupling process is not only necessary for the current CWE-DA trade. It is generally gaining in importance, as on the one hand, this trade is to be extended to the CORE region and on the other hand, the FBMC concept is to be expanded for intraday trading.

Flow-Based Market Coupling is not a single process, but an extensive process chain. Numerous tools are used in an iterative process flow in which the respective transmission system operators provide input and make changes at various points. Several processes are performed automatically, but there are exceptions for each of these automated calculation steps. Taking empirical values of TSOs into account is essential to ensure network security, but it makes it very difficult for outsiders[11] to understand the calculation. On the one hand, this explains the need for clear and comprehensible documentation of the processes and, on the other hand, underlines the importance of independent and simple performance monitoring.

Complete data provision in all process steps is made even more challenging because the underlying data are (argued to be) part of corporate and business secrets (e.g. GSKs). In addition, the electricity grid is a critical infrastructure worth protecting, which can also legitimately restrict transparency under certain circumstances.

While researching for the representations included in the previous sections, a number of challenges and problems occurred with regard to the available documentation. These include, for example, the difficulty of finding information, unclear structuring, or missing versioning, dates and the like. A more in-depth problem analysis can be found in Chapter 0, which is an essential result of the present study.

This is all the more important, given that transparency not only means providing information, but also doing this in a way so that interested outsiders can find it in reasonable time (i.e. avoiding pseudo-transparency).

For further reading and deeper insights into the subject of FBMC, see the literature recommended in Annex 2.

[11] Outsiders are defined as market participants, market observers, consultants, researchers, etc. who are not directly and personally involved in the process of drafting the relevant market rules, codes, regulations, etc. such as TSOs and regulator staff.

2.2 Economic incentives in cross-border capacity management

Cash flows, both costs and revenues, arise for transmission system operators in the context of Flow-Based Market Coupling – in addition to the costs for setting up and operating the process flow – mainly through congestion management methods. The proceeds from cross-border capacity management, the so-called congestion income (or congestion rent), are on the income side. These revenues are offset by the costs that arise either directly or indirectly from taking measures in the context of congestion management.

Figure 9: Cash flows in Flow-Based Market Coupling; source: own representation

The term congestion management is used to describe all measures taken by transmission system operators to avoid or eliminate network overload caused by congestion. Congestion can occur both at cross-border interconnections and within a bidding zone. Congestion management methods include a wide range of possible interventions in the market-based allocation of cross-border capacities as well as in the market-based use of power plants, such as:

- Measures regarding the network topology
- Control of the phase shifters
- Redispatching
- Countertrading
- Determining the final adjustment value as part of setting FBMC parameters

These congestion management methods are set by the transmission system operator at different times in the Flow-Based Market Coupling process. Some of them (e.g. redispatching) can be initiated in the entire process, i.e. already when calculating FB parameters or even when eliminating congestion in the short-term. Others are only set in certain periods of time, e.g. countertrading merely at short notice, setting of the final adjustment value solely in the context of the FB parameter calculation. By definition, however, network topology measures can only be taken on a long-term basis.

In the following chapters, the cost-intensive measures for short-term congestion management – redispatching and countertrading – will be discussed. The Regulation of the European Commission establishing a Guideline on Capacity Allocation and Congestion Management (European Commission, 2015), hereinafter referred to as the CACM Guideline (EU 2015/1222), instructs transmission system operators to take coordinated measures such as redispatching and countertrading in order to avoid both cross-zonal and internal congestion:

(10) The TSOs should use a common set of remedial actions such as countertrading or redispatching to deal with both internal and cross-zonal congestion. In order to facilitate more efficient capacity allocation and to avoid unnecessary curtailments of cross-border capacities, the TSOs should coordinate the use of remedial actions in capacity calculation.

The aim of this chapter is to compare the data flows presented in Chapter 2.1 with the cash flows arising in the market coupling process and to analyse them with regard to the resulting incentive structure.

2.2.1 Redispatching and countertrading (congestion management costs)

In the context of Flow-Based Market Coupling, in addition to the costs for the operation and the expansion of the market coupling process, there are, above all, costs for redispatching and countertrading measures. According to the Regulation on the Internal Market for Electricity (EU) 2019/943 (European Parliament and the Council, 2019), hereinafter referred to as the Internal Electricity Market Regulation (EU 2019/943), these are defined as follows:

- **Redispatching**: means a measure, including curtailment, that is activated by one or more transmission system operators or distribution system operators by altering the generation, load pattern, or both, in order to change physical flows in the electricity system and relieve a physical congestion or otherwise ensure system security;
- **Countertrading**: means a cross-zonal exchange initiated by system operators between two bidding zones to relieve physical congestion;

Redispatching can be used throughout the entire FBMC process flow – at the beginning while creating the common network model up until the point of eliminating short-term congestion. In contrast, market-based countertrading is a short-term measure to combat network congestion. Transmission system operators purposefully buy electricity on the intraday market to counteract the original flow and relieve the network.

Article 73 of the CACM Guideline (EU 2015/1222) obliges the TSOs of a capacity calculation region to develop a method for the coordinated process of redispatching and countertrading. According to Article 74 of the CACM Guideline (EU 2015/1222), all TSOs in the respective capacity calculation region should create a common cost-sharing method for redispatching and countertrading. This method includes measures of cross-border relevance and must be compatible, among other things, with the method for distributing the congestion rents. The Internal Electricity Market Regulation (EU 2019/943) also refers in Article 16 (4) to the use of coordinated and non-discriminatory redispatching and countertrading to maximise available congestion capacities. Transmission system operators in the CORE region have submitted a joint proposal for a method for coordinated redispatching and countertrading as well as for a joint cost-sharing method for both measures at ACER. ACER will decide on this proposal by 27 September 2020[12].

2.2.1.1 Congestion management costs in the CWE region

Congestion management costs, more precisely the costs for redispatching, countertrading, and "other costs", are published on the ENTSO-E transparency platform. For the CWE area, data are provided for Austria, Germany, France, and Belgium. For Belgium, only data from January 2019 are available. With the exception of May 2016, no congestion management costs are reported for the Netherlands. Regarding these costs, it must be noted that they do not only include congestion management costs in the context of Flow-Based Market Coupling, but all congestion management costs of the respective control area.

Figure 10 highlights the sum of the congestion management costs over the period from January 2015 to February 2020 for the four control areas considered. On average over all years, there are a total of approximately 1,054 million euros in congestion management costs. Germany has by far the highest costs (right axis), which is

[12] Source: https://www.acer.europa.eu/Media/News/Pages/ACER-to-decide-on-methodologies-for-the-coordination-and-sharing-of-cost-of-redispatching-and-countertrading-electricity-in.aspx; accessed 16 April 2020

due to the gradual phase-out of nuclear energy, the high proportion of fluctuating renewable energy sources (BDEW Bundesverband der Energie- und Wasserwirtschaft e.V., 2019), and a lack of line capacity in the north-south direction. A large part of the costs is borne by the transmission system operator TenneT. Austria has more costs particularly during the summer months due to a greater use of thermal capacities for redispatching, while in Germany, the raised costs in winter are due to a stronger demand for electricity, as well as the high wind feed-ins in the north and the low PV feed-ins in the south (BDEW Bundesverband der Energie- und Wasserwirtschaft e.V., 2019).

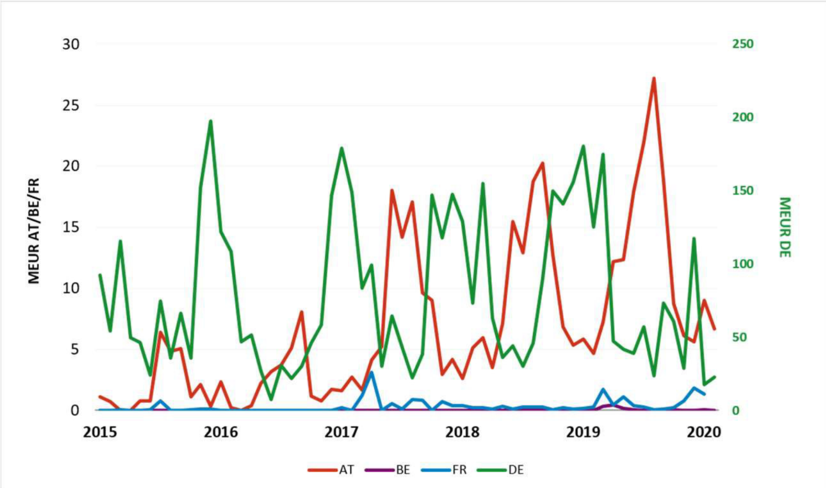


Figure 10: Congestion management costs, 2015–2020, Austria, Germany, Belgium, and France; source: own representation based on ENTSO-E

The use of methods for congestion management varies depending on the control area.

Figure 11 andFigure 12 provide an overview of the costs incurred – for better comparability per TWh network load – over the course of 2015 to 2019 by control area. Redispatching costs are mainly reported by Germany and Austria. At the beginning of the observation period, these are significantly higher in Germany in relation to the network load than in Austria. In 2019, Austria reported higher relative redispatching costs for the first time. This underlines the growing importance of transparency, also for the cash flows associated with FBMC.

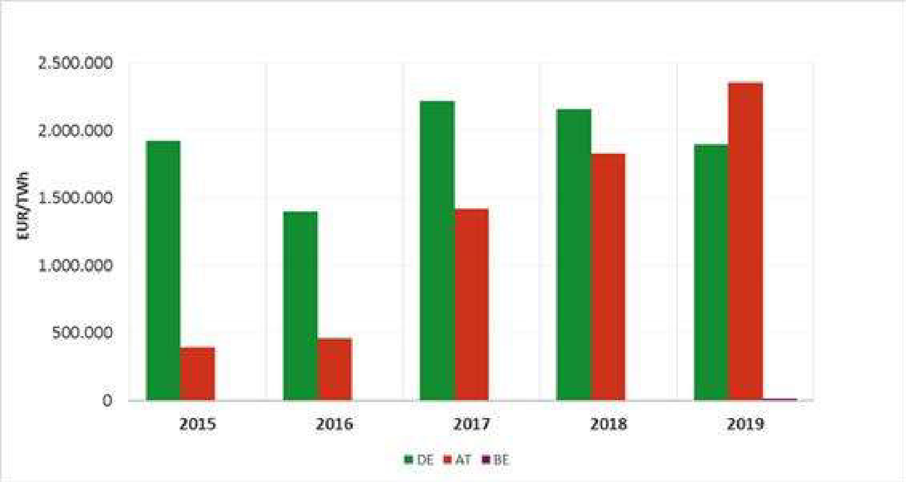


Figure 11: Redispatching costs per TWh network load, 2015–2020, Austria, Germany, Belgium; source: own representation based on ENTSO-E

Countertrading costs were only reported for Germany and France for the observation period.Figure 12 illustrates the costs incurred in relation to TWh network load in the respective control area.

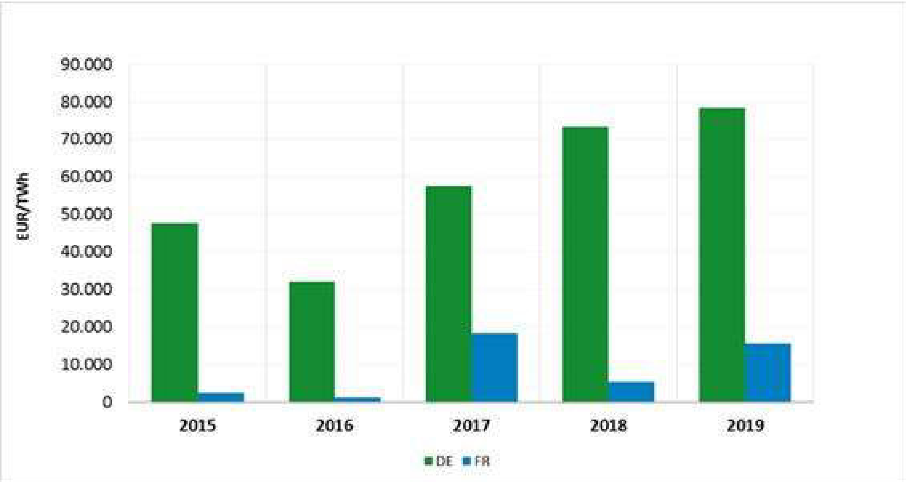


Figure 12: Countertrading costs per TWh network load, 2015–2020, Germany, France; source: own representation based on ENTSO-E

The Austrian transmission system operator APG only accrues redispatching costs and no countertrading costs from 2015 to February 2020[13]. Figure 13 reveals the monthly redispatching costs for the years 2015 to 2019. A total of around 149 million euros was incurred for redispatching measures in 2019.

[13] source: https://www.apg.at/de/markt/Markttransparenz/Uebertragung/Engpassmanagementkosten; accessed 10 April 2020

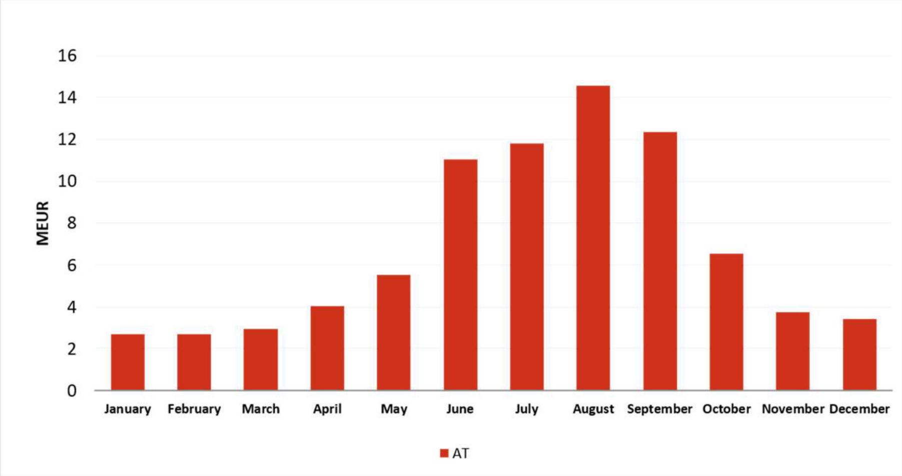


Figure 13: Average redispatching costs of APG per month, 2015–2019; source: own representation based on ENTSO-E

Overall, the situations with regard to redispatching and countertrading in the individual countries of the CWE-FBMC are difficult to compare due to the different starting conditions. While there are hardly any costs for redispatching and countertrading in France and Belgium, those costs are a major factor in Austria and Germany with over 2 million euros/TWh network load. In France, the low congestion management costs are due to the traditional generation structure (central producers, base load). In contrast, the rapid expansion of decentralised generation plants in Germany has led to a coordination problem between investments in generation plants and network infrastructure, which is reflected in higher costs for congestion management. In Austria, congestion management costs are particularly incurred from June to September, i.e. especially in those months in which the price differences between Austria and Germany in FBMC are small.

2.2.2 Congestion income

The costs for redispatching and countertrading are offset by the income from cross-border congestion management. According to the CACM Guideline (EU 2015/1222), these are defined as follows:

- **Congestion income**: means the revenues received as a result of capacity allocation;

The theory of congestion income and its influence on social welfare in cross-border trade is explained in more detail in Chapter 0.

Transmission system operators may not only allocate congestion capacities on the day-ahead market, but also through long-term allocation or on the short-term intraday market. Long-term, i.e. monthly or yearly, auctions are handled by the Joint Allocation Office (JAO). In addition, the external borders that do not participate in DA market coupling (Czech Republic, Hungary, Switzerland) are also processed via the JAO. The allocation of capacity for the intraday market takes place depending on the border via XBID (Czech Republic, Hungary, Slovenia, and Germany), via the JAO (Italy) or is handled by the APG itself (Switzerland). Table 3 gives an overview of the allocation of cross-border capacities in the APG control area according to the time scale of the allocation and according to border. Cross-border capacities in the context of market coupling are implicitly allocated. Auctions via the Joint Allocation Office concern the explicit allocation of cross-border capacity.

Table 3: Overview of allocation of cross-border capacities Austria, according to time horizon and border with the APG control area; source: own representation based on https://www.apg.at/en/markt/Markttransparenz/Uebertragung/Allokationen

Time scale of the allocation	Border with the APG control area (export/import)					
	Czech Republic	**Hungary**	**Slovenia**	**Italy**	**Switzerland**	**Germany***
Long-term (yearly & monthly)	Joint Allocation Office (JAO)					
Daily (day-ahead)	JAO		Market coupling		JAO	Market coupling
Intraday	XBID			JAO	APG	XBID

* Capacity allocation on this border was introduced on 01.01.2018.

For **day-ahead and intraday market coupling**, Article 73 of the CACM Guideline (EU 2015/1222) obliges TSOs to draw up a proposal for a method for **distributing the congestion income** to the participating bidding zones in the respective capacity calculation region. In August 2016, the TSOs submitted the first proposal for sharing the congestion income. On being required to insert certain changes, the TSOs worked out a modified proposal by April 2017. After the regulators had ultimately been unable to reach an agreement with the TSOs, they passed the proposal on to ACER in June 2017. In December 2017, ACER issued a decision on the distribution of the congestion income of the DA market (ACER, 2017) and the corresponding method in Annex I (ACER, 2017).[14] This decision of ACER including the corresponding methodology applies to the CORE region. The current method for dividing the congestion income in the CWE area was not found to be publicly accessible.

The methodology for the CORE region has three levels: in a first step, the congestion income is defined and collected for each capacity calculation region. The congestion income of the region is then distributed to the bidding zone borders. In the last step, the income per bidding zone border is divided between the TSOs with cross-border interconnections at these borders.

The regional allocation of the congestion income is important, among other things, as the congestion income of the DA market also includes the congestion income of non-nominated, i.e. long-term, transmission rights available to DA trading. Requirements for the TSOs with regard to coordination, stability, and remuneration of long-term capacities as well as the sharing of associated costs are defined at the level of the capacity calculation regions. The distribution of the congestion income must therefore be regulated at the same level. The final congestion income allocated to each TSO consists of the calculated congestion income less the cost of remuneration for long-term transmission rights, to be paid in accordance with Article 61 of the Guideline on Forward Capacity Allocation (FCA Regulation) (European Commission, 2016). This reduction only extends to the cost of remuneration for those long-term transmission rights that were made available to the DA market.

The congestion income is calculated as the absolute value of the product of the trade flow and the price difference between two bidding zones. The absolute value guarantees that even bidding zones with a negative price difference, i.e. with non-intuitive exchange (flow from the expensive to the cheap bidding zone), receive congestion income. This is justified on the assumption that these non-intuitive flows are executed with the objective of maximising welfare throughout Europe.

[14] source: https://acer.europa.eu/en/Electricity/MARKET-CODES/CAPACITY-ALLOCATION-AND-CONGESTION-MANAGEMENT/IMPLEMENTATION/Pages/POST-COUPLING-PROCESSES.aspx; accessed 17 April 2020

The breakdown between the TSOs at the bidding zone borders is based on a 50-50% split. In exceptional cases, TSOs can also agree on different distribution keys, such as based on ownership shares or investment costs.

The **use of the income** is specified in Article 19 of the Internal Electricity Market Regulation (EU 2019/943). The income from the allocation of cross-border capacity is to be used primarily for ensuring the actual availability of the allocated capacity or for maintaining or increasing cross-border capacities (Paragraph 2). Congestion income can be exploited to reduce network tariffs, if the primary objectives according to Paragraph 2 have been adequately met. The remaining income can be transferred to a separate internal account for future use for the above-mentioned purposes (Paragraph 3). In addition, transmission system operators are to develop a methodology for using the income for the purposes specified in Article 19 (2) and the conditions under which this income can be transferred to a separate internal account for future use for these purposes (Paragraph 4). A public consultation process is currently taking place regarding this method (see (All TSOs, 2020) and (All TSOs, 2020)). According to Article 19 (4), transmission system operators must submit the method adopted for the use of income to ACER by 5 July 2020.

2.2.2.1 Congestion income in Austria

Data on congestion income for the CWE area are published daily in hourly resolution in the JAO utility tool according to TSOs and bidding zones of the CWE region as well as on income of the external borders of the CWE region (without taking into account the remuneration for long-term capacities available to the DA market) (Joint Allocation Office, 2019). For Austria, this means that the congestion income of the APG, the bidding zone Austria (corresponding to those of the APG), as well as the congestion income of the Austrian borders with Italy and Slovenia can be found in the utility tool.

E-Control publishes an annual report on the revenue from congestion management[15]. The most recent report contains data from 2011 to 2016 inclusive (E-Control, kein Datum). There are no more recent data publicly available, which also consider the German-Austrian bidding zone split, at the time of the copy deadline of this report (June 2020). The congestion income published by E-Control includes not only that from FBMC, but the total congestion income of all markets (long-term to short-term) on all Austrian borders. The congestion income of the Austrian TSOs[16] amounted to 83.8 million euros in 2016. Of this, 75.7 million euros went to the APG, the rest to Vorarlberger Übertragungsnetz GmbH.

2.2.3 Conclusion economic incentives

Transmission system operators influence the Flow-Based Market Coupling process at various points. Even in the pre-coupling process, i.e. when determining the FB domain, TSOs are the decisive providers of information for calculating the input parameters in the EUPHEMIA market coupling algorithm: they create the network models, define the critical network elements, and repeatedly establish remedial actions or exceptions to the MinRAM process. In addition, TSOs also make decisions on redispatching and countertrading measures after the market coupling process (post-coupling). The cash flows described in Chapters 2.2.1 and 2.2.2 contrast with these massive possibilities of influence: TSOs are confronted with both costs and income from congestion management within the framework of Flow-Based Market Coupling. This dual function of the TSO as an essential data supplier in the FBMC process but also as an economic actor in the context of cross-border capacity management is one of the reasons for high transparency requirements in FBMC.

[15] see https://www.e-control.at/publikationen/publikationen-strom/berichte
[16] APG and Vorarlberger Übertragungsnetz GmbH

Capacity allocation

At the German-Austrian border, long-term auctions in the form of FTRs (financial transmission rights) are issued before DA market coupling. These FTRs do not authorise the physical use of the capacity, but are an instrument to hedge against price fluctuations. Within the scope of these FTRs, the TSO generates revenues from the allocation on the one hand. On the other hand, costs arise as soon as the price difference between Germany and Austria in the DA market exceeds the FTR price. The current methodology for distributing congestion income (ACER, 2017)[17] provides that income/costs from FTRs are borne by the same TSO as the revenues from congestion income in the DA market (see also Chapter 2.2.2). The interplay between these two markets and the resulting income and costs for the TSO make the allocation of capacities and the associated cash flows more complex. This underlines the need for transparency not only in the process of FBMC, but also with regard to the associated cash flows.

