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Distributed energy resources and electricity balancing: visions for future organisation

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Research Project Report
Issue 2022/02 - February 2022

Published by
European University Institute (EUI)
Via dei Roccettini 9, I-50014
San Domenico di Fiesole (FI)
Italy
doi:10.2870/95157
ISBN:978-92-9466-182-1

Co-funded by the Erasmus+ Programme of the European Union

The European Commission supports the EUI through the EU budget. This publication reflects the views only of the author(s) and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Abstract

This Report discusses how electricity balancing may best be organised in a future with greater penetration of distributed energy resources (DERs). Increased DER penetration can pose challenges to electricity balancing, while, at the same time, DERs can also help to balance the system more cost-effectively. Currently, participation by DERs in electricity balancing markets, whether individually or aggregated, is still somewhat limited. In the debate among practitioners and academics, most attention has been devoted to reducing market entry barriers for DERs. In this Report, we go one step further: we analyse whether the current organisation of the balancing mechanism is future-proof.

This Report comprises an introduction, four sections and conclusions. After the introduction, Section 2 explains the working of the balancing mechanism and introduces the relevant EU legislation. Section 3 shows that the current organisation of balancing mechanisms in the EU is a legacy rather than a well-thought-through design choice. We explain that alternative setups are possible in theory and that their performance in practice depends on the context. To assess different balancing setups, we introduce a multidimensional framework and illustrate it by comparing the current setups in the EU and the US. In Section 4, we highlight the challenges that the balancing mechanism in the EU is currently facing with increasing shares of DERs. We argue that, in the medium to long term, it will become increasingly challenging to operate the balancing mechanism cost-effectively without adjusting its organisation. In Section 5, we introduce two alternative ways of organising