Investments

The interplay of the manifold income and costs of TSOs can lead to the optimal investment volume of individual TSOs deviating from the investment volume that would be optimal in terms of welfare in all of Europe.Figure 14 highlights the optimal investment volume (Q1) in network capacity taking into account social welfare, costs of investment, operation and maintenance, and losses. A simplified view[18] of the problem can be presented as follows:

Profit = (social welfare) - (investment volume) - (cost of operation and maintenance) - (cost of losses)

Social optimum occurs at the point where the marginal increase in social welfare is higher than the marginal increase in costs. The congestion income is offset against this optimum (dashed line inFigure 14). As can be shown with the help of a simplified representation inFigure 14, the maximum congestion income for the TSO may result from a different investment volume (maxEP). This abstract representation makes it clear that, at least in theory, congestion income decreasing with further network expansion can offer an incentive for individual TSOs to invest less in network expansion than would be the case when maximising welfare throughout Europe. Regulatory incentives that are relevant to individual TSOs in different regulatory systems (cost-plus regulation, etc.) and that can theoretically encourage to overinvest (gold-plating) are not considered here.

[17] Applies to the CORE region in the future, but not currently to the CWE region.
[18] Other aspects such as integration of renewables or increase in security of supply are not taken into account.

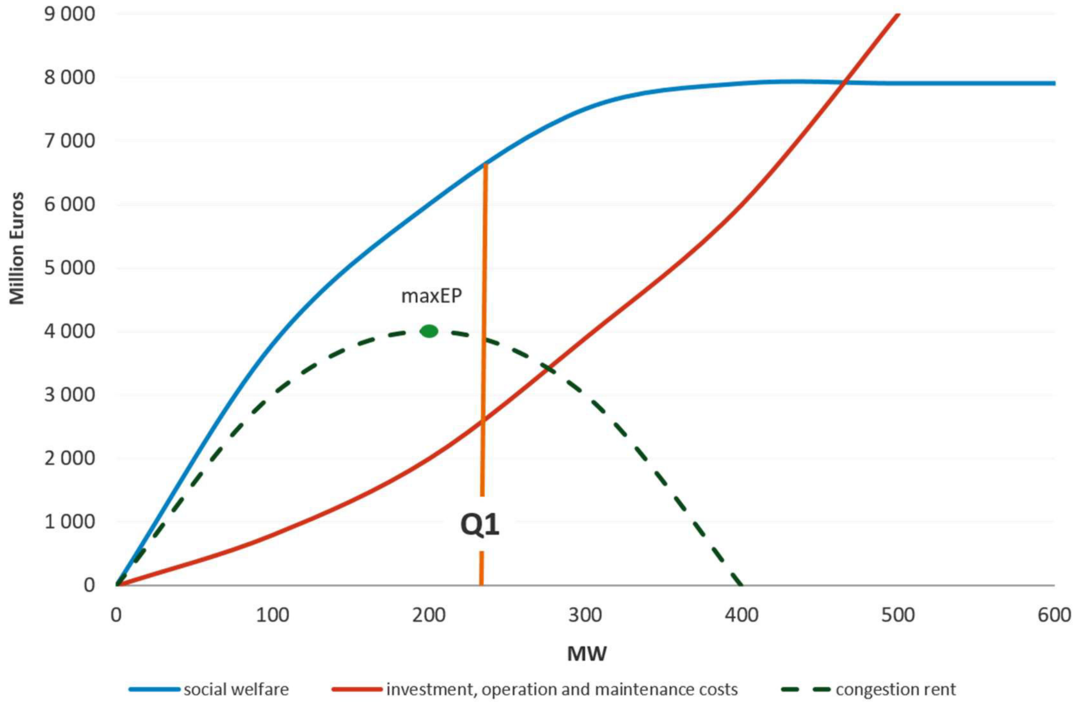


Figure 14: Optimal investment volume in network capacity; source: own representation based on (All TSOs, 2020)

Like the data flows, the cash flows in FBMC are characterised by a high level of complexity. Understanding the interaction of different markets and interests (e.g. pan-European versus national) is not trivial. Additionally, not all necessary data are published sufficiently and timely (e.g. congestion income). Comprehending cash flows generated in FBMC is currently not possible for outsiders or only with disproportionately high search and transaction costs. This in turn highlights the importance of enhancing transparency in electricity trading.

2.3 Functioning principles of EUPHEMIA

EUPHEMIA (EU Pan-European Hybrid Electricity Market Integration Algorithm) is the algorithm for calculating day-ahead prices for 25 European countries as part of single day-ahead coupling (SDAC). With an average daily turnover of around 200 million euros[19], EUPHEMIA is a central component of European electricity wholesale markets. For the calculation, EUPHEMIA collects all orders of all nominated electricity market operators (NEMOs), optimises the selection of orders, and thereby decides which ones are executed and which are rejected. The outcome reflects the set of executed orders – with the resulting flows and net positions – that

- maximises social welfare (generated by the executed orders) and
- corresponds to capacity restrictions specified by the TSOs.

The results are not only directly decisive for the day-ahead market, but also provide the basis for future/forward contracts and form the benchmark for all participants in electricity wholesale markets. In the following section, the functioning principles of EUPHEMIA are roughly outlined. After summarising the system boundaries of EUPHEMIA and the basic idea of welfare optimisation, the objective function of EUPHEMIA in relation to welfare optimisation is analysed. In the next step, the EUPHEMIA optimisation process is explained. The aim of this chapter is thus to outline the structure of EUPHEMIA and to describe the decisive process steps in more detail. For an exact description of the algorithm, the authors refer to the official documentation: "EUPHEMIA Public Description" (NEMO Committee, 2019).

2.3.1 Input and output of EUPHEMIA

For a better understanding of EUPHEMIA, the inputs and outputs are described first. The aim of this section is to indicate the environment of EUPHEMIA, while EUPHEMIA itself is considered a black box for the time being. This allows a more detailed description and an enhanced grasp of the calculations that take place within EUPHEMIA and the necessary process steps in the following sections.

Figure 15: Overview of the system boundaries of the EUPHEMIA optimisation algorithm; source: own representation

The inputs form the basis for the optimisation process and thus significantly determine the result (output). The orders, i.e. the willingness to trade, which is to be optimised, are introduced through the input. At the same time, the physical and organisational framework conditions are set. At this point, TSOs can insert their forecast for the grid status (CGM) as well as all balancing and congestion management methods for ensuring grid security. System boundaries specified by TSOs form the solution space available to the algorithm in order to find an optimal solution. EUPHEMIA optimises the result within this solution space defined by the input. The output of EUPHEMIA represents the result of the market coupling process.

[19] see http://www.nemo-committee.eu/sdac

The input can be roughly grouped in three categories:

- Orders
- Network topology
- Network data

The first category includes the orders. These range from simple hourly orders and block orders to complex and "Italian" orders. As shown inFigure 16, there are seven different order types. These types represent different physical (e.g. block orders) or regulatory requirements (e.g. PUNS, see Chapter 2.3.3.3), which reflect the needs of the stakeholders. The optimisation is executed by matching the supply and demand curves of individual bidding zones (more precisely NEMOs). The aim of the algorithm is to maximise the volume traded. The two categories of inputs on the network and network topology have a constraining effect. The latter is used to simulate the network of bidding zones and the corresponding interconnections. Bidding zones describe a geographically delimited area in which a uniform market price prevails. These areas are connected to one another by means of interconnections (cross-border lines). The resulting network model forms the basis for the optimisation process.

The input from the category "network data" then provides associated limit values for individual components of the network model. They represent physical and regulatory framework conditions, i.e. technical and regulatory limits that are used by the algorithm as limit values for the optimisation:

- **Losses:** Losses can (!) be ascribed to lines. When flowing through the line, the quantity of electricity is reduced by a factor.
- **Net positions**: Net positions describe the difference between import and export of a bidding zone. Maximum and minimum values can be assigned to the net position of each bidding zone.
- **Net position ramping**: The maximum temporal change in the net position can also be limited.
- **Remaining available margin**: free capacities of a network element (in FBMC)
- **Tariffs**: DC voltage cables operated by merchant companies can also be used for electricity trading. This can result in costs for the use of capacities.
- **Changes in the flow**: The rate of change in the flow can be subject to limits. These ensure that the load on individual elements of the network does not fluctuate too much. The limit can also be defined for a set of lines.
- **PTDF matrix**: matrix for converting net positions of bidding zones into resulting flows on individual network elements

A detailed description of individual inputs is available in (NEMO Committee, 2019).

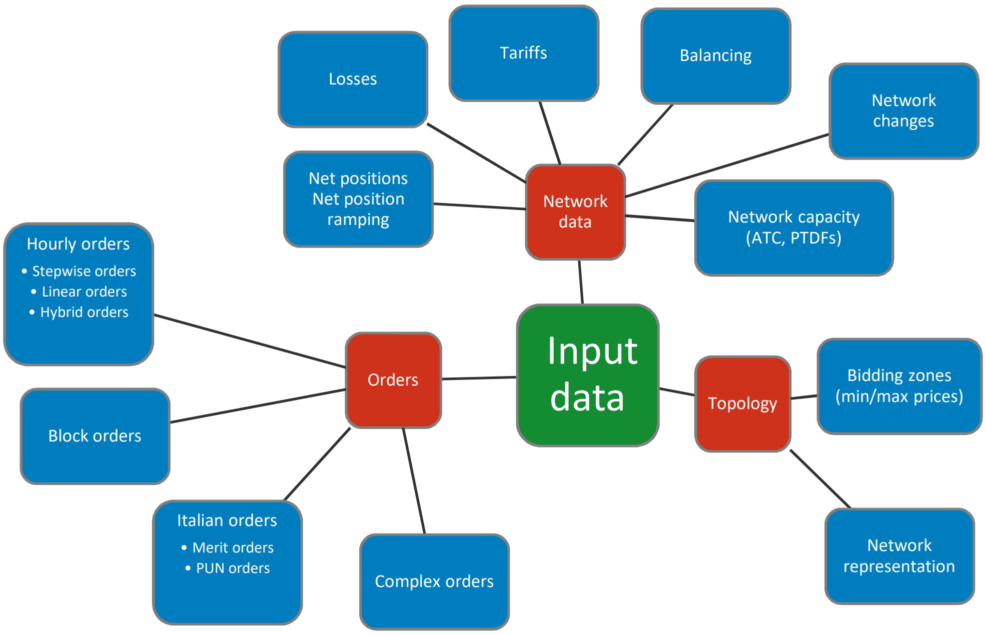


Figure 16: Input data EUPHEMIA; source: (Nside, 2016), own representation

The output of EUPHEMIA are four sets of results for all bidding zones and all hours of the following day:

- *one* market clearing price for each bidding zone
- the volumes matched
- net positions of bidding zones and resulting flows through interconnections
- a set with the selection of executed and rejected orders

2.3.2 Objective function and relationship to the concept of welfare

The objective criterion for the optimisation process is to enable the largest possible volume of trading transactions in SDAC. Within the optimisation problem, this objective corresponds to the maximisation of the entire surplus or “social welfare”, i.e. the sum of consumer surplus, producer surplus, and congestion income. The following shows how the basic objective function can be harmonised with the classic welfare concept. For a better understanding, a greatly simplified objective function is used below; the full formula is detailed inTable 6 in Section **Fehler! Verweisquelle konnte nicht gefunden werden.**. In principle, the number of executed orders is maximised in EUPHEMIA as follows:

$$\boldsymbol{max} \sum_{\boldsymbol{Bidding\ zones}} \sum_{\boldsymbol{Buy}} \boldsymbol{Volume} \cdot \boldsymbol{Price} \ \cdot \boldsymbol{Acceptance} - \sum_{\boldsymbol{Sell}} \boldsymbol{Volume} \cdot \boldsymbol{Price} \ \cdot \boldsymbol{accept}$$

in which "Acceptance" is the acceptance variable of orders (in the interval [0,1]). In principle, orders that are “in the money” are executed, i.e. those that can be fulfilled at market price (MCP, market clearing price).

In the case of an exporting bidding zone, meaning that there is an oversupply at market price, which is exported to another bidding zone, the components of the objective function can be represented as inFigure 17.

The theoretical basis behind the formulation of the optimisation problem is the welfare theory. According to this theory, the difference between a buyer's willingness to pay and the market price actually paid results in welfare gain, known as consumer surplus. This is offset by the producer surplus. The producer surplus is the difference between marginal costs and market price. When arranging quantities demanded according to decreasing willingness to pay and the quantity supplied according to increasing marginal costs, the result at the intersection is the equilibrium price (market price). For all buyers who are willing to pay more (inFigure 17 to the left of the intersection), the result is a surplus equal to their willingness to pay multiplied by the quantity demanded. For all producers whose marginal costs are below market price (inFigure 17 to the left of the intersection), there is a producer surplus equal to the market price achieved minus the marginal costs multiplied by the volume supplied. By adding up producer and consumer surplus, welfare gain created through trade is obtained. It should be noted that both further demand at a price higher than the equilibrium price and supply at a price below the equilibrium price lead to increased volumes traded and thus to welfare gains.

Usually, there are different prices in isolated electricity markets due to different supply and demand structures. Providing transmission capacities can therefore trigger more trade in that producers from submarkets with lower prices can export part of their supply to countries with higher prices. The quantity of the traded volume grows accordingly without changing the supply and demand curves. Assuming market-driven trade, overall welfare increases in both countries (Böhmer, 2015).

The aim of the algorithm is to optimise the use of cross-border capacities between all submarket areas so that the traded volume and thus the overall welfare are maximised under the given restrictions.

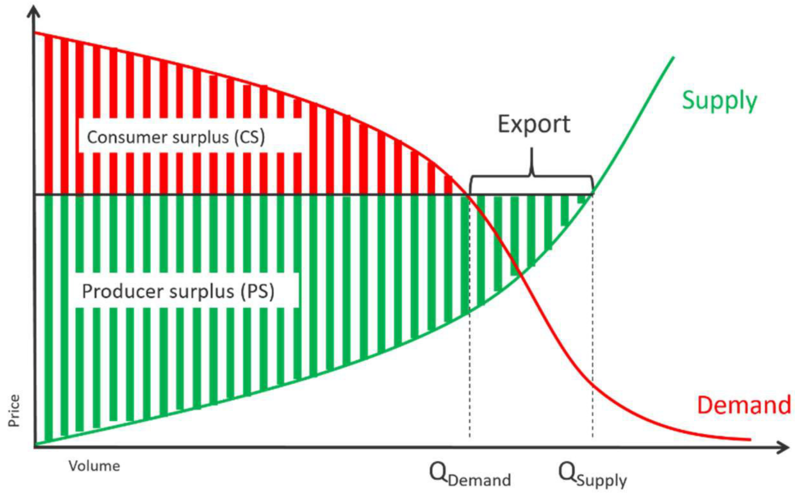


Figure 17: Representation of surplus in an exporting market area; source: own representation

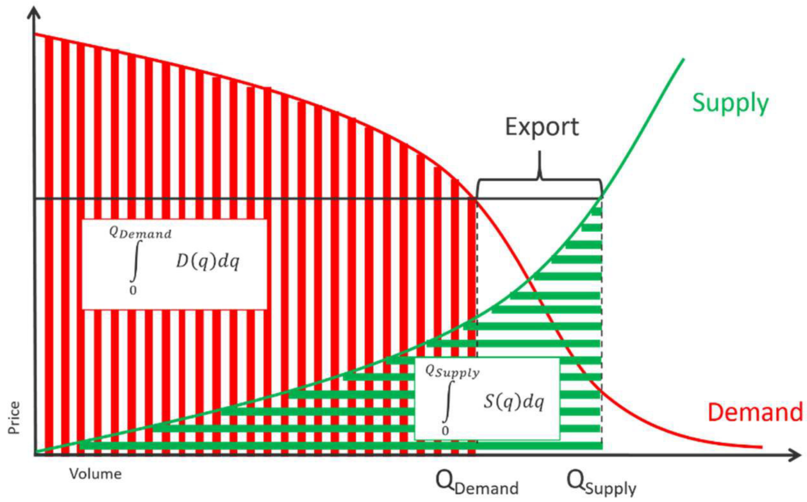


Figure 18: Representation of supply and demand in an exporting market (seeFigure 17); source: own representation

- CS consumer surplus
- PS producer surplus
- CI congestion income
- P market price
- Q_{Supply} volume supplied
- Q_{Demand} volume demanded
- D demand
- S supply
- z market area from the number of market areas Z

The figure illustrates that maximising welfare also maximises traded volumes.

Table 4: Derivation of the optimisation problem; source: own representation based on (NEMO Committee, 2019)

Derivation of the optimisation problem

$$WF_Z = \sum_{z\epsilon Z}\left(\int_0^{Q_{demand_z}} D(q)_z dq - \int_0^{Q_{supply_z}} S(q)_z dq\right)$$

(1) Welfare (WF) is defined as the sum of the difference between demand and supply across all market areas (All TSOs, 2014).

$$CS = \int_0^{Q_{demand}} D(q)dq - P * Q_{demand}$$

(2) Consumer surplus (CS) results from the difference between the integral of the demand function and the market price multiplied by the volume sold.

$$PS = P * Q_{supply} - \int_0^{Q_{supply}} S(q)dq$$

(3) Producer surplus (PS) results from the difference between the market price multiplied by the volume sold and the supply function.

$$NP_z = Q_{supply_z} - Q_{demand_z}$$

(4) The net position of individual market areas results from the difference between supply and demand in the respective market area[20].

$$NP_z - export_z + import_z = 0$$

(5) The sum of the net position, import, and export must be 0 in each bidding zone.

$$\sum_{z\epsilon Z}(CS + PS) = \sum_{z\epsilon Z}\left(\int_0^{Q_{demand}} D(q)dq - \int_0^{Q_{supply}} A(q)dq\right) + \sum_{z\epsilon Z}(NP_z \cdot P_z)$$

(6) The sum of consumer surplus and producer surplus over all market areas can be represented as follows by substituting the supply and demand dates with the net position:

$$\sum_{z\epsilon Z}(CS + PS) = WF + \sum_{z\epsilon Z}(NP_z * P_z)$$

(7) A simplification is obtained by inserting the initially defined welfare.

$$CI_{total} = \sum_{z\epsilon Z}(NP_Z * P_z)$$

(8) Congestion income across all market areas results from the sum of net positions multiplied by the respective market price.

$$WF_Z = \sum_{z\epsilon Z}(CS_z + PS_z - NP_z * P_z) = \sum_{z\epsilon Z}(CS_z + PS_z + CI_z)$$

(9) Inserting welfare (1) and congestion income (7) results in the following term:

$$\max(WF_Z) = \max(\sum_{z\epsilon Z}(CS_z + PS_z + CI_z)) = \max(\sum_{z\epsilon Z}\left(\int_0^{Q_{demand_z}} D(q)_z dp - \int_0^{Q_{supply_z}} S(q)_z dq\right))$$

(10) By maximising trade, welfare (CS + PS + CI) is maximised.

[20] In the literature, net position is also often abbreviated as *nex*.

It should be noted that EUPHEMIA only optimises the traded volume. All costs not directly related are ignored or must be regulated by means of restrictions via inputs (e.g. RAMs).Table 5, therefore, indicates essential constraints of the optimisation algorithm.

Table 5: Constraints of the optimisation problem; constraints that enforce an "intuitive result" are omitted for the sake of clarity; source: (NEMO Committee, 2019)

Formula	Description
$NP_z + \sum_{b \in B} Q_b^z * x_b^z + \sum_{b \in B} Q_s^z * x_s^z = 0$	Calculation of the net position of the bidding zone z
$\sum_{z \in Z} NP_z = 0$	The sum of net positions of all bidding zones must be 0.
$\sum_{z \in Z} PTDF_z^{cb} * NP_z \leq RAM_{cb}$	Flows that are induced by net positions must not exceed the RAM in total.
$0 \leq x_b^z \leq 1$	The acceptance variable of a buy order must be between 0 and 1.
$0 \leq x_s^z \leq 1$	The acceptance variable of a sell order must be between 0 and 1.

In a complex market, in contrast to the simplified theoretical representation, some details and regulatory specifications must be considered, which make the programmatic implementation of the problem significantly more intricate.

The requirements for the formulation of this algorithm are considerably increased by two aspects: on the one hand, the algorithm must be integrated into the processes of the TSOs, exchanges, and market participants (e.g. binding publication times), which limits the time horizon for solving the optimisation problem. In order to guarantee a smooth market coupling process, valid solutions must therefore be produced quickly. On the other hand, complex physical, regulatory, and political framework conditions must be taken into account. Because of this complexity, the algorithm cannot be solved in one single step, but is broken down into the master problem and three independent subproblems. Finally, there is a number of secondary requirements. After optimising welfare, these requirements are used to decide between solutions that lead to the same social welfare. Thus, by using additional requirements, the quality of the solution is further improved (for example, the number of rejected market orders must be reduced).

It follows that in terms of practical implementation, the relatively simple theoretical formulation of welfare optimisation is particularly complex and difficult to understand for market participants and market observers. The next chapters, therefore, give a more detailed overview of the functionality of EUPHEMIA.

2.3.3 EUPHEMIA process in detail

To solve the price determination problem, the concept of bidding zones is crucial. EUPHEMIA is designed in such a way that a unit price prevails within each bidding zone, regardless of how many transmission system operators (or NEMOs) there are in the respective zone. This means that all orders within a bidding zone can be combined to form a demand and a supply curve. This significantly reduces the complexity of the problem.

At the same time, numerous constraints, order types, and framework conditions are introduced so that the comprehensible and simple principle of welfare optimisation becomes significantly more complex when actually implemented. Moreover, other aspects (such as redispatching costs, transaction costs) are not considered. It is also noteworthy that theoretically, in addition to optimising the allocation of cross-border capacities, the algorithm also co-optimises the use of power plants.

The EUPHEMIA process can be divided into four steps (see Figure 19), which are described in detail in the following sections.

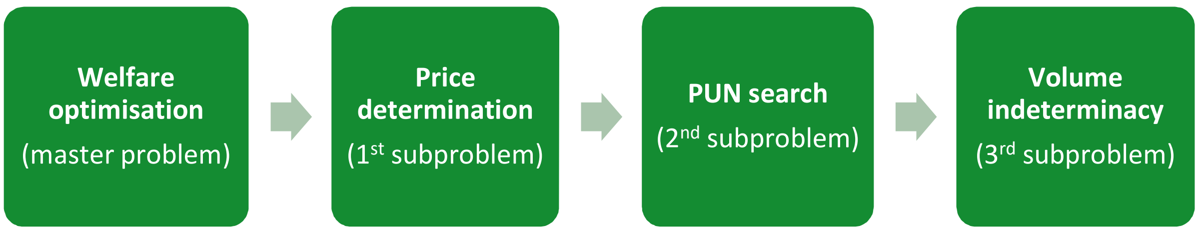


Figure 19: Overview of the EUPHEMIA process: master problem and three subproblems; source: own representation based on (NEMO Committee, 2019)

2.3.3.1 Welfare optimisation: the master problem

The idea that lies behind the structure of the algorithm to solve the market coupling problem is to increase the complexity step by step, that is, increasing step by step the extent of the considered complex orders and organisational framework conditions (aiming at preventing so-called non-intuitive solutions, see further below). The algorithm was developed in such a way that the first step – the calculation of the solution with the highest social welfare – takes place using a significantly simplified model. This enables the problem to be solved in an acceptable time span. The first problem is referred to as the "master problem: maximising social welfare". In this context, not all requirements for complex orders are met and these are presented as simple hourly orders. Merit and PUN orders are ignored altogether. This simplification leads to a drastic reduction in the complexity of the problem. The solution to the fill-or-kill requirements of block orders is then analysed using a branch-and-cut algorithm. In doing so, block orders are gradually, one after another, fully executed or rejected. The result is examined for conformity with the restrictions and its effects on social welfare. Solutions that do not lead to a valid result or to lower social welfare are removed from the solution space.

Complex orders

Complex orders are sales orders that are composed of several hourly orders across different hours of the day and that contain complex conditions (e.g. last gradient or minimum income orders).

At the same time, all constraints on the submitted orders as well as the network topology and configuration remain in place:

- Acceptance criteria for supply and demand curves (price)
- Fill-or-kill requirements of block orders
- Stop, load gradient, and minimum income orders (MIC)[21]
- Capacity and ramping restrictions of the ATC and FB network model

The representation of MIC and block orders requires introducing decision variables (1: block is executed, 0: block is rejected). These decision variables must be binary in the final solution. In a first step, however, this restriction is relaxed (integer relaxation) leading to orders being partially executed. As a result, the algorithm can quickly find an initial solution that reflects the optimal allocation of capacities or of simplified orders executed. This simplified, i.e. less restrictive, optimisation problem leads to an initial preliminary result. Due to the simplifications, it represents an upper limit of the achievable social welfare.

In rare cases, the results – if all orders can be executed correctly – already corresponds to a valid solution. However, implementing correctly all the prerequisites or conditions to be fulfilled must be mathematically ensured. This is done using a branch-and-cut algorithm. In the process, new subproblems are constructed in which the block orders, one after another, are executed or rejected. This creates a group of problems that meet the requirements for an additional block order. Gradually, these problems can be resolved and their effects on social welfare analysed. As soon as a solution is found in which all restrictions of the block orders are fulfilled (all decision variables are binary), the next step begins, i.e. the price determination subproblem, in which the solution is checked for validity. If in the following subproblems valid solutions can still be found, the solution remains valid and becomes a lower limit for further searching valid solutions. If no valid solution is found in the price determination subproblem, the solution is removed from the solution space of the master problem.

2.3.3.2 Price determination problem

The price determination problem aims at determining the market clearing prices (MCP) for all bidding zones. This ensures that the solution generated above is valid from a market perspective. The following must apply:

- MPC for all bidding zones and all hours must match the quantity of orders in the corresponding bidding zones.
- The clearing price corresponds to the applicable market rules (e.g. maximum/minimum MCP or intuitive solution).

At the same time, it is necessary to guarantee that no block or MIC orders have paradoxically been executed or rejected. Paradoxically executed orders are orders that were executed even though they were "out of the money". In addition, non-intuitive solutions are prevented. This is done iteratively, by introducing constraints that specifically remove invalid solutions from the solution space. This

Intuitive solutions

...are solutions in which electricity trading only takes place from bidding zones with low price levels to bidding zones with higher price levels. In FBMC, electricity trading in the opposite direction can make sense because welfare in all of Europe is increased, in which case, the solutions are referred to as non-intuitive solutions. However, these are suppressed by EUPHEMIA.

In order to guarantee (within an acceptable time) that the solution is indeed "intuitive", a heuristic is used that enforces intuitive solutions. The implemented reduction of the solution space can be too strict and thus prevent an optimal result (PCR, 2014).

[21] see info box in Chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**

can lead to block orders being rejected that are "in the money". A mechanism within the algorithm prevents the rejection of block orders that are "deep in the money".

Finally, it is ensured that no energy is destroyed. As soon as prices become negative, it makes sense algorithmically to destroy energy by means of line losses. Theoretically, this is possible by sending energy back and forth between two areas only to pick up losses. Since energy can only be scheduled in one direction, this does not make any sense and EUPHEMIA blocks such results by requiring zero flow in either one or the other direction.

$$I_{AB} \cdot I_{BA} = 0$$

If a valid solution to the pricing problem can be found, the algorithm continues by solving the PUN subproblem (see below). If this is not the case, i.e. no valid solution can be found, it can be concluded that a block or MIC order cannot be validly executed. In this case, the solution space is reduced by this now invalid solution, making sure that the most promising orders remain in the solution space. The master problem is solved again with this reduced solution space.

2.3.3.3 PUN search problem

The PUN subproblem (Prezzo Unico Nazionale) ensures that all requirements for PUN orders are met. This applies in particular to the imbalance restriction and the strict consecutiveness restriction. Calculating the PUN prices is an iterative process in which a uniform price (P_{PUN}) is calculated for all four Italian bidding zones (z).

$$P_{PUN} \cdot \sum_{z} Q_z = \sum_{z} Q_z \cdot Pz \pm IMB$$

P_{PUN} ... $PUN\ price$
Q_z ... $volume\ traded\ in\ bidding\ zone\ z$
P_z ... $prevailing\ price\ in\ bidding\ zone\ z$
IMB ... $tolerance\ limit\ for\ PUN\ imbalance$

The imbalance restriction examines whether the PUN imbalance tolerance is respected when calculating the PUN. The consecutiveness restriction guarantees that orders with the same quantity are executed in a certain order (based on the merit order number). This is not necessarily the optimal result, but is defined by regulation.

Prezzo Unico Nazionale (PUN) orders

...are a particularity of the Italian bidding zones and a specific kind of merit orders. They are cleared at the national standard price ("Prezzi Unico Nazionale"). The PUN can be lower than the MCP of the zone. The following applies: the PUN corresponds to the volume-weighted mean value of all executed PUN orders at the respective MCPs in the bidding zones. The PUN cannot be calculated ex ante.

A check is then conducted to establish whether the changes to the PUN subproblem have turned any block or MIC orders to paradoxically executed orders (due to changes in the price level). In the event that the solution contains paradoxically executed values, the solution space is again reduced by this solution. The programme then restarts with a reduced solution space.

2.3.3.4 Paradoxically rejected MIC orders (PRMIC module)

The current solution may include paradoxically rejected MIC orders by mistake. Paradoxically rejected MIC orders are orders "in the money" that have been rejected. In this step, all potentially paradoxically rejected MICs are examined again individually. To do so, every single one of them is executed one after the other. If social welfare remains the same and other restrictions are not violated, the MIC order is executed; otherwise, it is rejected.

Minimum income orders (MIC)

...are hourly stepwise orders that are defined by two economic parameters: fixed costs and variable costs. The order is executed as soon as the income is higher than the total costs.

2.3.3.5 Paradoxically rejected block orders (PRB module)

This step also involves reducing the number of paradoxically rejected orders, namely the number of paradoxically rejected block orders (PRB). However, not all PRB can be reinserted. It should be noted that at this stage, a heuristic is used that cannot guarantee that the optimal solution (global optimum) will be found. In addition, it must be taken into account that a further time limit is introduced to ensure sufficient time for the remaining steps.

2.3.3.6 Indeterminacy subproblem (improving the quality of the solution)

In the last step, it is examined which constellations are possible that improve meeting secondary requirements while keeping the same social welfare.

The algorithm uses five modules that are intended to improve secondary requirements:

- Curtailment minimisation: minimising the rejection of market orders
- Curtailment sharing: distributing the rejection of market orders across different bidding zones; the algorithm tries to find additional solutions that – with the same welfare – distribute the rejection of market orders equally across all bidding zones.
- Volume maximisation: maximising the volume traded
- Merit order indeterminacy
- Flow indeterminacy: minimising the cost of load flows (NEMO Committee, 2019)

This step merely constitutes an improvement in the quality of the results (secondary goals) and is not an enhancement of overall welfare.

2.3.4 Stopping criteria

EUPHEMIA stops when:

- all solutions have been examined;
- a time limit has been exceeded.

If the time limit has been reached without a valid solution being identified, the calculation continues until the first valid solution has been found or a second time limit has been exceeded. If the latter, it means that there is no valid solution.

In addition, further limits can be set to determine the maximum number of solutions.

2.3.5 Additional properties of the result

- EUPHEMIA produces valid solutions and, among them, selects the one that provides the highest social welfare and respects all constraints. The result is validated by the acceptance of market participants.
- EUPHEMIA calculates with exact numbers. The results are rounded according to normal rounding rules before publication.
- EUPHEMIA provides one valid solution. Due to the time limit and the use of heuristics, however, there is no guarantee that the optimal result will always be found. To limit the solution time, three stopping criteria were introduced: time limit, maximum iterations, and maximum solutions.
- The result is reproducible (assuming the same hardware; this applies in particular to the time limits).

2.3.6 Mathematical description of the problem

In EUPHEMIA, the objective function (master problem) describes the maximisation of social welfare by maximising the executed orders.Table 6 details the order types that are included in the objective function. The formula consists of various parts that represent the different order types. In addition, the income from cross-border capacities is taken into account. The objective function thus is the sum of all order types plus the income from cross-border capacities over all hours of the day and bidding zones. Moreover, a term is introduced representing the acceptance of the market orders and multiplied by a sufficiently large number. This method ensures that the solution accepts all market orders if possible.

Common to all elements is that they contain a binary acceptance variable (ACCEPT), which indicates for each order whether it is executed (1) or rejected (0).

Table 6: Exact mathematical formulation of the objective function; source: (NEMO Committee, 2019)

Minimisation problem:
$$-\sum_{\substack{m,h,s,o:\\ Step\ Orders}} ACCEPT_{m,s,h,o}\, q_{m,s,h,o}\, p_{m,s,h,o}{}^{o}$$
Share of hourly step orders o for every hour h and every bidding zone m: the volume q is positive for supply orders and negative for demand orders.
$$-\sum_{\substack{m,h,s,o:\\ Interpolated}} ACCEPT_{m,s,h,o}\, q_{m,s,h,o} * \left(p_{m,s,h,o}{}^{o} + ACCEPT_{m,s,h,o} * \frac{p_{m,s,h,o}{}^{1} + p_{m,s,h,o}{}^{o}}{2}\right)$$
Share of **interpolated** hourly orders: the other parameters are identical to those of the hourly step orders.
$$-\sum_{\substack{bo,h\\ block\ orders}} ACCEPT_{bo}\, q_{bo,h}\, p_{bo}$$
Share of block orders bo: each block order has only one ACCEPT variable ensuring that all block orders are either completely executed or completely rejected.
$$-\sum_{\substack{m,co,h\\ complex\ orders}} ACCEPT_{m,co,h}\, q_{m,co,h}\, p_{m,co,h}$$
Share of complex orders co for each hour and each market area

$$- \sum_{\substack{mo \\ merit\ orders}} ACCEPT_{mo} q_{mo} p_{mo}$$

Share of merit orders mo: the merit orders are selected based on regulatory requirements.

$$- \sum_{\substack{l,u\ h, \\ Tarifs}} TARIFF_{f,h} * Flow_{l,u,h}$$

Share of tariffs[22]: individual lines (e.g. DC lines) could be managed separately, i.e. with tariffs.

$$- M * \sum_{\substack{m,h,o \\ Price\ Taking\ Hourly\ Demand\ Orders}} |q_o| * (1 - ACCEPT_o)^2$$

M is a sufficiently large value, which does not falsify the result of the optimisation. This term helps to minimise the number of rejected market orders. By squaring, curtailment ratios are distributed evenly across bidding zones.

Table 7: Abbreviations in objective function EUPHEMIA; source: own representation based on (NEMO Committee, 2019)

Formula symbol	Description
m	Bidding zone
h	Time step (hour)
s	Direction (supply or demand)
C	Order defined by market area, hour, and direction
O	Hourly order
bo	Block order
mo	Merit order
co	Complex order
l	Line (grid)
u	Direction of flow
ACCEPT	Acceptance
P	Price offered
q	Volume offered

2.3.7 Conclusion EUPHEMIA

The basic idea of European market coupling, as outlined in Chapter 2.3.2, is to strengthen market integration, i.e. to merge European electricity wholesale markets as much as possible. The aim is to increase social welfare throughout Europe by enhancing cross-border trade. Against this backdrop, the EUPHEMIA algorithm was developed with its main optimisation goal of maximising social welfare. In complex market realities, however, a large number of physical, regulatory, and political (European and national) requirements must be met. Compliance

[22] In an ATC network model, the DC cables could be operated by companies that charge for the use of their capacities. These costs can be represented as tariffs in the algorithm. Inquiries to nside about the exact derivation remained unanswered until the completion of the report.

with thermal line capacities, avoidance of paradoxically rejected orders, prevention of a non-intuitive solution, national particularities such as the PUN orders, and the needs of market participants (block orders, MIC orders) are merely some of the frameworks to be considered. These requirements lead, either directly or indirectly, to a reduction of welfare.

In addition, the optimal use of available cross-border capacities requires a large calculational effort, which in most cases exceeds the available time horizons. For pragmatic reasons, the algorithm has to be terminated in many cases before the optimal solution has been found. Nonetheless, EUPHEMIA also focuses on maximising trade, i.e. maximising the orders that have been fulfilled.

By complying with the numerous constraints, the complexity in EUPHEMIA itself, but also the complexity of the calculation of the input parameters for EUPHEMIA, has increased to such an extent that understanding the results has become difficult for market participants and market observers. Assessing the quality of the solution on a regular basis is not feasible with the information currently available. All of this underlines the need for clear and comprehensible documentation of the EUPHEMIA market coupling algorithm and emphasises the importance of independent and simple performance monitoring.

In addition, solely the effects within SDAC are taken into account due to the basic system that is characterised by the legal and regulatory framework. From an economical standpoint, however, an analysis of welfare is not limited in time; it should represent the electricity market and the players in the electricity market in their entirety to maximise the total surplus. A number of effects are therefore not considered by design, such as:

- Search and transaction costs
- System boundaries
- Calculation of social welfare

These three points are briefly outlined below.

Search and transaction costs

Due to different requirements, the optimisation of SDAC has developed into a complex process. Its mechanisms are only comprehensible to experts with in-depth knowledge particularly in two complex subject areas: mathematical programming and electrical engineering/electricity systems. At the same time, it is essential for market participants to understand the underlying processes to be able to anticipate the market situations appropriately. One example in this regard is the internal modelling of changes in available cross-border capacities. Furthermore, the system is subject to constant further development. However, associated search and transaction costs are not explicitly taken into account in the optimisation.

Acquiring and maintaining this necessary knowledge translates into ongoing costs that market participants (including regulators, TSOs, market observers, etc.) have to bear. With respect to a holistic welfare optimisation, these costs should be evaluated in an assessment of the performance of EUPHEMIA and, if necessary, reduced by corresponding measures. Chapter 4 illustrates examples of measures to reduce these search and transaction costs.

System boundaries

EUPHEMIA merely optimises within the system boundaries specified by TSOs. In addition, TSOs must estimate in advance the costs lying outside this system (e.g. countertrading or redispatching costs). Based on these estimates, framework conditions (e.g. RAM input) are defined by EUPHEMIA. This means that the result is directly influenced by the estimates, which are not optimised by the algorithm itself, however. This also applies to the allocation of capacities for different market segments (e.g. balancing markets). The quality of the estimates affects the result and potentially leads to suboptimal results, even though EUPHEMIA has found an optimal result within the given system boundaries.

How complex these aspects and a comprehensive economic assessment are, which go beyond the narrow system boundaries of SDAC, is shown repeatedly in key questions relating to market design, such as in the "CACM Annual Report" (All NEMO Committee, 2019).

EUPHEMIA uses welfare theory as a basis for optimisation, which is based on the assumption that welfare gains are to be rated equally in all market areas. The result is that an increase in welfare in a market area with high purchasing power is equal to that in a market area with low purchasing power. This can lead, for example, to electricity being exported from a market area with a low price level and low purchasing power to a country with a higher price level and higher purchasing power. Assuming the difference in purchasing power is large enough and the price differential would be reversed after adjusting for purchasing power, there would be a non-intuitive flow (i.e. from a high price level adjusted for purchasing power to a low price level). If the purchasing power of market areas were taken into account, there would also be observable effects when allocating exports. When allocating exports between two market areas from a third country, the correction for purchasing power can affect the result. This fundamental point of criticism of European market coupling remains unaffected by the selection of the market coupling methodology, since this effect can be observed under all market-based trading regimes. The difference, however, is that this decision and the associated responsibility are now implicitly borne by an algorithm and not explicitly by a trader.

Calculation of social welfare

The calculation of the overall welfare, as shown for example in the "CWE Enhanced Flow-Based MC feasibility report" (All TSOs, 2011), is to be discussed. It is imperative that supply and demand match on the electricity market. This means that market participants are willing to pay extremely high prices in the short term. In the longer term, however, such a situation would lead to establishing adaptation measures (e.g. setting up additional capacities, implementing efficiency measures, etc.). However, social welfare gain is calculated based on this short-term willingness to extreme overpayment. Consequently, long-term welfare gains tend to be overestimated.

3 Transparency in Electricity Trading | Barriers and Recommendations

3.1 Background and objective

In the European Union, transparency in energy wholesale markets is determined in various regulations. The Regulation on Wholesale Energy Market Integrity and Transparency (REMIT) (Regulation (EU) No. 1227/2011) defines obligations of commercial market participants (e.g. producers, electricity traders, etc.) against market manipulation and insider trading. For example, the fundamental data on the Austrian market area is published on the EEX (European Energy Exchange) transparency platform. The transaction data are reported to the European supervisory authority ACER and indirectly to the national regulatory authority E-Control. The "Transparency Regulation" (Regulation (EU) No. 543/2013) on the transmission and publication of data in electricity markets obliges all market participants (e.g. transmission system operators, producers, etc.) to report and publish data in the electricity market. The data on the Austrian market is published, for instance, on the transparency platform of the European Network of Transmission System Operators for Electricity (ENTSO-E) and by the transmission system operator APG. These regulations only relate indirectly (e.g. when covering the unavailability of transport lines, generation units, etc.) to Flow-Based Market Coupling, which is addressed in the Guideline on Capacity Allocation and Congestion Management (CACM Guideline (EU 2015/1222)). The following considerations refer exclusively to requirements of the CACM and do not draw a comparison with other transparency regulations.

Article 3 of the CACM Guideline sets the objective of transparency and reliability of information. A fair and non-discriminatory treatment of all stakeholders (market participants, TSOs, regulatory authorities, and NEMOs) is to be guaranteed. This requires equal access to information (European Commission, 2015).

Transparency is a relevant component to ensure successful participation in the electricity market. The provision of market-relevant information is only *one* element of transparency. Traceability of the origin, timeliness, and quality of both information and data must also be provided. The highest possible degree of transparency enables market access with a reasonable amount of time and reduces transaction costs for all market participants. This is key to establish a level playing field, also to maximise the entire economic surplus – which also includes search and transaction costs.

The issue of ensuring transparency was an essential part of discussions as early as the conception phase of Flow-Based Market Coupling. A good example is the following question posed in 2013 regarding the provision of the CGM (Joint Allocation Office, no date):

“The proposed Utility Tool has the objective to allow market participants to explore the ‘securitydomain’ in the Day Ahead stage. Market parties, however, need to perform price forecasting/market analysis for much longer periods. For example, market parties need to do price forecasting for the next calendar year, when submitting bids for the yearly explicit auctions of cross-border capacity. For investment decisions, time frames up to 10–20 years are not uncommon. For this purpose, it is necessary that market parties receive much more detailed information on the network. Can the full Common Grid Model be made public?” [Market participant, anonymous, 03.05.2013]

Although issues of market and data transparency have been a central part of the discourse since the beginning of liberalisation, the challenges with regard to the information required are multiplied in a system as complex as Flow-Based Market Coupling. This relates particularly to uncertainties that market participants face when assessing future market situations, if the market coupling process cannot be forecast, or at least not in its entirety. It can be assumed that additional understanding of individual coupling processes creates potential for a more efficient market, primarily through reduced transaction and search costs, and better forecast quality. A good understanding of the market is also crucial for long-term price assessment and has an impact on risk premiums and ultimately also on investment activity, since higher uncertainties are always associated with higher costs.

At European level, transparency deficits have been repeatedly identified and criticised in the past, see e.g. (Eurelectric; MPP; EFET, 2016), (EFET, ifiec europe, 2018) and (Eurelectric, 2019). Some of the points stated have already been successfully implemented in recent years; others, such as the publication of remedial actions, are still to be tackled. There is also a lack of transparency of historical developments in some data sets. The subdivision of the RAM into the parameters F_{max}, F_{ref}, FRM, FAV, and AMR is now available in the utility tool after criticism from market participants has been implemented, but only retrospectively until May 2017. Moreover, justification for excluding critical network elements from the MinRAM process (20% rule) is not sufficiently published (EFET, ifiec europe, 2018).

Some points of criticism from the open letter (EFET, ifiec europe, 2018) have already been addressed in connection with the update of the JAO utility tool[23]. The so-called virgin domain is now published before the LTA inclusion; the final domain is published after the LTA inclusion and application of the MinRAM process. To determine whether the requirements of market participants are sufficiently met would require a more in-depth analysis of the data sets published in the JAO utility tool.

Furthermore, the lack of interaction or inconsistencies between the information published on ENTSO-E and those provided by TSOs was criticised, for example in relation to failures of critical network elements. Availability of coherent information on the various platforms was therefore one of the wishes expressed. According to market participants (EFET, ifiec europe, 2018), information on the network models provided by the TSOs varies in form and content and, furthermore, is insufficient.

In February 2020, Eurelectric published a position paper on transparency of transmission system operators with regard to cross-border transmission capacity (Eurelectric, 2020). The three main requirements formulated therein are: (1) publication of all details on the DA and ID capacity calculation (for each CBCO: forecast flow, F_{max}, PTDF, remedial actions, RAMs; as well as the GSKs for each bidding zone); (2) publication of the forecast of cross-border DA capacities at least one week in advance, one month in advance, one season in advance, and one year in advance, as well as timely information on failures of lines and transformers; and (3) publication of the CGM (progress towards input-based transparency). Although efforts of individual TSOs to publish data have been recognised in the position paper, there was criticism again that the uncoordinated development has led to a large number of different data, formats, and platforms with significant differences across the borders. All required data should therefore ideally be provided on *one* single platform. Among other things, the publication of remedial actions was again discussed in detail; for example, inexpensive remedial actions were still not disclosed publicly. Data (both forecasts and ex-post data) on redispatching and countertrading should be available to a greater extent. Eurelectric explained the various points in detail and showed best practices of individual TSOs or regions.

These experiences at international level were similar to those made by Austrian market participants. In addition, compared with other countries in the CWE region, Austrian market participants had less lead time to implement

[23] End of 2019/beginning of 2020; the exact date of the relaunch cannot be reconstructed ex post.

the FBMC process. Against this background, the status of transparency in the CWE-FBMC should be comprehensively and systematically examined and evaluated.

While criticism at the European level addresses details of the data sets and, above all, claims precise and additional evaluations, the aim of the present analysis is to examine the findability, traceability, and consistency of existing information and data. This will provide the basis for formulating recommendations on how to enhance transparency.

3.2 Methodology

The problem analysis and the elaboration of the proposed solutions are based on a two-stage process: The Austrian Energy Agency provides the scientific external perspective on the FBMC process and can thus illustrate where problems arise when dealing with the topic. Market participants contribute their experience and competence in the daily handling of the process of day-ahead electricity trading. As a result, the topic is investigated from two different angles: on the one hand, there is a systematic screening of available sources; on the other hand, first-hand experience of market participants is taken into account.

In a first step, challenges, barriers, and problems relating to transparency in electricity trading are presented using specific examples (Chapter 3.3). This analysis is supplemented with experiences from Austrian traders and market participants (questionnaire survey). The aim of this survey was to concretise problems pertaining to the FBMC process and to identify precisely the need for additional information, which also provides a more thorough overview of the status quo. A detailed description of the survey methodology can be found in Annex 1. Based on this problem analysis, the study proposes relevant solutions, which were discussed with market participants in a workshop and adapted according to their statements (Chapter 4).

3.3 Barriers to transparency in electricity trading

The following section discusses challenges, barriers, and issues related to transparency in electricity trading, which are identified and examined by means of specific examples. This analysis is supplemented with the experience of Austrian traders and market participants, who were asked to give a general satisfaction rating for individual subareas of the market coupling process.

As a result, the authors identify three central points of criticism:

- Document management
- Provision of data
- External communication

Systematic storage should lie at the heart of document management. Furthermore, metadata, consistency in naming conventions and structure, as well as keywording must be homogenised and adapted to scientific standards. The provision of data must also comply with scientific standards with respect to findability, performance, data interfaces, and data documentation. A more active and inclusive approach in communication must be adopted. Market participants should receive relevant information in good time without having to monitor several news channels simultaneously.

3.3.1 Document management in FBMC

3.3.1.1 General remarks

The documentation of individual process steps is key for understanding the European market coupling process. Many process steps of European market coupling are not self-explanatory merely in terms of physics or economy, but must also be seen in a historical context. Numerous current structures are shaped by a long preceding stakeholder process. If market participants have no access to this information or only under difficult conditions, the market coupling process becomes too complex to comprehend. As a result, new and smaller market participants particularly or those who intend to enter the market are faced with overwhelming barriers, which prevent fair competition.

Transparency is only considered sufficient if market participants can familiarise themselves with the process and track changes and updates at reasonable search and transaction costs. Solely publishing documents and data without system or context can be viewed as pseudo-transparency, resulting in a disadvantage for companies with a smaller analysis team. Lack of transparency is also a crucial barrier to market entry.

The following examples show why the information available makes it difficult for market participants to learn, understand, and analyse the market coupling process. To document the examples in this report, screenshots in shades of grey are used for better readability.

Findability of documents

In the area of European market coupling, a large number of stakeholders and platforms provide information and/or data, such as the ENTSO-E transparency platform, the ENTSO-E network codes, the JAO platform, the JAO utility tool, the European regulatory authority ACER, national transmission system operators, national regulatory authorities, as well as private providers. The quantity of platforms resulting in information being scattered make it much more difficult to find relevant documents and data sets. In addition, all of these platforms are different and, in some cases, not sufficiently structured given the amount of information (vertical versus horizontal structures, tiled-based system, with/without archive, etc.). Dispersed data and information inject an unnecessary degree of complexity and multiply search and transaction costs. Of course, implementing and maintaining parallel platforms also incurs additional costs.

Due to the lack of a central platform, documents concerning FBMC are not systematically stored and archived on the relevant JAO platform. Document versions, especially previous versions, are not managed in a separate **archive**. Regarding the current documentation with respect to the CWE-FBMC, for example, there are two versions available with the same title, date stamp, and version number. Only the validity dates on the two title pages are different (seeFigure 20).

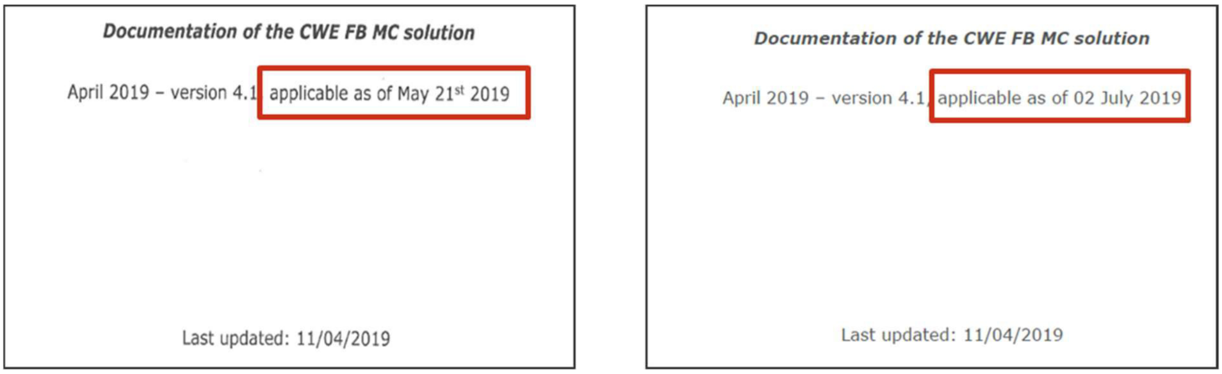


Figure 20: Different document description, screenshot of CWE-FBMC documentation[24]

It is not clear whether the documents are from an official source or whether they were uploaded by a “third party”. This makes it more difficult to find the official documents and recognise the currently valid version. Previous versions can only be partially accessed, which makes it challenging to trace any changes ex post.

Some of the documents found on the CWE-FBMC do not feature a search function within the document (seeFigure 21). Searching systematically in these documents using keywords must take place manually, which requires an unreasonable effort. It appears that this is a scanned version of the document, which is difficult to verify ex post due to the lack of a central platform and the lack of search engine indexing (see below).

Figure 21: Missing search function within the document, screenshot of CWE-FB-MC documentation

Searching for annexes, which include detailed methodological descriptions, mentioned in the CWE-FBMC documentation (Amprion, et al., 2019) is also particularly difficult. Discovering further relevant documents in the download area of the JAO platform may be even considered as chance hits. Ultimately, it is impossible for market observers and interested users to determine if they have indeed found all related documents.

Search engine indexing

[24] source: (Amprion, et al., 2019) https://www.jao.eu/support/resourcecenter/overview?parameters=%7B%22IsCWEFBMCRelevantDocumentation%22%3A%22True%22%7D; accessed 7 January 2020, second version no longer traceable

The findability of documents is also affected by insufficient search engine optimisation. Documentation on FBMC is not always indexed for common search engines such as Google, Startpage, or Ecosia. This means that it is not possible even to find already known documents (i.e. title and source known).

Document structure

The documents published concerning the FBMC process flow do not follow any standardised template or structure. Title pages of documents alone show variations in terms of title, versioning type, author, and information about the time of publication. Some documents are even published without a date or versioning information, e.g. the document relating to the public consultation of the FB methodology in the CORE area (Amprion, et al., no date). This means that the historical development of the documents cannot be traced and that previous versions are difficult to find. It is not always possible to determine clearly the timeliness of the documents, which can lead to outdated versions being used as the primary source of information.

No contact is given for any of the relevant documents in case of questions. This is certainly due to the large number of authors (mostly a merger of TSOs), but makes it notably difficult for market participants and other interested parties to familiarise themselves with the topic.

Property rights – use of documents

According to the title page of the official EUPHEMIA documentation, its content may not be copied, reproduced, distributed, or displayed:

“All materials, content and forms contained in this document are the intellectual property of PCR PXs and may not be copied, reproduced, distributed or **displayed** […]“ (NEMO Committee, 2019)

Against the background of public interest and the significance of EUPHEMIA in European electricity wholesale markets, this disclaimer hinders public discourse about the basic functionality of European market coupling – however necessary it is to protect commercial interests of NEMOs. If these property rights are taken literally, neither the objective function of EUPHEMIA nor other details of the documentation could be used in presentations or in any other way. This general restriction on further use of the information provided in publicly available documentation causes legal uncertainty for market participants.

Insufficient descriptions

Finally, after the publicly available documentation concerning the CWE-FBMC has been reviewed, several questions remain unanswered, e.g. the use of remedial actions.

3.3.1.2 JAO platform

In the scope of this study, all relevant platforms were taken into account. However, special attention was paid to the JAO platform, since relevant data for FBMC is also published here in connection with the utility tool. The download area of the JAO platform offers a variety of documents concerning FBMC. At the same time, the platform has great potential for improvement in terms of structure, timeliness, and sorting and search functions.

Dating of documents

Documents in the download area of the JAO platform are stored according to the date of the upload and not the date of creation. Figure 22 shows six documents, all having the same upload date (27.01.2016) but different publication dates (an example for one of the documents is included). In general, it can be stated that the upload date alone – without reference to timeliness, creation date, validity period, etc. – has no benefit for the interested user.

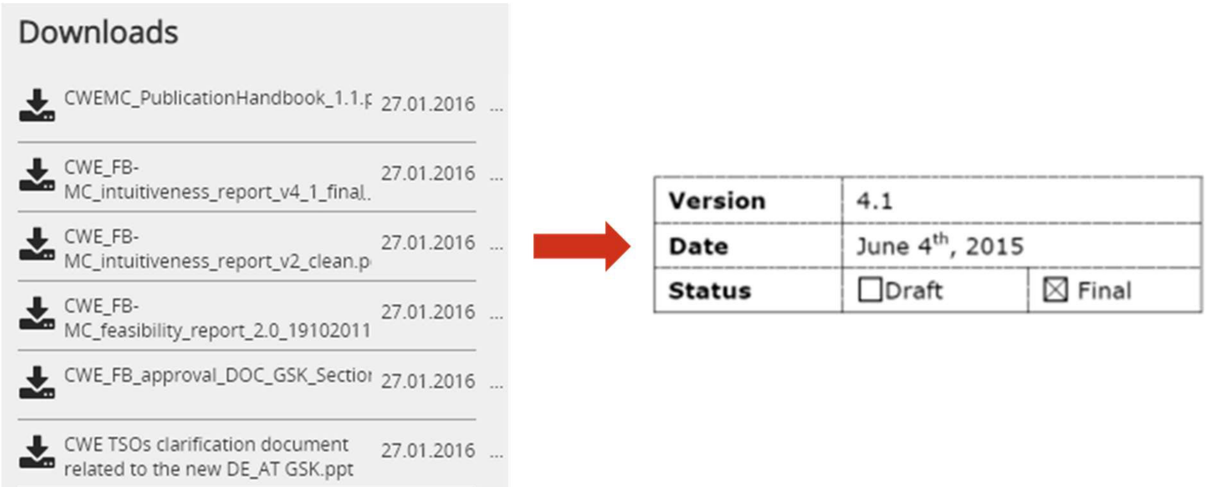


Figure 22: Dating of documents, screenshot of JAO download area[25]

Naming convention

Documents in the download area of the JAO platform do not follow any standardised naming convention. For instance, the abbreviations "CWEMC", "CWE_FB-", "CWE_FB_", "CWE MC FB", or "CWE MC" are all used as prefixes (seeFigure 23). Dates, if any, either are at the end of the file name or arranged in a sequence that makes sorting difficult ("19102011" instead of "20111019" or "2011_10_19"). Furthermore, the names of the documents are not always self-explanatory and therefore do not provide information about the content of the document. For example, a file named “ForumExport.pdf” was uploaded on 27 January 2016 (seeFigure 24), which includes a list of frequently asked questions on the subject of FBMC for the years 2013 to 2015.

[25] source: https://www.jao.eu/support/resourcecenter/overview?parameters=%7B%22IsCWEFBMCRelevantDocumentation%22%3A%22True%22%7D; accessed 10 March 2020

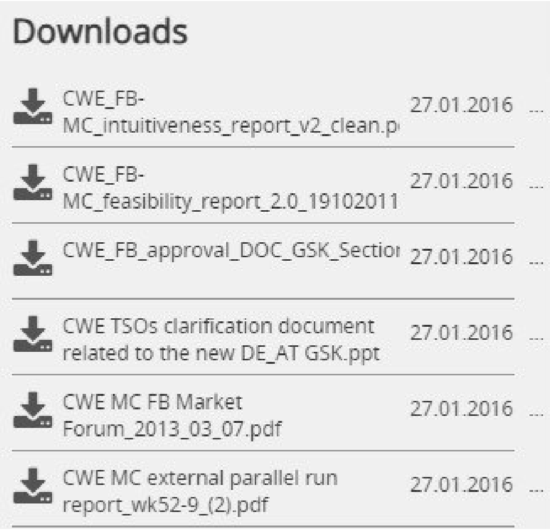


Figure 23: Naming convention, screenshot of JAO download area[26]

Sorting

Another problem with the JAO platform is that published documents do not follow any sorting standards (with the exception of the upload date) (seeFigure 24): e.g. alphabetically (here “F” before “C”) or thematically (here “Publication Handbook” next to “UIOSI Note”). Some documents, such as "CWEMC_PublicationHandbook_1.1.pdf", are indistinguishable from each other or duplicated and not available in the current version (for example, in January 2020, the version 1.8 of the "Publication Handbook" was already available). This makes it much more difficult to find the documents and information needed.

Figure 24: Sorting of documents, screenshot of JAO download area[27]

[26] source: https://www.jao.eu/support/resourcecenter/overview?parameters=%7B%22IsCWEFBMCRelevantDocumentation%22%3A%22True%22%7D; accessed 10 January 2020
[27] source: https://www.jao.eu/support/resourcecenter/overview?parameters=%7B%22IsCWEFBMCRelevantDocumentation%22%3A%22True%22%7D; accessed 10 January 2020

3.3.1.3 View of market participants

The view of Austrian market participants largely coincides with the analysis presented above.Table 8 shows the satisfaction of market participants with the documentation of six subprocesses of the market coupling process as well as with the announcement of changes/updates of the documentation. The evaluation is based on four categories: general satisfaction, comprehensibility, timeliness, and findability. A five-point system was used as rating system with five points indicating maximum satisfaction. The results have been averaged and colour-coded for clearer graphical representation. High satisfaction is shown in green, low satisfaction in red.

Overall, the satisfaction of market participants with the documentation is low (highest average of the evaluations: 3.5 out of 5). This is particularly remarkable given that market participants are the main target group.

Table 8: Summary of the results "Satisfaction with the documentation of the processes", mean values; source: own representation

Documentation	General satisfaction	Comprehen-sibility	Timeliness	Findability
European market coupling (GD)	**3,1**	2,7	3	2,4
Modelling of EUPHEMIA	**2,7**	3	2,5	2,2
Building of the common grid model (CGM)	**2,3**	2,7	3,5	1,8
Documentation of fallbacks	**2,3**	3	3	2,3
Performance of EUPHEMIA	**2,2**	2,4	2,3	2
Calculation process of FB parameters	**1,8**	2,1	2,8	2,1
Further developments and adjustments in the process	**1,8**	2,8	1	1,3
Average	**2,3**	**2,7**	**2,6**	**2,0**

In addition to the overall result showing low – at best medium – satisfaction, additional findings can be drawn: findability of documents is assessed particularly badly. At the same time, comprehensibility tends to get a better rating (but in no way good). This experience also coincides with that of the authors. If documentation is found, it can be used as a basis. However, the individual documentation, viewed in isolation, hardly provides any support in understanding the processes. With respect to individual subprocesses, it is noticeable that two of them are rated particularly poorly: the calculation of the FB domain, which is an important input for the price coupling, as well as the performance of EUPHEMIA and the documentation of the further development of the processes.

3.3.2 Provision of data in FBMC

3.3.2.1 JAO utility tool

The Joint Allocation Office (JAO) is a service company owned by 25 transmission system operators from 22 countries. The JAO holds long- and short-term auctions of cross-border transmission capacities. It offers anual, non-calendar annual, semi-annual, quarterly, monthly, weekly, daily, and intraday auctions. TSOs and regulatory authorities decide which auctions are performed on individual borders. The JAO also provides administrative and settlement services to TSOs and acts as a fallback for European market coupling. In October 2018, the JAO became the single allocation platform (SAP) for long-term transmission rights for all European transmission system operators.

The JAO utility tool offers extensive data sets with regard to FBMC, publishing information on pre-coupling and post-coupling, and additional data sets. All data can be downloaded directly into Excel using the utility tool; automated download is also possible via the web service.

In the following, the study does not examine the data sets themselves but the problems and barriers that arise when working with the utility tool.

One problem is the **findability of the tool** itself. While the utility tool can be accessed via the link https://www.jao.eu/marketdata/implicitallocation, both the authors and the market participants reported that it was not detectable on the JAO platform itself during their searches (e.g. in January 2020). During these periods, the tool could only be found via search engines. However, this search is only possible if users know of its existence and are already familiar with it.

In addition, there are **performance problems** when working with the Excel version, regardless of the hardware used. The tool often crashes both when downloading the data for the first time and updating the data (see e.g. error messages inFigure 25). These recurring issues make working with the available data particularly difficult.

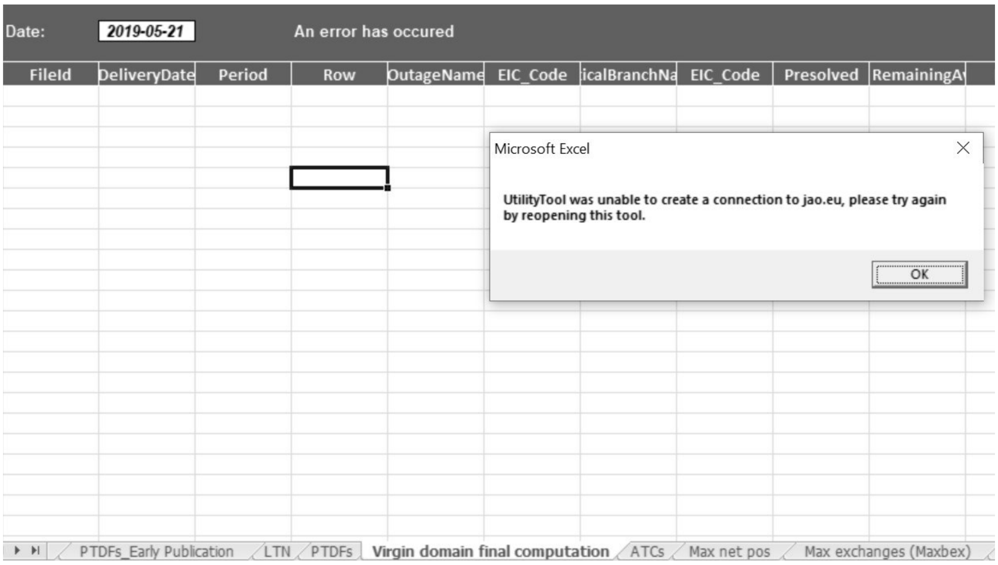


Figure 25: Error message in the JAO utility tool[28]

[28] source: http://utilitytool.jao.eu/; accessed 9 March 2020

The **web service** offers an API (application programming interface) for the automatic download of data available in the JAO utility tool. This facilitates integrating the data into the user's own software solutions or analysis tools. The technical connection is feasible in adequate time with the appropriate IT knowledge. However, little support is provided to people with insufficient experience in using such services. This can represent a considerable barrier, especially for market participants and market observers who do not have access to necessary IT expertise.

There are two problems concerning the structure of data of the web service:

- On the one hand, the data are poorly documented. This applies in particular to the metadata and further documentation for the individual time series. The web service offers a good interface; without an exact description of the data and clear definitions, however, misinterpretations can occur.
- On the other hand, the data are not tagged with a clearly defined time stamp. This can lead to problems, particularly, when changing between summertime and wintertime. Although the data field "CalendarDate" theoretically already includes time information, the time is stored in an additional variable. Especially on days when the clock changes, this can lead to ambiguity. On 27 January 2019 (change from summertime to wintertime), there were 25 hours, whereas there were only 23 hours on 31 March 2019 (change from wintertime to summer time). No reference is made to this peculiarity of the data set. Also in connection with the expansion of the market coupling area, which in the future will possibly extend over different time zones, special attention should be paid to the exact definition of time stamps.

Documentation on the utility tool

The JAO provides **documentation on the utility tool**: the JAO Publication Handbook (Joint Allocation Office, 2019). The documentation briefly describes the content of individual worksheets of the utility tool and indicates the time of publication of individual data sets. The documentation presupposes advanced knowledge about FBMC and does not refer to the corresponding sources. Without prior knowledge of the process, market participants cannot benefit from the documentation. Even if the entire process of FBMC is not integrated in the documentation on the utility tool, at least cross-references to relevant documents are recommended.

Without a cross-reference to the FBMC process, the content of the documentation is in part difficult to understand. It is not always possible to associate directly and clearly the published parameters with the process. While the data set "Virgin domain (initial computation)" corresponds to the result of the "Initial FB parameter calculation" (see flowchart in Section 2.1), other data sets are difficult to assign to the individual process steps.

For example, according to the documentation, the description of the worksheet "Virgin domain (final computation)" corresponds to the FB matrices of the "Final FB parameter calculation". At the same time, however, these are the same values before the LTA inclusion and before the application of the MinRAM process. This contradicts the publicly available documentation on the FBMC process, since according to that, the MinRAM process is performed before the final calculation of FB parameters. In addition, the documentation states that the final flow-based domain (including the LTA inclusion and MinRAM process) is not published before day D at 10:30 a.m. In fact, these data are already available in the utility tool on day D-1 at 10:30 a.m.

The description of the data presented is inadequate. For example, when describing the worksheets for the FB domains, not all column headings are addressed. Terms such as "FileID", "Row", "Min-RAMFactor" or "Outage Name" are not explained or not sufficiently explained. If specific terms are used, it is essential to provide descriptions or appropriate cross-references to supplementary documentation/sources. Moreover, terms in the documentation do not always match those in the utility tool. For example, the term "AMR_Exclusion" (which is described as "Justifications for MinRAM exclusions") is not included in the relevant worksheet; instead, there is a column titled "MinRAMFactorJustification".

It is assumed that published data sets are correctly represented (to confirm this, a more detailed analysis is required), but the inadequate preparation and explanation makes the traceability notably difficult.

The **updates and versioning of the documentation on the utility tool** are not always comprehensible. For example, the documentation was not updated between May 2017 and December 2019 (seeFigure 26). During this period, however, circumstances changed significantly, for instance due to the split of the bidding zones for Germany and Austria. In January 2020, version 1.8 with the creation date on 10.12.2019 was online.

Figure 26: Title page JAO Publication Handbook v1.5 and v1.8[29]

In the following March 2020, version 1.7 created on 1.10.2019 (i.e. a previous version) was online. However, this one had no version number in the document name like other versions hitherto, but the addition "final" (seeFigure 27).

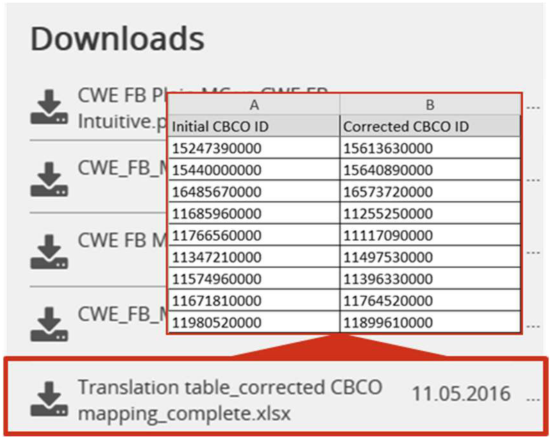
Figure 27: Publication Handbook final, screenshot JAO[30]

In January 2020, only version 1.1 created on 25.11.2015 was available in the download area of the JAO platform, (seeFigure 24). Overall, it can be concluded, on the one hand, that the documentation on the utility tool has great potential for improvement. On the other hand, versioning and regular updates should be introduced in accordance with scientific standards.

It must be ensured that the documentation is up to date. For example, in the version of the documentation available on the website in March 2020, it was announced that the adaptation of the input data of Elia would take place at the end of 2019/beginning of 2020 and that this update would be communicated via "Market Message". Ultimately, the documentation did not confirm whether the data from Elia had been updated on time, nor did it provide a cross-reference to make it easier to find “Market Messages”.

Frequently, **important data** are not included in the utility tool, but are **stored in other locations**. For example, there are large amounts of data compiled as Excel files in the download area of the platform, seeFigure 28.

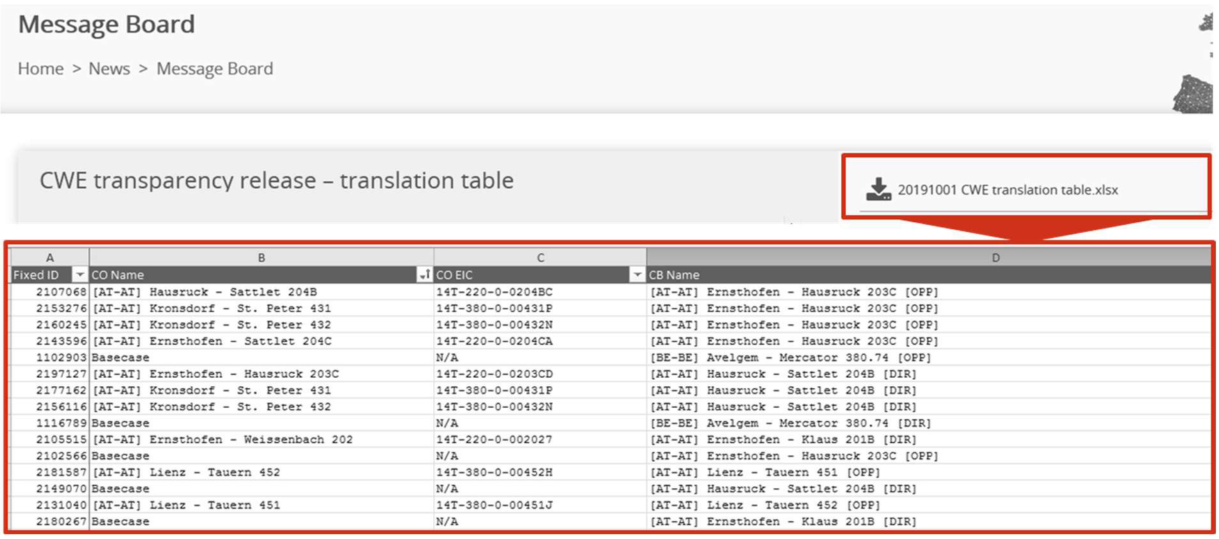
[29] source: https://www.jao.eu/support/resourcecenter/overview?parameters=%7B%22IsCWEFBMCRelevantDocumentation%22%3A%22True%22%7D; accessed 26 July 2019 for v1.5 and 10 January 2020 for v1.8
[30] source: http://utilitytool.jao.eu/; accessed 8 March 2020



Initial CBCO ID	Corrected CBCO ID
15247390000	15613630000
15440000000	15640890000
16485670000	16573720000
11685960000	11255250000
11766560000	11117090000
11347210000	11497530000
11574960000	11396330000
11671810000	11764520000
11980520000	11899610000

Figure 28: Excel file in the download area, screenshot JAO[31]

The JAO also offers two news feeds (JAO Messages and TSO Messages) for interested users via the so-called "Message Board". These messages regularly consist of large volumes of data assembled as Excel files (seeFigure 29). Relevant data are thus scattered across the entire JAO website. This makes the data search more difficult and markedly increases search and transaction costs.



Fixed ID	CO Name	CO EIC	CB Name
2107068	[AT-AT] Hausruck - Sattlet 204B	14T-220-0-0204BC	[AT-AT] Ernsthofen - Hausruck 203C [OPP]
2153276	[AT-AT] Kronsdorf - St. Peter 431	14T-380-0-00431P	[AT-AT] Ernsthofen - Hausruck 203C [OPP]
2160245	[AT-AT] Kronsdorf - St. Peter 432	14T-380-0-00432N	[AT-AT] Ernsthofen - Hausruck 203C [OPP]
2143596	[AT-AT] Ernsthofen - Sattlet 204C	14T-220-0-0204CA	[AT-AT] Ernsthofen - Hausruck 203C [OPP]
1102903	Basecase	N/A	[BE-BE] Avelgem - Mercator 380.74 [OPP]
2197127	[AT-AT] Ernsthofen - Hausruck 203C	14T-220-0-0203CD	[AT-AT] Hausruck - Sattlet 204B [DIR]
2177162	[AT-AT] Kronsdorf - St. Peter 431	14T-380-0-00431P	[AT-AT] Hausruck - Sattlet 204B [DIR]
2156116	[AT-AT] Kronsdorf - St. Peter 432	14T-380-0-00432N	[AT-AT] Hausruck - Sattlet 204B [DIR]
1116789	Basecase	N/A	[BE-BE] Avelgem - Mercator 380.74 [DIR]
2105515	[AT-AT] Ernsthofen - Weissenbach 202	14T-220-0-002027	[AT-AT] Ernsthofen - Klaus 201B [DIR]
2102566	Basecase	N/A	[AT-AT] Ernsthofen - Hausruck 203C [OPP]
2181587	[AT-AT] Lienz - Tauern 452	14T-380-0-00452H	[AT-AT] Lienz - Tauern 451 [OPP]
2149070	Basecase	N/A	[AT-AT] Hausruck - Sattlet 204B [DIR]
2131040	[AT-AT] Lienz - Tauern 451	14T-380-0-00451J	[AT-AT] Lienz - Tauern 452 [OPP]
2180267	Basecase	N/A	[AT-AT] Ernsthofen - Klaus 201B [DIR]

Figure 29: Excel file in the "Message Board", screenshot JAO[32]

[31] source: https://www.jao.eu/support/resourcecenter/overview?parameters=%7B%22IsCWEFBMCRelevantDocumentation%22%3A%22True%22%7D; accessed 10 January 2020
[32] source: https://www.jao.eu/news/messageboard/view?parameters=%7B%22NewsId%22%3A%22e7de98dc-af34-4efd-82a1-aad90081fb13%22%2C%22FromOverview%22%3A%221%22%7D; accessed 10 January 2020

3.3.2.2 View of market participants

In addition to the snapshots described above, Austrian market participants were asked about their satisfaction with the JAO utility tool.

In the course of the survey, the satisfaction with the utility tool and the web service was assessed based on five criteria.Table 9 summarises the results[33]. It is striking that half of the market participants are "very dissatisfied" with the JAO utility tool; and this applies to all five criteria. It is also noticeable that there were no positive responses as to the documentation of the metadata and updates. As the utility tool is the key platform for publishing the data sets relating to FBMC, relevant improvements in this area are crucial.

The situation is different with the web service. The satisfaction with the web service is generally higher, but there is still further potential for improvement.

Table 9: Evaluation of satisfaction with the JAO web service and JAO utility tool; source: own representation

Utility Tool	+ + Satisfaction - -					Don't know	Refuse to answer
	Very satisfied	Satisfied	Somewhat satisfied	Dissatisfied	Very dissatisfied		
Total	**0%**	**14%**	**14%**	**0%**	**29%**	**14%**	**29%**
Reliability	0%	14%	0%	0%	14%	43%	29%
Manageability	0%	29%	0%	0%	29%	14%	29%
Structure	0%	14%	14%	0%	29%	14%	29%
Documentation of metadata	0%	0%	0%	14%	29%	29%	29%
Documentation of updates/data changes	0%	0%	0%	0%	29%	43%	29%

Web service	+ + Satisfaction - -					Don't know	Refuse to answer
	Very satisfied	Satisfied	Somewhat satisfied	Dissatisfied	Very dissatisfied		
Total	**14%**	**29%**	**14%**	**14%**	**14%**	**14%**	**0%**
Reliability	29%	43%	0%	0%	14%	14%	0%
Manageability	14%	29%	0%	29%	14%	14%	0%
Structure	14%	29%	0%	14%	29%	14%	0%
Documentation of metadata	0%	29%	0%	14%	29%	29%	0%
Documentation of updates/data changes	0%	29%	14%	0%	14%	43%	0%

Market participants were also surveyed about other data sets such as day-ahead prices. They were to provide answers on the importance (x-axis) and satisfaction with these data sets (y-axis) (seeFigure 30). The aim was to show how central the individual data sets were for understanding the market coupling process. Moreover, respondents could add data sets that did not figure in the questionnaire. Data sets added by market participants are shown inFigure 30 as purple dots.

All surveyed data sets were rated as important or very important by market participants. This underlines the relevance of reliable data sources for understanding the processes, but above all for the transparency of the respective calculations. The remaining available margin (RAM), final adjustment values (FAV), and remedial actions (RA) were considered as particularly important. However, only the RAMs are sufficiently documented according to respondents. The level of satisfaction was lowest for the documentation on remedial actions among all data sets. This is consistent with the authors' point of view. Chapter 2 discusses this aspect in detail.

[33] Only seven participants provided content-related answers to the questions (a high proportion of respondents chose “I don't know” or “I don't want to answer”), which must be taken into account when interpreting these results.

The creation of the D-2CF, i.e. the assumptions of TSOs regarding the network situation, is also rated as important for the market coupling process by the surveyed. As part of the FBMC process, these are combined to form a common base case for all CWE countries. The base case provides a decisive input for the calculation of the possible solution space of EUPHEMIA. The satisfaction with the documentation on the creation of the D-2CF is low.

Another important group of data are market data (prices, electricity flows). In contrast, SPAIC[34] analyses are assessed as least important by market participants. Yet, in the case of modifications to the system or the processes, they are the only point of reference for market participants to evaluate the future behaviour of the common market area. Their assessment may be linked to the fact that the published analyses require in-depth background knowledge to be interpreted accurately.

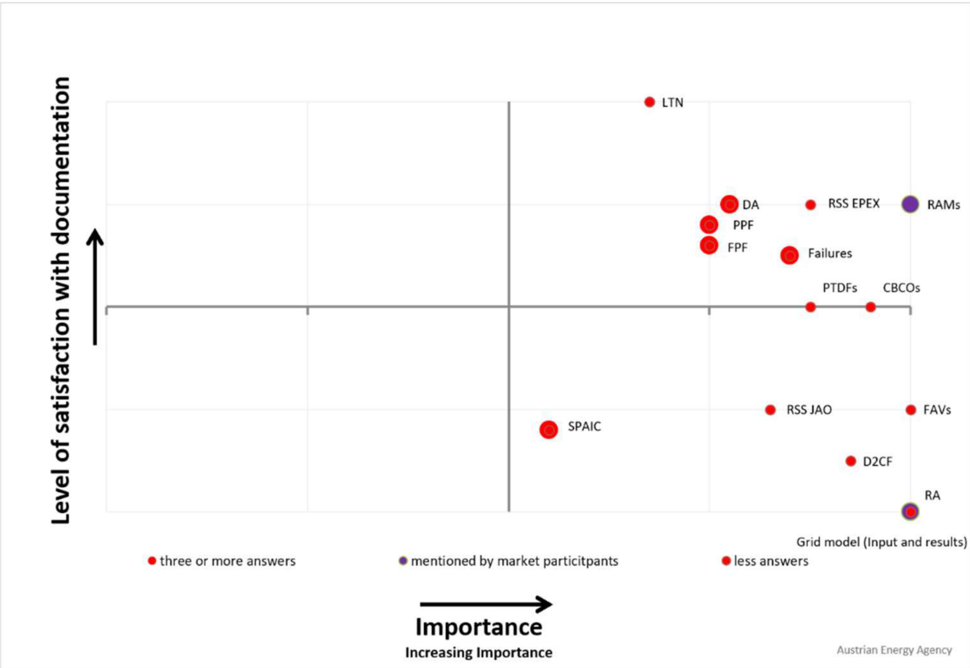


Figure 30: Scatterplot of data sources to enhance transparency; source: own representation

The availability of data in sufficient quality and in the appropriate format is crucial in order to increase transparency in FBMC and thus the ability of market participants and market observers to understand the process. Against this background, the quality of various other data sources should be assessed. Data sources are “contact points” that make data available to market participants.

The sources listed inTable 10 were considered central by the authors. In the context of the survey, however, respondents could add other sources. The individual sources were rated according to their importance and qualitative criteria. A high level of importance indicates the central relevance of the source for the market participants surveyed. Thus, low values in terms of the qualitative criteria for sources that score high in importance are viewed as a more serious problem. It should be noted that in the case of two sources (namely EPEX and JAO RSS feed) only two participants provided answers, reducing the reliability of the results. On the other hand, this allows drawing conclusions about the “actual importance”: while it is true that the source was assessed as important,

[34] Standard process to communicate on and assess the impact of significant changes

the number of answers can be used to determine the degree of importance. Compared to the numbers of responses given to the other sources, importance can be viewed as low for these two sources.

The five qualitative criteria used to assess the sources are listed inTable 10. These criteria allow conclusions to be drawn about opportunities for improvement, which facilitate ongoing operations as well as event-related evaluations.

Table 10: Summary of results “Satisfaction with existing data sources”; source: own representation

Data source	Importance	Quality of information	Comprehensibility	Time of publication	Format	Documentation & provision of data
JAO	4,1	3,1	2,7	3,3	2,9	2,6
EPEX-RSS feed	4	3,7	4	2	3,5	3,5
ENTSO-E	3,9	3,2	3	2,6	3,4	2,6
JAO-RSS feed	3,3	3	3	3,7	3	2,5
APG market data	3,2	3,2	3,7	3,3	2,8	2,6
Average	n.a.	3,2	3,3	3,0	3,1	2,8

In principle, the satisfaction of market participants, as the most important target group, with available sources is not acceptable. Several results should be emphasised:

- The comprehensibility of the information tends to score highest. The central JAO platform is an outlier in this context.
- The second highest score (mean of 3) is awarded to the quality of the information.
- The time of publication of the EPEX RSS service was rated particularly low with only 2 points. The basic idea of an RSS service, however, should be the timely (earliest possible) transfer of information. Yet, given the small number of responses, it cannot be ruled out that it is an outlier.
- With a score of 3.1, the formats available are assessed poorly. This point is particularly surprising. Using the numerous recognised data formats, interfaces, and conventions could significantly increase the acceptance of sources. Conversion between formats is possible in most cases.
- Documentation is rated worst. Poor quality of documentation is a central recurring problem.

3.4 Recommendations to increase transparency in electricity trading

In the following chapter, concrete solutions are derived based on the problem analysis. These are subdivided, on the one hand, into solution approaches that are intended to help meet current scientific standards in terms of information processing, document structure, and data provision. On the other hand, more extensive and complex solutions are proposed by means of specific application examples.

Here once again, a two-stage process is used. Similar to the problem analysis, the Austrian Energy Agency offers the scientific external view of the FBMC process. Market participants add to the discussion their experience and competence in dealing with the day-ahead electricity trading process on a daily basis.

3.4.1 Transparency requirements

Transparency requirements relate to those areas that correspond to the current scientific standard for documents and data. For the most part, this involves establishing basic requirements for information processing, document structure, and data provision. In the best-case scenario, these improvements should give the target group easy and transparent access to the necessary information at minimised search and transaction costs.

Table 11: Transparency requirements of FBMC; source: own representation

Transparency requirements	Quick win	Large gain
Documentations on FBMC		
Standardised document structure	x	
File format	x	
Findability of annexes	x	
Systematic storage of documents		x
Naming convention	x	
Indexing in search engines	x	
Data on FBMC		
Availability, completeness, and findability of data		x
Findability of the utility tool	x	
Sources and contacts	x	
Performance of the utility tool		x
Documentation utility tool | Versioning and updating	x	
Documentation utility tool | Reference to methodological descriptions	x	
Documentation utility tool | Updates	x	
Utility tool web service		x

The transparency requirements discussed are divided into quick wins and large gains. Quick wins describe solution approaches that can be implemented with relatively little implementation effort and without the need for considerable adaptation of the infrastructure. Large gains refer to solutions that are more extensive and require high (or higher) implementation efforts, but that are viewed as a central requirement to provide comprehensible data and as a benefit to the market and to transparency.

For all requirements, implementation effort has been assessed in relation to a future implementation. An ex-post implementation in already existing documents would mean, if indeed possible, a significantly higher effort.

The points listed are described in more detail in the following subsections.

3.4.1.1 Document management in FBMC

Standardised document structure

It is advisable to create and use a standardised template for the documents published about FBMC. Transparency requirements for this template are:

- Author/organisation responsible/contact
- Creation date
- Validity (when and where)
- Version number
- Changes to the previous version (possibly in a separate version)
- Information on the validity of unchanged parts of the previous version
- Other relevant documents on this subject

A standardised structure facilitates understanding the development of the documentation and enables to determine the timeliness of the information.

File format

Documents must be available in common file formats, e.g. as a PDF file and/or in HTML (see examples in Section **Fehler! Verweisquelle konnte nicht gefunden werden.**). For reports, a report format with appropriate explanations of the methodology and illustrations should be preferred over a presentation format. As far as possible, raw data for representations in reports should be provided in a machine-readable format together with the documents.

Findability of annexes

Annexes mentioned in the documents must be either attached to the document or findable via appropriate cross-references (links) or a digital object identifier. The files must not be moved or replaced. It must also be clear who is responsible for providing the documents.

Systematic storage of documents

Documents must be findable with the lowest possible search costs. In addition, documents should be stored systematically so that market participants and market observers can find the current document as quickly as possible and identify previous versions (e.g. archive). To make traceability of changes easier, introducing a change log or a comparison with colour coding would be helpful. This is also relevant with regard to the dynamic future development, since it is to be expected that the (change) processes within the scope of the CORE expansion will become even more complex. Moving towards solutions that allow large amounts of text to be searched and linked is therefore clearly preferable to a visually oriented solution (e.g. ENTSO-E tile-based system) (see examples in Section **Fehler! Verweisquelle konnte nicht gefunden werden.** or **Fehler! Verweisquelle konnte nicht gefunden werden.**). The standard of transparency and, above all, the traceability of documents of FBMC should ultimately be based on the publication standard of legal matters.

Document archiving and versioning are crucial wherever documents are subject to a constant development process or are regularly updated, or wherever several authors are involved in the preparation. The aim is to provide to the reader prompt information about the status and chronology of the present document (Rochfort, 2015).

In the case of more complex development processes, it is helpful to chronicle the process through document control tables and to make them available to users.

Table 12: Example of a document control table; source: (Rochfort, 2015)

Version	Title	Author	Date	Link	Changes
0.1	Process_XY_2019_Draft_0.1.pdf	John Smith	2018-08-01	Link_to_0.1	Draft
0.2	Process_XY_2019_Draft_0.2.pdf	John Smith	2018-09-05	Link_to_0.2	Chapter 2: methodology
0.3	Process_XY_2019_Draft_0.3.pdf	Jane Smith	2018-10-05	Link_to_0.3	Quality control
0.4	Process_XY_2019_Draft_0.4.pdf	John Smith	2018-11-15	Link_to_0.4	Consultation
1.0	Process_XY_2019_Final_1.0.pdf	John Smith	2018-11-30	Link_to_1.0	Final version
1.1	Process_XY_2019_Final_1.1.pdf	John Smith	2019-06-30	Link_to_1.1	Data update of chapter
2.0	Process_XY_2020_Final_2.0.pdf	Jane Smith	2019-11-30	Link_to_2.0	Update of legal texts
2.1	Process_XY_2020_Final_2.1.pdf	John Smith	2020-04-08	Link_to_2.1	Update link
…	…	..	..	..	..

Naming convention

In order to make it easier for users to work with documents, naming conventions should be defined and observed. For example, Princeton University's recommendations for minimum requirements are[35]:

- File names should be named consistently
- File names should be short but descriptive (less than 25 characters)
- Special characters and spaces should be avoided
- Upper and lower case letters and underscores should be used instead of periods or hyphens
- The date format should follow ISO 8601: YYYYMMDD (prefixed to enable chronological sorting)
- A version number should be included
- The specific naming convention should be part of the data management plan

Following these conventions already when creating documents results in users not having to introduce a naming convention for systematic file storage every time. In order to reduce transaction costs, and because it is relatively easy to implement, this is a central recommendation for all (new) documents.

Indexing in search engines

In addition, complete indexing in all common search engines would make it easier to find and retrieve existing documents.

3.4.1.2 Provision of data in FBMC (JAO utility tool)

Data provision should guarantee market participants and market observers a low-threshold access to all necessary data sets with the lowest possible search and transaction costs. The present study does not focus on discussing which additional evaluations should be generated to increase comprehensibility of FBMC, but how findability, traceability, and consistency of existing data in the JAO utility can be improved.

“High quality data are accurate, available, complete, conformant, consistent, credible, processable, relevant and timely.” (EU Open Data Support, 2014)

According to (EU Open Data Support, 2014), high-quality data provision should meet the following criteria:

- Accuracy: Do the data represent the actual event correctly?
- Consistency: Are there no contradictions in the data?
- Availability: Is it always possible to access the data?
- Completeness: Do the data contain all data items?
- Conformity: Do the data comply with recognised standards?
- Credibility: Are the data based on trustworthy sources?
- Processability: Are the data machine-readable?
- Relevance: Do the data contain an adequate amount of data?
- Timeliness: Do the data represent the current situation and are they published in time?

[35] https://libguides.princeton.edu/c.php?g=102546&p=930626

The weighting of these criteria always depends on the respective data set and the aim of the publication. The assessment of costs and benefits also plays a role. The JAO utility tool promptly provides a large part of the relevant data for Flow-Based Market Coupling and thus fulfils many of the specified criteria (such as accuracy, consistency, or timeliness). In terms of increasing transparency, however, the utility tool still has room for improvement in some of the above-mentioned criteria. With regard to the provision of data, changes to the JAO utility tool in particular – with a few exceptions – involve medium to large effort, but offer the possibility of major improvements in transparency. In the following, therefore, possible improvements with regard to the provision of high-quality data are examined.

Availability, completeness, and findability of data

Availability and findability of complete data sets must be guaranteed. This requires that all data be collected at as few access points as possible. Most of this is done in the JAO utility tool. Further data sets should not be available in the message board of the JAO website, but (also) collected in one place. In addition, the utility tool must always be accessible on the JAO platform.

The completeness of all data relevant to market coupling, such as those on the ENTSO-E transparency platform or similar platforms, is discussed in detail in Section **Fehler! Verweisquelle konnte nicht gefunden werden.**.

Sources and contacts

The traceability of origin, timeliness, and quality of both information and data must also be guaranteed. Sources of individual data sets should be traceable in the utility tool. Contacts should be available in case of problems of understanding as well as questions about the data.

Performance of the utility tool

The performance of the utility tool should be monitored and further improved. Given that the utility tool is a central data set on FBMC, smooth functionality and availability must be ensured and, if possible, a performance standard must be defined and tested. In addition, the question must be raised as to whether an Excel tool is the best solution for the large amount of data that is published daily in Flow-Based Market Coupling.

Documentation of the utility tool

To document the utility tool, versioning corresponding to scientific standards (see also Chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**) and regular updates should be introduced.

Data sets must be clearly defined and with reference to official methodological descriptions (cf. the term “virgin domain”, which is mainly found in the documentation on the JAO utility tool, but not in the official documentation on FBMC). It must be feasible with the lowest possible transaction costs to assign published data sets to individual parameters in the FBMC process. Cross-references to more detailed methodological descriptions are necessary.

Announcements about **updates** should be effectively communicated to market participants and in good time. In general, updates should be implemented as often as necessary but not too frequently, so that users can work with the data and the tool as efficiently as possible. Every change to the data sets and tool always entails another familiarisation period (or adjustments to the IT).

Utility tool web service (processing of data)

The web service of the JAO utility tool offers an API for the automatic download of data. This facilitates the integration of data into the user's own software solutions or analysis tools. The web service provides numerous improvement possibilities that could make it easier for market participants to access the data. To support machine processing of data, the JAO web service should include code snippets in additional programming languages (R, Python). As a result, people with no experience in using web services could access the raw data more easily (e.g. universities).

In general, the web service is not sufficiently documented. Good documentation significantly reduces the implementation effort and gives developers the opportunity to inform users precisely about all functions so that the service can be used at its optimum. This includes, for example:

- Access options
- Queries and query examples
- Error handling
- Tracking of changes between versions[36]

Documentation is a key communication channel from developers to users. The documentation of the "Statistical Data and Metadata eXchange for Python" is a good example in this context.

Data evaluation can be further simplified by making additional machine-readable data formats such as JSON or XML available in bulk download. The resulting additional effort for a file server is low. A wider range of access options also allows a larger number of market participants access to the raw data and, thus, insights into the functioning of European market coupling.

In contrast to what is usually perceived in everyday life, time zones play a fundamental role in internationally coordinated (IT) processes and the resulting time series data. It must be ensured that data are provided with a clearly defined time stamp. It is recommended to use a UTC and a local time stamp with the corresponding clearly identified time zone information and the internationally valid UTC stamp[37]. In addition, the provision of different data formats (keyword machine-readable vs. human-readable) makes working with data easier and the information more accessible to different users.[38] An example of a complete time stamp is provided by ISO 8061[39]: *2009-01-01T12:00:00+01:00 -> 12:00:00 on January 1, 2009 in Vienna (CET).*

In particular, these requirements apply during the development and test phase of new interfaces. Traceability of data must be guaranteed at all times. In this context, reference should also be made to the relevant documentation of the file structure (metadata files e.g. EEX; cf. EEX Market Data – SFTP CSV Interface Specification) (EEX, 2020).

Another measure to increase transparency relates to the RSS feeds, which should be subject to a rating system based on addressee and importance.

[36] Best practices in the API documentation
[37] https://en.wikipedia.org/wiki/Coordinated_Universal_Time
[38] https://phpdevapi.wordpress.com/2015/02/25/time-zone-and-its-importance/
[39] https://www.iso.org/iso-8601-date-and-time-format.html

3.4.2 Recommendations for improving transparency based on specific examples

The following examples show specific applications that can contribute to improving transparency in FBMC. Data transparency plays a vital role in many disciplines, organisations, and processes. Accordingly, various institutions (including universities, government agencies, and standardisation institutes) have developed conventions and standards, which are presented here as examples.

For better clarity, the examples are divided into three categories (seeFigure 31), which help to differentiate between different dimensions of current challenges.

Figure 31: Categories for examples of applications to improve transparency; source: own representation

To allow for a better understanding, the categories are briefly described in the following. It should be noted that not all solutions suggested can be clearly assigned to one individual category. Some application examples offer approaches for the same or similar problems. Not all examples need to be implemented, but all problems identified should be addressed.

Document management

Examples of document management include solutions that focus on a more structured preparation of information to make it easier to find and retrieve them. Players in many different disciplines (e.g. scientific or legal spheres) face similar challenges. As a result, diverse solutions have already been developed, which differ in their implementation effort.

Provision of data

The second category covers various approaches that facilitate data management and data access. There are two dimensions to be observed: interpretability by humans and interpretability by machines (programmes).

The aim is to improve the findability of data and to simplify both machine and human data access. This category also includes solutions that improve the documentation and the description of data (e.g. metadata) (EU Open Data Support, 2014)

Knowledge transfer

Transfer of knowledge is the core content of the last category, which is aimed to ensure that market participants also have access to the background knowledge required to understand all processes relevant to market coupling. Different examples of knowledge exchange will be presented. They range from conventional measures to innovative and interactive concepts.Table 13 gives an overview of all the examples shown.

They were assessed based on three requirements:

- Effectiveness: Does the measure increase transparency and/or traceability?
- Effort: What is the level of implementation effort of the measure? How quickly can changes be implemented?
- Efficiency: Does the benefit justify the effort?

Table 13: Overview of application examples to improve transparency; source: own representation

Examples	Main features	Effort	Effectiveness	Efficiency
Document management				
Document archiving à la E-Control	Document archive	medium	medium	high
HTML-based document management system à la "Gesetze im Internet" (Laws on the Internet)		low	high	high
Central document management	One-stop shop of documents	high	high	medium
Provision of data				
FAIR principles	Consistent scientific standards for data provision	low	high	high
Central data management with machine access à la Quandl	One-stop shop of data	high	high	high
Knowledge transfer				
Periodic report on FBMC key figures à la BNetzA quarterly report		medium	high	medium
Organisation chart	Graphic representation of all stakeholders	low	low	low
Interactive flowchart	Visualisation of process flows	medium	medium to high	high
Visualisation à la ENTSO-E grid map and 50Hertz network load map		high	medium	low
Open source of all tools und algorithms		medium	low	medium

The assessment above is of course subjective and reflects the type of implementation of the measure. Developed together with Austrian market participants during a workshop the assessment is indicative of the relevance of individual examples.

3.4.2.1 Document management

3.4.2.1.1 Document archiving à la E-Control

The example of E-Control, the Austrian electricity regulator, shows a document management system that is effective but easy to implement. E-Control uses a simple type of document archiving on its website. Each category has an archive in which the historical versions of the documents are stored chronologically (seeFigure 32). The archive is on the same hierarchy level and can therefore be found without much search effort. The advantages of this type of document management are simple implementation and manageable maintenance effort. Nevertheless, market participants can understand quickly and easily the timeliness and historical development of the documents.

Figure 32: Abstract of archive of regulations, E-Control[40]

Of course, merely archiving the documents on multiple platforms does not improve the decentralised organisation of documents. The effectiveness of this measure is therefore lower than that of implementing a one-stop shop or an HTML-based platform. At first glance, efficiency is increased with only little effort (joint consideration of effort and effectiveness). However, this minimum of effort might be put into perspective when offset against the fact that the measure would have to be implemented on numerous platforms.

3.4.2.1.2 HTML-based document management system à la “Gesetze im Internet“ (Laws on the Internet)

An example of an HTML-based document management system is the platform “Gesetze im Internet”[41] (Laws on the Internet) of the German Federal Ministry of Justice and Consumer Protection. It is an online database for all legal norms in Germany. The platform gives access to legal texts in all common formats such as HTML, PDF, XML, and EPUB[42]. The documents available as HTML allow an online full-text search (seeFigure 33) and can thus make the keyword search considerably easier, since the search function enables systematic queries through all documents. Changes to documents are recorded, reported, and immediately incorporated into the relevant document, which ensures their timeliness. In addition, stakeholders can trace the development of the documents ex post.

[40] source: https://www.e-control.at/recht/bundesrecht/oekostrom-energieeffizienz/verordnungen-archiv#p_p_id_com_liferay_journal_content_web_portlet_JournalContentPortlet_INSTANCE_10306A20241; accessed 16 March 2020; only German
[41] https://www.gesetze-im-internet.de/; only German
[42] Common e-book format

Figure 33: Platform "Gesetze im Internet" (Laws on the Internet), German Federal Ministry of Justice and Consumer Protection[43]

Market participants awarded a high score to both effectiveness and efficiency of an HTML-based document management system. Effort was rated manageable compared to the great benefit. Issues concerning responsibility and cost coverage for the implementation, support, and liability have yet to be resolved. It is crucial that such a source of information is publicly accessible and has low access requirements (see ENTSO-E).

3.4.2.1.3 Central document management (one-stop shop of documents)

By providing a central document management, making all relevant information available on a single platform instead of distributing it on different platforms – as is currently the case –, search and transaction costs in FBMC will be greatly reduced. Ideally, this platform is used as a central collection point for all relevant documents as well as for all relevant raw data. In addition, this platform can also be used as a bidirectional communication platform between market participants and TSOs/NEMOs.

A one-stop shop platform was rated extremely positively by Austrian market participants. Centrality is considered a major asset of the one-stop shop, which could solve the current problem of platform diversity (ACER, ENTSO-E, JAO, NRAs, TSOs...). In addition, it guarantees certainty for users in terms of obtaining all relevant data by only observing one source. Establishing a central document management involves extensive effort. This concerns both the technical and organisational implementation. The responsibility for implementing and updating must be clarified and clearly determined, which is considered a key obstacle to the development. Moreover, it is necessary to discuss which body can assume this responsibility and to what extent legal framework conditions are therefore required (e.g. revision of the CACM Guideline (EU 2015/1222)). If there is no obligation of implementation for any organisation and the one-stop shop is then operated on a commercial basis, the resulting monopoly must be regarded as a critical problem.

It could be argued that offering a central document management system does not prevent other platforms from establishing parallel structures with additional information or interpretations. However, this would not be an issue supposing that the information in the one-stop shop is exhaustive. In any case, the one-stop shop must bundle all public information in sufficient quality.

[43] source: https://www.gesetze-im-internet.de/volltextsuche.html; accessed 16 March 2020, only German

3.4.2.2 Provision of data

3.4.2.2.1 FAIR principles

The FAIR principles have become a standard in the scientific community for the handling of data. The FAIR principles define that data must be **f**indable, **a**ccessible, **i**nteroperable, and **r**eusable (seeFigure 34).

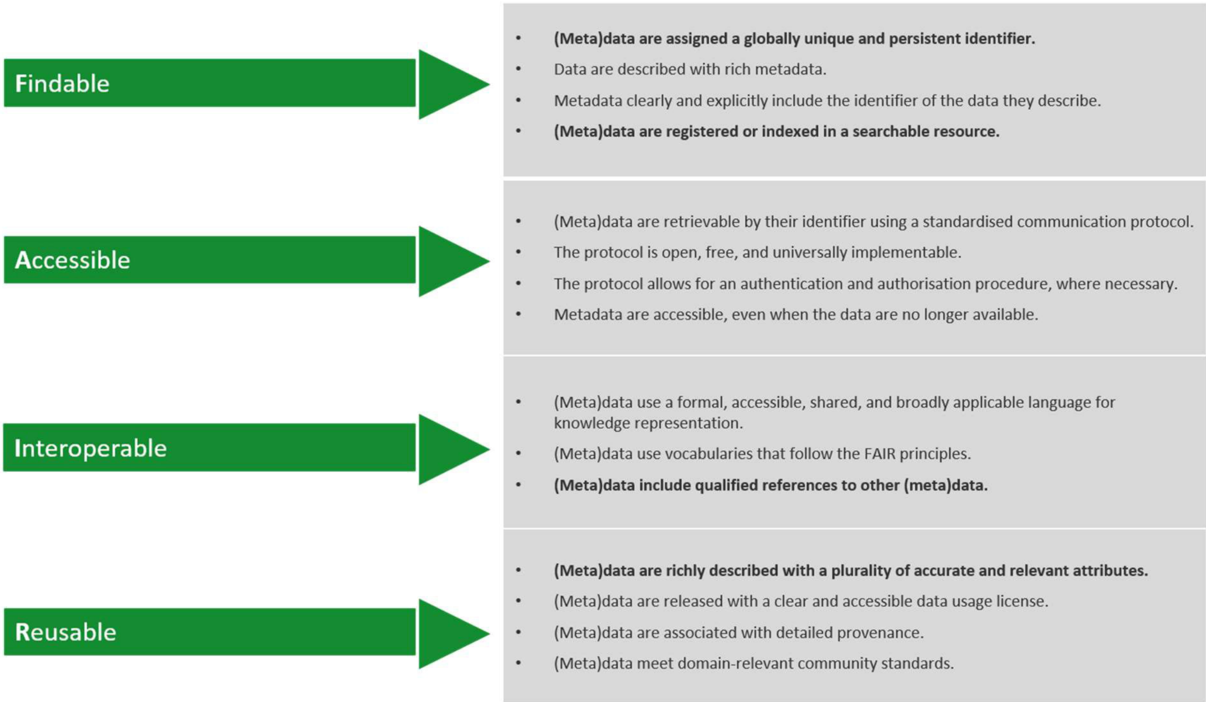


Figure 34: Summary of the FAIR principles[44]

To meet the findability principle, for example, a globally unique identifier (digital object identifier – DOI) is linked to the data and the associated metadata. The data/metadata are indexed in search engines. Accessibility calls for a standardised communication protocol, which is used when retrieving the data/metadata. Access to the metadata must remain available, even after the data and the resulting evaluations are no longer available. Interoperability means that the storage of data corresponds to common transmission and structure protocols. Reusability, the last principle, imposes that data/metadata must be adequately described so that they can be interpreted unequivocally by anyone without further context or prior knowledge.

The application of FAIR or similar principles has meanwhile become a scientific standard and is often a prerequisite for receiving research funding (European Commission, 2016). Applying it to the data published as part of European market coupling would fundamentally improve the user-friendliness of platforms such as the JAO platform, but above all the transparency and traceability of the processes. To ensure practicality, the principles do not have to be adopted as they stand, but can be adapted to the needs of the target group. This requires the participation of all stakeholders. In general, however, the FAIR principles represent a useful framework for generating transparency and traceability that are interdisciplinary and stable over time.

[44] source: The FAIR Guiding Principles for scientific data management and stewardship; https://doi.org/10.1038/sdata.2016.18

The FAIR principles consistently received positive evaluations by market participants in terms of effectiveness, effort, and efficiency. Implementing the concept would also be feasible with manageable effort, for example by incorporating it into the quality management (e.g. ISO 9001) of all affected stakeholders (TSO, JAO...). Finally, an authority must be established to enforce and demand this set of rules.

3.4.2.2.2 Central data management with machine access à la Quandl (one-stop shop of data)

Quandl is an example of a central collection point for financial data. The platform allows access via the browser, but also via other channels that support machine access through a programming interface (API).

This concept can be applied to data sets generated during the FBMC process. The dashboard view in the browser enables market participants to obtain a quick overview of the data and the current situation. Furthermore, market participants benefit from a standardised access due to the use of common languages (Python, R, and Excel) and formats (seeFigure 35). Quandl also provides programming examples to facilitate data access via API.

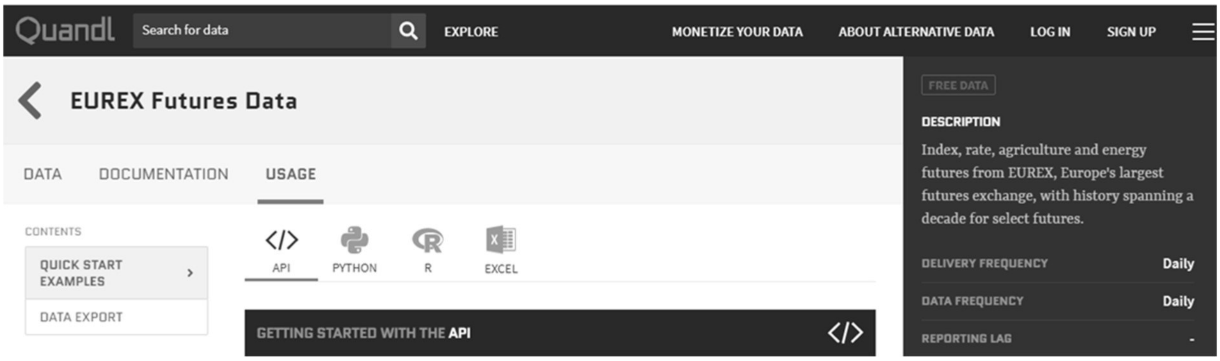


Figure 35: Extract of machine data access to EUREX Futures Data, Quandl[45]

Effectiveness and efficiency scored highly among market participants. A possible problem is responsibility: even appointing a responsible organisation will not completely prevent that responsibilities will multiply. The question of financing is also an issue. In principle, access must be open to everyone. Premium models for high-resolution data or query limits could be a possibility to ensure the user-pays principle. To support public interest in a highly transparent market and create a level playing field, it is advisable to make the data available free of charge (for example, through cost sharing of TSOs and subsequent socialisation of costs).

3.4.2.3 Knowledge transfer

In this context, attention should also be drawn to the proper publication and management of metadata. Metadata are a prerequisite for data to be and remain interpretable by users (European Commission, 2016).

3.4.2.3.1 Periodic report on FBMC key figures à la BNetzA quarterly report

The BNetzA quarterly report is a regular report on network and system security. The report is a combination of quantitative and qualitative information. With regard to FBMC, the presentation of relevant key figures and the development as well as the description of irregularities are of interest. The report provides market participants with an interpreted version of the data. This means that the background, context, problems, and considerations of TSOs are better communicated. As a result, market participants get a more thorough understanding than from pure data analysis or description of process flows (Bundesnetzagentur, 2020).

[45] source: https://www.quandl.com/data/EUREX-EUREX-Futures-Data/usage/quickstart/api; accessed 16 March 2020

However, the obligation to report is not sufficient in itself. A well-functioning quality assurance system and minimum requirements for content and extent of the report must also be specified. A disadvantage is of course that the format of a periodic report is not machine-readable, which could be sidestepped, however, by providing relevant raw data in parallel. The effort for preparing an extensive report is considered as relatively high.

3.4.2.3.2 Organisation chart

Organisation charts are another means of boosting knowledge transfer. They are useful in illustrating all subjects involved in the FBMC process and their relationships to each other. Subjects include sources, players, or institutions, for example. When representing the complex interactions between subjects, graphical models are particularly effective;Figure 36 is an illustrative example thereof.

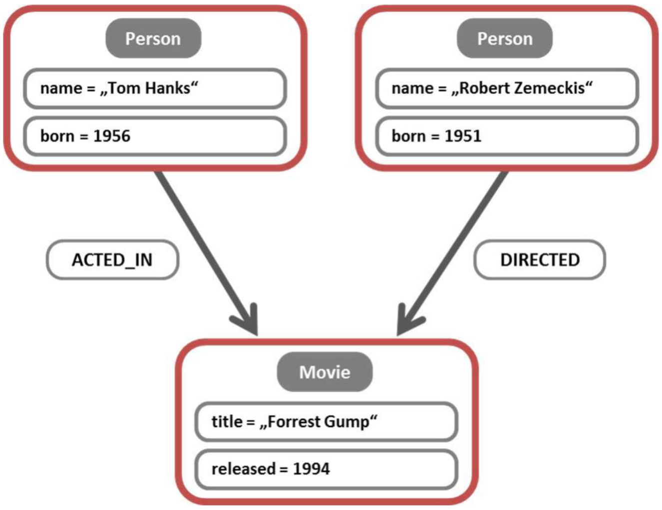


Figure 36: Example of a graphical model; source: own representation

Austrian market participants assessed the benefits of organisation charts as rather low with a comparatively high implementation effort.

3.4.2.3.3 Interactive flowchart

Interactive flowcharts also support the transfer of knowledge by representing complex processes and subprocesses in FBMC. They help market participants to obtain a quick overview of the relevant process steps and are particularly suitable for illustrating processes, algorithms, and existing data sets (seeFigure 37). Flowcharts can be complemented with contextual help, toolboxes, and interactive hoverboxes[46] to enable additional links to further literature.

[46] A hoverbox is a pop-up box that only appears when the mouse is placed over a certain object. A click is not necessary to activate the hoverbox.

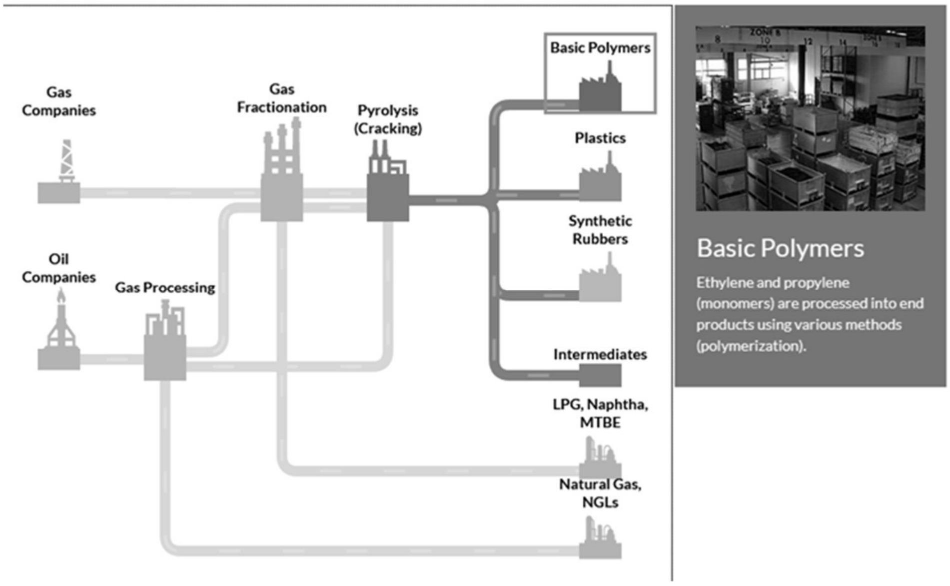


Figure 37: Example of an interactive flowchart[47]

Of course, the effort required depends on the level of detail of the implementation. The necessary effort for ongoing updates must also not be disregarded. However, the effectiveness of an interactive flowchart was rated positively across the board. This is due to the combination of a visualised overview of complex process flows and the addition of detailed information. As in most of the above-mentioned examples, responsibility for implementation, maintenance, and content must first be determined.

3.4.2.3.4 Visualisation à la ENTSO-E grid map and 50Hertz network load map

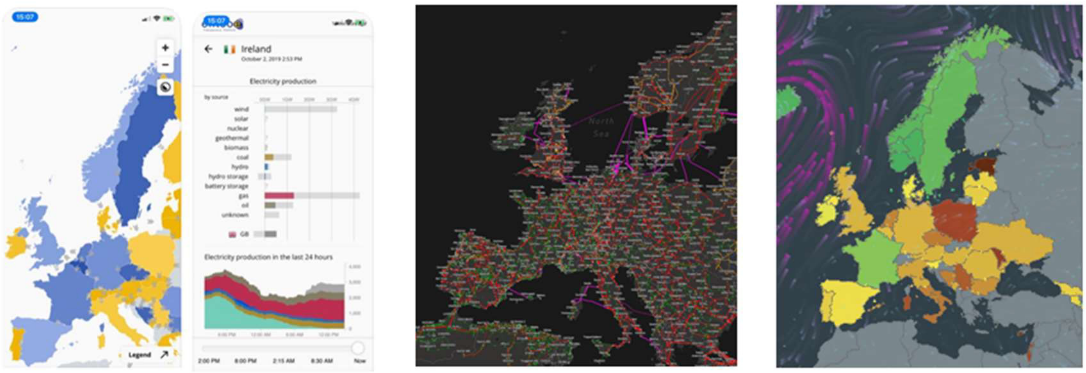


Figure 38: Examples for the implementation of maps for information transfer in the energy market. The underlying data structure can be queried using the API. Sources from left to right: (1) & (2) ENTSO-E transparency APP, (3) ENTSO-E grid map, (4) ElectricityMap of Tomorrow

In addition to a central data platform (Chapter 3.4.2.2.2), visualising data similarly to the ENTSO-E transparency APP, the ENTSO-E grid map, or the ElectricityMap could improve knowledge transfer. The latter offers a graphically well-prepared interface to visualise the generation, import, and export of data (Tomorrow, 2020).

[47] source: https://gojs.net; accessed 9 January 2020

This type of representation would be particularly suitable to visualise and spread the CBCOs (seeFigure 39) or the electricity flows to a wide audience. It can provide an overview of the market situation and detailed information on individual CBCOs and congestions (zoom function). In addition, similar to the flowchart, the grid map could be supplemented with hoverboxes containing accurate information on individual CBCOs.

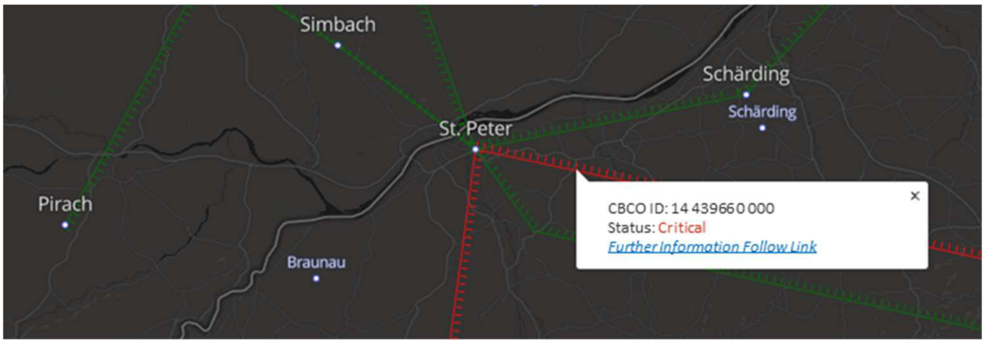


Figure 39: Illustrative example of the grid map with extended FBMC function[48]

According to market participants, such a visualisation can only be sensibly implemented if backed up by a central data management system. Primarily, this type of visualisation is considered an initial assessment of the data and a communication tool.

The transmission system operator 50Hertz includes a network load map with data on transmission lines, electricity plants, and substations on its website (seeFigure 40). Users can select both the date and the time of the illustration as well as download the data as CSV files.

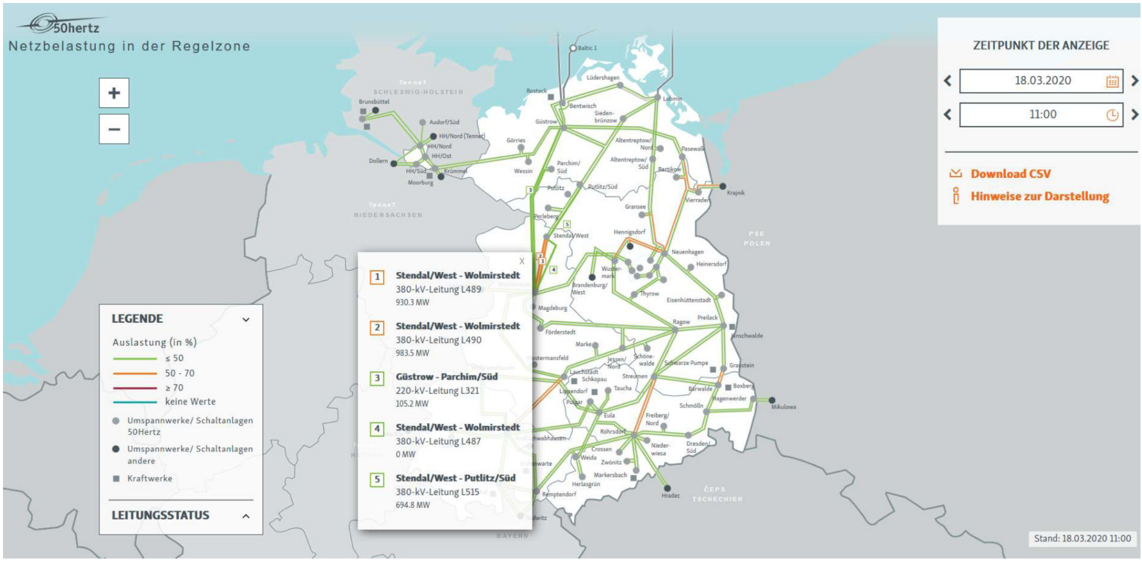


Figure 40: Network load map of 50Hertz[49]

[48] source: https://www.entsoe.eu/data/map/; accessed 16 March 2020; edited illustration
[49] source: https://www.50hertz.com/Netzlast/Karte/index.html; accessed 19 March 2020, only German

3.4.2.3.5 Open source

In order to achieve full transparency, all process steps, tools, and algorithms need to be managed according to the open-source model, which enables the use of so-called collective intelligence. The collective intelligence would constantly develop tools and algorithms; a form of self-organisation can arise. In particular, complex algorithms such as EUPHEMIA could be checked for errors and ways of achieving improvement by universities and other research institutions (Minister of State for the Cabinet Office and Paymaster General, 2016).

However, this can lead to an increased risk in terms of manipulation and abuse for the system, in particular, and for the market, in general (keyword market manipulation or bug exploits). Above all, safety-relevant data, such as detailed network models, would generally be excluded from this principle.

The effectiveness of publishing all algorithms did not score highly, mainly due to the reason that many market participants do not have the resources to deal with this wealth of information. The question is whether this measure would actually contribute to a so-called level playing field, i.e. equality for all market participants, or whether financially strong companies would stand to benefit more.

According to market participants, the effort required for the practical implementation, i.e. making the codes available, is low. Moreover, the decision-making process was considered highly time-consuming. In particular, developers and/or owners of the code hold a legitimate commercial interest and intellectual property rights.

Generally, only critical and safety-relevant data sets should be excluded from publication. However, especially algorithms such as EUPHEMIA, where property rights are the main reason for non-publication, should be considered for publishing (but not e.g. commercial or further use) – above all because of the importance of this algorithm for European market coupling and the associated economic influence on market participants.

3.5 Conclusion transparency

Based on the present problem analysis, it can be concluded that the findability of documents and the description of data represent the greatest barrier. As soon as relevant documents on a topic or process step are retrievable, understanding the process is generally possible. Yet, the challenge is to find relevant documents in their latest version, which are scattered across multiple sources. This is made even more difficult, on the one hand, by various platforms/websites providing similar information, and on the other hand, by a lack of search and/or overview functions on these platforms. Naming of documents, versioning, information on timeliness, etc. are also areas of improvement.

The quality of data also poses a challenge for market participants. While some important data sets are published in good time and sufficient quality, other data necessary to assess the situation (e.g. input into the network model or remedial actions) are not published. Data formats and interfaces only partially correspond to the state of the art and good practices with regard to documentation and metadata. The communication of important information and changes to processes or data systems does not reach all market participants to the desired extent.

Numerous options are available to improve transparency in Flow-Based Market Coupling. The above-mentioned examples show that many of them have already been implemented in other disciplines, organisations, and processes. However, all proposed solutions are caught between effort and effectiveness. Consequently, solutions can be optimally selected along these two parameters. Bearing the costs of implementation is certainly a challenge that needs to be clarified, as is assuming responsibility for the content and the required quality management.

The preferred solution would be to set up a one-stop shop, i.e. a central point of contact that allows market participants access to all relevant documents and data. Documents should be available as HTML, with the option of downloading them as PDF with a corresponding time stamp. If possible, contacts should be listed. A flowchart linked to the HTML-based description would be ideal to illustrate process flows. Filter and search options should be available for both data and documents. Data should be accessible as Excel with a time stamp as well as machine-readable with appropriate documentation. In addition to flowcharts (understanding of the process), visualising data similarly to the ENTSO-E grid map with zoom functions and cross-references to data sets would advance knowledge transfer. This requires a functioning document and data management. The existing JAO platform (including web service) can be used as an organisational and infrastructural basis to be gradually adjusted over time. In any case, it must be guaranteed that sufficient resources are available for implementation and support.

4 Indicators

4.1 Challenge and overview

4.1.1 Challenge

In the context of FBMC, a large number of complex data sets are generated. In order to interpret them properly, a deep understanding of the processes and the appropriate analysis tools are required. Ad hoc analyses are merely possible to a limited extent. This leads to reduced transparency in the ongoing process. Developing and regularly publishing indicators enables market participants, on the one hand, to get a quick overview of the current situation and acute irregularities. On the other hand, indicators can also contribute to increasing the general functionality in daily operation. In addition, with regard to the further development of the electricity market design, meaningful and regularly published indicators are highly relevant.

The challenge that market participants face in the market coupling process is characterised by three aspects: (1) numerous players and different market areas are involved in the process. The resulting complexity requires precise knowledge of the processes. (2) FBMC is a combination of two complex subject areas; each demands a high level of knowledge and a substantial learning time. Both market coupling and the IT-related implementation of the optimisation process require a deep understanding of the subject matter. (3) The resulting large amounts of data must be processed. The situation is exacerbated by the constant further development of processes and regulations. Communicating the current situation and upcoming changes clearly and specifically to target groups is therefore a prerequisite for the efficient and transparent implementation of European market coupling.

Monitoring the processes and performance of market coupling on a daily basis currently involves great effort for market participants. Key performance indicators (KPIs) can help players to observe the market; they can also increase trust in the correct handling and the transparency of the market coupling process.

The aim of these indicators is to enable market participants, market observers, and decision-makers to understand quickly and easily current developments and the resulting market situations. The indicators should be available centrally and on a daily basis and should give users a quick overview of the current situation and future developments. They do not represent detailed information, but aggregated values that make it possible to obtain initial information without any further analysis steps.

4.1.2 Indicator dashboard

The key indicators should allow short-term market observation. Published with only little delay, they should be easily and freely accessible to all market participants. A suitable form of presentation are dashboards. Dashboards are graphical user interfaces that represent a collection of information (e.g. indicators). The objective is to give market participants an overview of the current market situation. By means of easily understandable indicators, users can follow the main results of SDAC and the underlying processes. In addition, the information is placed in context with statistical key figures allowing a faster assessment of the situation.

Exactly describing the graphic and content of a dashboard would exceed the scope of this project. In any case, the following points should be taken into account in the implementation:

- Focus on key figures

The dashboard should not be filled with unimportant information. Every published indicator must ensure a better understanding of SDAC. Indicators and information with no added value in this context should not be displayed on the dashboard.

- Visual support for interpretation

Information is graphically represented on the dashboard, e.g. red arrow for decreasing values, green arrow for increasing values. In addition, charts with visualised time series are included.

- Provision of the historical context

Often, indicators only provide meaningful information in connection with associated time series. It is therefore necessary to make this context available as well. In the electricity market, in addition to typical key figures such as the mean value of the last 30 days or the last year, key figures such as the same day from the previous period have become standard.

- Availability of metadata and documentation

Apart from the indicators, the corresponding metadata and documentation for calculating the individual indicators must also be available or linked.

- Timeliness

As a supplement, historical data can represent past situations. In order to enable support during operation, data must be relevant to the current market situation. The more up to date the data, the greater the benefit for day-to-day operations.

- Machine readability

In addition to the numerical and graphic representation, indicators must also be machine-readable, so that market participants can integrate them into their decision-making and control systems.

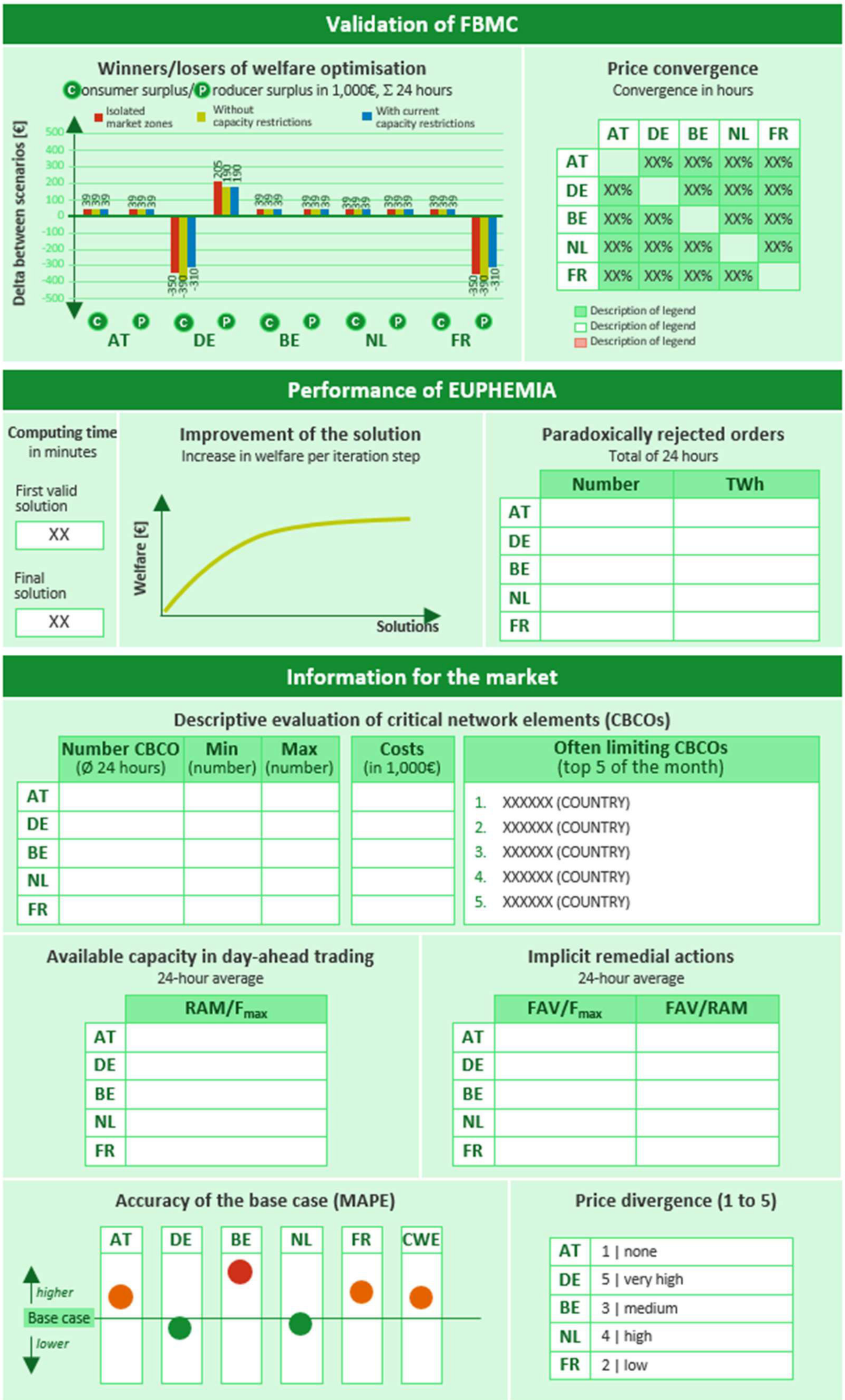


Figure 41: Exemplary representation of key indicators on a dashboard; source: own representation

4.1.3 Overview indicators

For a better analysis, the indicators are divided into three categories according to objectives. The overall objective of all indicators is to give a quick overview of the result of market coupling as well as to increase trust in the result and the transparency of individual process steps.

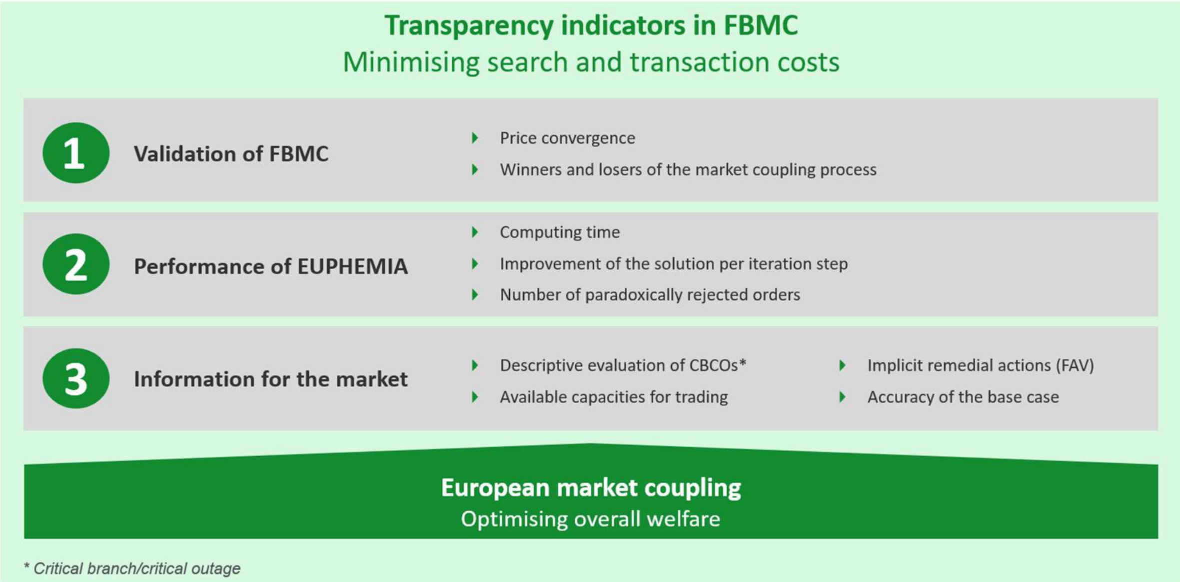


Figure 42: Overview classification of indicators to promote transparency in FBMC; source: own representation

The first category (validation of FBMC) describes indicators that serve to validate FBMC as a market organisation process. These indicators compare the performance of different market coupling mechanisms according to various requirements, for example the increase in welfare or the decrease in volatility. This validates Flow-Based Market Coupling as the preferred calculation method for free cross-border capacities. The second group of indicators evaluates the performance of EUPHEMIA, such as the required solution time until the first valid solution has been found, the improvement of the solution per iteration step, or the number of paradoxically rejected orders (PRB). Indicators of this group are used to monitor the performance of the algorithm. They become more important as soon as the regulatory or topological framework conditions change (e.g. bidding zone split DE-LU/AT). In this event, it must be ensured that the results of the algorithm still meet the quality criteria. The last category (information for the market) gives market participants information and insights into the current market situation. This category includes descriptive evaluations of critical network elements (CBCOs), their capacities, and implicit remedial actions that have been set. It also covers indicators that provide market participants with information about the quality of the inputs from EUPHEMIA (e.g. CGM).

Possible implementation of key indicators

It is usually possible to calculate indicators for each hour, but also in aggregated form as an average or total over 24 hours, if obtaining a quick overview is preferred. However, there is always a trade-off between comprehensiveness and accuracy. Choosing a one-day aggregate may be a reasonable compromise.

In principle, the dashboard should provide a quick overview of the market situation updated daily. In the download area, additional detailed data, for example for each hour, as well as historical data sets can be provided.

Most of the indicators can be updated daily and published ex post. For some indicators (accuracy of the base case, price divergence), it might be useful to publish them before the actual market coupling process. Wherever possible and sensible, data should be presented both as aggregate and for individual bidding zones.

By using shadow runs, the impact of predictable changes in the market coupling process (e.g. the expansion of the market coupling zone, changes in the network topography) can be tested. For some key indicators, it also makes sense to publish the indicators for the shadow runs so that users can anticipate the effects of changes in individual bidding zones.

The indicators are available as time series for all participating market areas in suitable form (numbers, graphically, or as a dimensionless scale) on a dashboard and for download in a common format. The final decision regarding meaningful evaluations requires a test phase including feedback from market participants.

Possible indicators for increasing transparency in electricity wholesale markets are presented in detail below.

Table 14: Summary of key indicators and possible implementation; source: own representation

Indicator	**Short description**	**Possible implementation**	
		Dashboard	Download
Validation of FBMC			
Winners and losers of welfare optimisation	Consumer surplus, producer surplus e.g. for three standard scenarios (isolated market areas, without capacity restrictions, and with current capacity restrictions); delta between scenarios	Total over 24 hours, per bidding zone	For each hour, per bidding zone
Price convergence	Hours in which two bidding zones are fully coupled e.g. for three standard scenarios (isolated market areas, without capacity restrictions, and with current capacity restrictions)	Convergence in hours e.g. matrix, heat map, or bar chart of bidding zones	Price data available (EN-TSO-E transparency)
Performance of EUPHEMIA			
Computing time of EUPHEMIA	Comparison of the solution time until the determination of the first valid solution with the solution time until the determination of the final solution	Solution times in minutes	Solution times in minutes
Improvement of the solution	Increase in welfare per iteration step	Graphical, data point per valid solution	Data point per valid solution
Paradoxically rejected orders	Number of paradoxically rejected orders	Total over 24 hours, per bidding zone, number of offers and quantity in MWh	For each hour, per bidding zone
Information for the market			
Descriptive evaluation of CBCOs	For example: ▸ Number of critical network elements per bidding zone; average over 24 hours, minimum and maximum ▸ Often limiting CBCOs; top 5 of the week, month, year ▸ Costs/welfare losses of the limiting CBCOs	Varies depending on the evaluation	For each hour, per bidding zone

Available capacity for DA trading	RAM/F_{max}	Ø 24 h, Ø over all CBCOs of a bidding zone, total over all bidding zones	For each hour, per bidding zone
Implicit remedial actions	FAV/F_{max} FAV/RAM	Total, positive, and negative, Ø 24 h, Ø over all CBCOs of a bidding zone, total over all bidding zones	For each hour, per bidding zone
Accuracy of the base case	Describes the quality of the base scenario based on statistical evaluations of historical base cases; statistical key figure representing the probable deviation of the base case from the actual situation	Aggregated and per bidding zone	For each hour
Price divergence	Warning for spikes in electricity prices and spreads	Dimensionless scale for risk assessment (e.g. danger levels: 1 = low to 5 = very high), per bidding zone	For each hour

4.2 Validation of FBMC

4.2.1 Winners and losers of welfare optimisation

Problem

Optimising welfare entails that there are winners and losers. Cross-border trade reduces producer surplus and increases consumer surplus in high-priced countries. In low-priced countries, the situation is reversed. Publishing this data daily gives market participants, but also regulators, decision-makers, and other stakeholders an overview of the shift in welfare in individual bidding zones. In addition, changes, such as in network topography, generation capacities, or in the market coupling process, lead to a change in consumer and producer surplus. Estimates of these changes must be communicated transparently and in such a way, that all market participants can adjust accordingly to the new situation.

Objectives

Stakeholders have access to temporally resolved information about current or future shifts in producer and consumer surplus from all bidding zones. They can use this data to improve their assessment of the impact on affected markets. In doing so, uncertainties and associated costs can be reduced.

Proposed calculation

This indicator can be calculated by comparing different parallel runs. The target value is the level of producer and consumer surplus. Standard evaluations are, for example, the comparison between network models either with isolated market areas, without capacity restrictions, or with current capacity restrictions. Whenever a change is made in the network topography, another set of shadow runs should be included in which the planned changes have already been implemented. The calculation of the indicator can be performed similarly to the calculations in the feasibility report (Amprion, et al., 2011).

Proposed implementation

The indicator covering three standard scenarios (isolated market areas, without capacity restrictions, and with current capacity restrictions) is published daily. If changes affecting the distribution of surplus are foreseeable, the indicators are also published for shadow runs in which the changes have already been implemented. On the dashboard, the indicators are presented for all participating market areas in suitable form (graphically, cf. (Amprion, et al., 2011)) as a sum over 24 hours for all bidding zones. Hourly values for each bidding zone are available for download as time series in a common format.

4.2.2 Price convergence

Problem

Price convergence as an effect might be considered an indicator of the success of market coupling. Market participants can use this indicator to determine which bidding zones are fully coupled at the time.

Objectives

Market participants can use the indicator to access data on price convergence of current and future network configurations on a daily basis. This information is helpful for daily analyses of the current situation (e.g. seasonal fluctuations). Another benefit of the indicator is that upcoming changes in the network topology or in the generation capacities can be examined in parallel by means of shadow runs. This contributes to a better understanding of the market coupling process as well as the effects of changes and enables market participants to execute quick ad hoc assessments of new framework conditions. At the same time, the impact of measures on price convergence can also be systematically examined.

Proposed calculation
The calculation of the price convergence for each hour results from the realised market prices. It can be performed on an hourly basis or in aggregated form weighted by hours. Standard evaluations are, for example, the comparison between network models either with isolated market areas, without capacity restrictions, or with current capacity restrictions. Whenever a change is made in the network topography, another set of shadow runs should be included in which the planned changes have already been implemented.

Proposed implementation
The indicator covering three standard scenarios (isolated market areas, without capacity restrictions, and with current capacity restrictions) is published daily. If changes affecting the distribution of surplus are foreseeable, the indicators are also published for shadow runs in which the changes have already been implemented. On the dashboard, the indicators are presented for all participating market areas in suitable form (for example as a matrix, heat map, or also as a bar chart) for all bidding zones.

4.3 Performance of EUPHEMIA

4.3.1 Computing time

Problem
Due to the algorithm's integration into business processes of the DA market, the computing time of EUPHEMIA is limited. This means that the optimisation process is usually terminated before the globally optimal solution has been found. The quality of the result can indirectly be inferred from the time that EUPHEMIA would need to find the optimal result.
Here again, it is again important to monitor the performance in view of upcoming changes. Additional dimensions, due to combinatorial effects, can have serious implications for the computing time and, thus, for the quality of the result. Furthermore, EUPHEMIA is programmed to find the first valid solution rapidly, which is then increased iteratively. However, an additional rise in complexity can lead to no valid solution being found within the time limits and the decoupling of the electricity markets as a fallback being started (All TSOs, 2020).

Objectives
Stakeholders can evaluate the performance based on the required computing time up to the determination of the first valid solution as well as of the optimal solution. Additionally, the effects of upcoming changes on the performance of the algorithm are transparent and can be retraced.

Proposed calculation
No specific calculation is necessary to define this indicator. In addition to the officially valid instance of EUPHEMIA, a second one without a time limit is triggered simultaneously, which runs until the optimal solution is found. The times until the determination of the first valid solution and the final solution are recorded and published.

Proposed implementation
The solution times until the first valid solution and the final solution have been found are compared; both solution times are displayed in minutes on the dashboard.

4.3.2 Improvement of the solution

Problem

EUPHEMIA is programmed to find a first valid solution quickly. The solution space is then systematically scanned for further valid solutions until either all further possible solutions have been examined (optimal result) or the time limit has been reached (possibly suboptimal result). At the same time, the solution is gradually being improved. The level of welfare increased during the improvement of the result is an important information for market participants, which can be used to estimate how far the solution found is away from the optimal solution and the associated welfare.

Objectives

Market participants can obtain up-to-date information on the increase in welfare from the first valid solution to the end of the optimisation process.

Proposed calculation

This indicator is represented by a curve, with all valid solutions being plotted chronologically on the x-axis and the corresponding welfare on the y-axis. The gradient of the curve can be used to estimate the quality of the solution or the potential for improvement under uncertainty. If large increases in welfare are evident during the last iteration steps before the termination, there is a high probability that the result can still be substantially improved. The flatter the curve, the greater the probability that the result is already close to the global optimum.

Proposed implementation

The curve is represented graphically on the KPI dashboard, with one data point corresponding to one valid solution.

4.3.3 Paradoxically rejected orders

Problem

The fill-or-kill condition of block orders means that some block orders paradoxically have to be rejected (i.e. although they are “in the money”). As market participants are not compensated for PRBs, there is great interest in keeping the occurrence of PRBs as low as possible. Since the introduction of market coupling, the number of PRBs has been used as an indicator to assess the quality of the result. The focus is on changing PRBs by further developing market coupling and its influence on welfare and opportunity costs.

Objectives

Market participants can monitor and systematically analyse the number of PRBs on a daily basis. At the same time, opportunity costs and the impact of PRBs on welfare are recorded. This allows market participants to monitor any deterioration in the quality of the solution using current figures.

Proposed calculation

Both the number of PRBs and the quantity in MWh involved are available after the optimisation has been completed. The calculation of the effects on welfare can be calculated from the difference between the welfare of two solutions in which a PRB is either executed or rejected. The opportunity costs result from the price difference of the two solutions multiplied by the rejected quantity.

Proposed implementation

The number of PRBs and quantity in MWh involved are published per bidding zone as a total over 24 hours. Values for each bidding zone and each hour are available for download.

4.4 Information for the market

4.4.1 Descriptive evaluation of CBCOs

Problem

Critical network elements or CBCOs are a central input for calculating the FB domain. They provide the basis for restrictions within the optimisation problem. Having a precise knowledge of the effect of individual CBCOs helps to understand the market coupling process and to assess the current and future situations more thoroughly. Although data on CBCOs are available online, an aggregated form with corresponding evaluations is not provided on a daily basis.

Objectives

Market participants, market observers, and decision makers have access to a set of daily updated standard evaluations for CBCOs. Central results are descriptive statistics in the form of evaluations grouped over time (e.g. hourly or monthly). This enables market participants to understand the current situation with regard to critical network elements more accurately. Exemplary evaluations of CBCOs are:

- Number of critical network elements per bidding zone; average over 24 hours, minimum and maximum
- Often limiting CBCOs; top 5 of the week, month, year
- Costs/welfare losses of limiting CBCOs

Proposed calculation

Data on CBCOs and associated shadow prices are already available. The indicators are calculated using descriptive evaluations.

Proposed implementation

The detailed implementation of the descriptive indicators varies depending on the evaluation. Here again, aggregated indicators are displayed on the dashboard for a quick overview and hourly values are accessible in the download area.

4.4.2 Available capacity for trading

Problem

Not all capacities physically available are placed at the disposal of the DA market. However, it is essential for market participants to be able to assess which real export and import capacities in the bidding zones are available to the DA market. Data on RAM and F_{max} per CBCO can be accessed online, but an aggregated form with corresponding evaluations is not provided on a daily basis.

Objectives

Market participants get an overview of what proportion of physically possible cross-border capacities are made available to the DA market. The figure allows market participants to analyse quickly the current situation of cross-border capacities of individual bidding zones.

Proposed calculation

The indicator describes the proportion of RAMs in F_{max} as the sum of all CBCOs in a bidding zone and as an average over 24 hours.

Proposed implementation
The indicators are published daily as an average over all CBCOs and over 24 hours. Data are presented both in aggregated form and for individual bidding zones. Values for each hour are available for download.

4.4.3 Implicit remedial actions (FAV)

Problem
TSOs have the possibility to indicate remedial actions that cannot be explicitly represented by using implicit remedial actions, the so-called FAV. This allows TSOs to increase or reduce the RAM for individual CBCOs. Data on the FAVs per CBCO are available online, but an aggregated form with corresponding evaluations is not provided on a daily basis.

Objectives
Market participants, market observers, and decision makers can enhance their understanding of implicit RAs. In an overview, FAVs limiting the solution space as well as those increasing the solution space are communicated clearly and transparently.

Proposed calculation
The indicator describes the proportion of the FAV in relation to RAM or F_{max} per bidding zone as an average over 24 hours. Three indicators would be ideal: positive FAVs, negative FAVs, and the total of all FAVs in a bidding zone.

Proposed implementation
The indicators (positive, negative, total) are published daily as an average over all CBCOs and over 24 hours. Data are presented both in aggregated form and for individual bidding zones. Values for each hour are available for download.

4.4.4 Accuracy of the base case

Problem
The base case is the central assumption for TSOs and their foundation to determine free capacities, their measures, and consequently the input for EUPHEMIA. The base case itself depends on estimates by TSOs drawing on historical data. As a result, the quality of the base case can vary, which creates uncertainties.

Objectives
Market participants know the estimated quality of the base case and can perform their analyses and forecasts accordingly.

Proposed calculation
A possible approach to calculating the quality of the base case is to compare it with historical base cases. Using analyses of net positions and flows that have actually occurred and of those forecast in the base case, statistical key figures can be calculated that describe how precisely the base case can predict the future situation with a certain probability. In this way, base cases can be identified in which the expected deviation is greater or smaller. In order to identify a synthesis indicator that adequately describes the quality of the base case, a precise investigation of the available data is necessary.

Proposed implementation

The indicator is published as a statistical key figure on a daily basis before market coupling (pre-coupling). For the dashboard, an overview representation for all 24 hours is useful. This means that data are presented both in aggregated form and for individual bidding zones. Values for each hour are available for download.

4.4.5 Price divergence

Problem

Spikes in electricity prices and spreads are a well-known phenomenon in the electricity market. Since monitoring all participating markets is resource-intensive, an indicator published by a central body to identify the risk of spikes in prices and spreads is a helpful source of information for market participants.

Objectives

Market participants can use the indicator to estimate the risk of price or spread spikes quickly. As a result, events in other market areas can be anticipated more easily. The estimate can also serve as a comparison with other analyses.

Proposed calculation

The spike warning can be derived from assumptions of the base case drawing on historical values.

Proposed implementation

The indicator is published daily before market coupling (pre-coupling) as a dimensionless scale for risk assessment (e.g. danger levels: 1 = low; 5 = very high). For the dashboard, an overview of each bidding zone for all 24 hours is useful. Values for each hour are available for download.

5 Bibliography

ACER, 2017. *Annex I Congestion income distribution methodology in accordance with Article 73 of the Commission Regulation (EU) 2015/1222 of 24 July 2015 establishing a Guideline on Capacity Allocation and Congestion Management,* : .

ACER, 2017. *Decision of the Agency for the cooperation of energy regulators No 07/2017 of 14 December 2017 on the congestion income distribution methodology.* : .

All NEMO Committee, 2019. *CACM Annual Report 2018; http://www.nemo-committee.eu/assets/files/cacm-annual-report-2018.pdf.* : .

All TSOs, 2011. *„CWE Enhanced Flow-Based MC feasibility report,* : .

All TSOs, 2014. *Documentation of the CWE FB MC solution as basis for the formal approval-request; Annex 16.18 Flow-Based "intuitive" explained.* [Online]
Available at:
https://www.jao.eu/support/resourcecenter/overview?parameters=%7B%22IsCWEFBMCRelevantDocumentation%22%3A%22True%22%7D
[Accessed 05 05 2020].

All TSOs, 2020. *All TSOs´proposal for Use of Congestion Income Methodology in accordance with Article 19(4) of the Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity; For Public Consulation.* : .

All TSOs, 2020. *CWE Report: Comparsion Flow-Based Plain and Flow-Based Intuitive,* : .

Amprion; APG; creos; elia; hertz, 50; Rte; TenneT; BW, Transnet, no date. *Annex 16.6 Information regarding LTA inclusion; Documentation of the CWE FB MC solution as basis for the formal approval-request (Brussels, 9th May 2014).* s.l.:s.n.

Amprion, et al., 2019. *Documentation of the CWE FB MC solution; April 2019 - version 4.1, applicable as of May 21st 2019,* : .

Amprion, et al., no date. *Explanatory note DA FB CC methology for Core CCR, For Public Consultation.* s.l.:s.n.

Amprion, et al., 2011. *CWE Enhanced Flow-Based MC feasibility report, version 1.0 - 15th March 2011,* : .

Auer, H. & Fleischhacker, A., 2019. *Energy Systems and Grids.* Wien: TU - Wien.

BDEW Bundesverband der Energie- und Wasserwirtschaft e.V., 2019. *Redispatch in Deutschland Auswertung der Transparenzdaten April 2013 bis einschließlich September 2019 (only german).* s.l.:s.n.

Böhmer, S., 2015. *Methoden zur Strommarktkopplung (only german).* 2015: Grin.

Bundesnetzagentur, 2020. *Netz- und Systemsicherheitsmaßnahmen, Erstes Quartal 2019 (only german).* [Online]
Available at:
https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Allgemeines/Bundesnetzagentur/Publikation

en/Berichte/2019/Quartalsbericht_Q1_2019.html
[Accessed 07 04 2020].

CCR Core TSOs' Cooperation, 2019. *Derogation proposals of Core TSOs in accordance with Art. 16.9 Regulation 2019/943: Core common document,* s.l.: s.n.

E-Control, kein Datum *Erlöse aus grenzüberschreitendem Engpassmanagement, Bericht gemäß Punkt 6.5 der Engpassmanagement-Leitlinien (only german).* s.l.:s.n.

EEX, 2020. *EEX Group DataSource SFTP CSV - Interface Specifications, Version 010.* [Online]
Available at: https://www.eex.com/blob/93736/dc22d9eab28400a24d84fc3b13009718/eex-group-datasource-sftp-csv-interface-specification-de-en-data.pdf
[Accessed 07 04 2020].

EFET, ifiec europe, 2018. *Open letters to CWE regulators regarding the transparency of data provided by TSOs in the framework of flow-based market coupling.* s.l.:s.n.

Energinet_DK, Kraftnät, S., Fingrid & Statnett, no date. *Methodology and concepts for the Nordic Flow-Based Market Coupling Approach.* s.l.:s.n.

EU Open Data Support, 2014. *Training Module 2.2, Presentation metadata, Open Data & Metadata Quality.* [Online]
Available at:
https://www.europeandataportal.eu/sites/default/files/d2.1.2_training_module_2.2_open_data_quality_en_edp.pdf
[Accessed 07 04 2020].

Eurelectric; MPP; EFET, 2016. *Joint statement of transparency on flow-based market coupling parameters,* s.l.: s.n.

Eurelectric, 2019. *Eurelectric's response to ENTSOE on the algorithm methodology review incl. SIDC and ID auctions.* [Online]
Available at: https://cdn.eurelectric.org/media/3941/algorithmreview_sidc_position-2019-030-0436-01-e-h-ED58E92B.pdf
[Accessed 17 02 2020].

Eurelectric, 2020. *Transparency of system operators on cross-border exchange capacities: a survey paper (A Eurelectric position paper).* s.l.:s.n.

European Commission, 2015. *Commission Regulation (EU) 2015/1222 of 24 July 2015 establishing a guideline on capacity allocation and congestion management.* s.l.:s.n.

European Commission, 2016. *Commission Regulation (EU) 2016/1719 of 26 September 2016 establishing a guideline on forward capacity allocation.* s.l.:s.n.

European Commission, 2016. *H2020 Programme; Guidelines on FAIR Data Management in Horizon 2020, Version 3.0.* [Online]
Available at: https://ec.europa.eu/research/participants/data/ref/h2020/grants_manual/hi/oa_pilot/h2020-hi-oa-data-mgt_en.pdf
[Accessed 05 04 2020].

European Parliament and the Council, 2019. *Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity.* s.l.:s.n.

Joint Allocation Office, 2019. *JAO Publication Handbook.* s.l.:s.n.

Joint Allocation Office, no date. *CWE Flow-based Market Coupling, Q&A.* s.l.:s.n.

Minister of State for the Cabinet Office and Paymaster General, 2016. [Online]
Available at:
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/78946/CM8353_acc.pdf
[Accessed 07 04 2020].

NEMO Committee, 2019. *EUPHEMIA Public Description.* s.l.:s.n.

Nside, 2016. *Euphemia Public Description.* [Online]
Available at: https://www.n-side.com/wp-content/uploads/2017/08/Euphemia-Public-Presentation.pdf
[Accessed 10 11 2019].

PCR, 2014. *Documentation of the CWE FB MC solution as basis for the formal approval-request (Brussels, August 2014); Annex 16.18 Flow-Based "intuitive" explained.* [Online]
Available at: https://www.acm.nl/sites/default/files/old_publication/bijlagen/13001_annex-16-18-flow-based-intuitive-explained.pdf
[Accessed 11 04 2020].

Rochfort, J., 2015. *Guidance Document: Version Control.* [Online]
Available at: https://www.nottingham.ac.uk/governance/records-and-information-management/documents/guidance-documents/version-control---copy.pdf
[Accessed 07 04 2020].

Schönheit, D., Weinhold, R. & Dierstein, C., 2020. The impact of different strategies for generation shift keys (GSKs) on the flow-based market coupling: A model-based analysis of Central Western Europe (only german). *Applied Energy*.

Tomorrow, 2020. *www.electricitymap.org.* [Online]
Available at: https://www.electricitymap.org/?lang=de
[Accessed 07 04 2020].

6 List of Figures

7 List of Tables

8 List of Abbreviations

ACER	Agency for the Cooperation of Energy Regulators
AMR	Adjustment for minimum RAM
APG	Austrian Power Grid
API	Application programming interface
ATC	Available transfer capacity
BDEW	Bundesverband der Energie- und Wasserwirtschaft
BNetzA	Bundesnetzagentur
CACM	Capacity Allocation and Congestion Management
CB	Critical branch
CBCO	Critical branch/critical outage
CCR	Capacity calculation region
CGM	Common grid model
CNEC	Critical network element and contingencies
CS	Consumer surplus
CSV	Comma-separated values
CWE	Central West Europe
D-1	Day before delivery
D-2	Two days before delivery
D-2CF	Day-2 congestion forecast
DA	Day-ahead
DACF	Day-ahead congestion forecast
DOI	Digital object identifier
EC	External constraints
EEX	European Energy Exchange
EFET	European Federation of Energy Traders
et al.	lat.: et alii
EUPHEMIA	EU Pan-European Hybrid Electricity Market Integration Algorithm
EUR	Euro
FAV	Final adjustment value
FB	Flow-based
FBMC	Flow-Based Market Coupling
F_{max}	Maximum possible flow in MW
FPF	Financial power flows
F_{ref}	Reference flow in MW
FRM	Flow reliability margin
FTR	Financial transmission rights
GSK	Generation shift key
I_{max}	Maximum possible flow in amperes
ID	Intraday

JAO	Joint Allocation Office
JTSOS	Joint TSO pre-coupling system
KPI	Key performance indicator
LTA	Long-term allocations
LTN	Long-term nominations
MCP	Market clearing price
MIC	Minimum income orders
MinRAM	Minimum remaining available margin
NEMO	Nominated electricity market operator
NP	Net position
NRA	National regulatory authority
PS	Producer surplus
PCR	Price coupling of regions
PPF	Physical power flows
PTDF	Power transfer distribution factor
PUN	Prezzo Unico Nazionale
RA	Remedial action
RAM	Remaining available margin
RAO	Remedial action optimisation
RSS	Rich site summary
SAP	Single allocation platform
SDAC	Single day-ahead coupling
SPAIC	Standard process to communicate on and assess the impact of significant changes
TSO	Transmission system operators
UIOSI	Use it or sell it
UTC	Coordinated universal time

9 Annex 1 | Methodology of the Questionnaire Survey

The aim of the survey was to identify the view of electricity traders on transparency requirements in Flow-Based Market Coupling. The topic of transparency in relation to processes and data availability was examined.

Participants were explicitly chosen according to their thematic relevance and thus preselected. The target group for the survey were people from trading departments of energy suppliers. Geographically, the survey was limited to companies in Austria.

No screening question was included in the questionnaire, as the participants were preselected. In addition, no demographic data was collected. The first part of the survey included questions with respect to understanding the FBMC process. In the second part, the questions covered the subject of data availability.

In general, given the small population, the response rate was satisfactory. When interpreting the results, however, it must be taken into account that a sample with 13 questionnaires answered is of course small.

10 Annex 2 | Further Reading on FBMC

For the literature prepared in Chapter 2.1, it is assumed that facts that were presented in an older document version (e.g. CWE-FB documentation from 2011) and were not explicitly revoked or changed later on in a more recent version (e.g. CWE-FB documentation from 2016) are still valid.

The information presented here is largely based on the documents officially available for FBMC:

- **Documentation of the CWE FB MC solution, version 4.1** (author: CWE TSOs; date: April 2019, applicable as of 21 May 2019) – (Amprion, et al., 2019)
- **CWE Enhanced Flow-Based MC feasibility report, version 1.0** (author: CWE TSOs; date: 15.03.2011) – (Amprion, et al., 2011)
- **Explanatory note DA FB CC methodology for Core CCR, for Public Consultation** (author: Core TSOs; date: no date) – (Amprion, et al., no date)

Furthermore, scientific publications, and current guidelines and regulations were accessed; they are cited accordingly in the text.

The following literature (some German) is recommended for deeper insights into the subject of FBMC. This is by no means an exhaustive list, but rather a recommendation by the authors for possible documentation and articles in professional journals. The authors assume no responsibility for the accuracy of the information in further literature.

- **Methoden zur Strommarktkopplung in Europa: „Net-Transfer-Capacities-“ und „Flow-Based-Verfahren“ zur Allokation von grenzüberschreitenden Übertragungskapazitäten** (author: Sebastian Tobias Böhmer; date: 2015; student thesis at the Karlsruhe Institute of Technology)
- **The flow-based market coupling in Central Western Europe: Concepts and definitions** (authors: Kenneth Van den Bergh, Jonas Boury, Erik Delarue; date: 2016; published in: The Electricity Journal)
- **Methodology and concepts for the nordic flow-based market coupling approach** (authors: Energinet, Svenska Kraftnät, Fingrid, Statnett; no date)
- **Flow-based market coupling – What drives welfare in Europe´s electricity market design?** (authors: Simon Voswinkel, Björn Felten, Tim Felling, Christoph Weber; date: 19.07.2019; published in: House of Energy Markets and Finance)
- **Flow-based market coupling revised – part I: Analyses of small- and large-scale systems** (authors: Björn Felten, Tim Felling, Paul Osinski, Christoph Weber; date: 11.06.2019; published in: House of Energy Markets and Finance)
- **The impact of different strategies for generation shift keys (GSKs) on the flow-based market coupling domain: A model-based analysis of Central Western Europe** (authors: David Schönheit, Richard Weinhold, Constantin Dierstein; date: 2020; published in: Applied Energy)

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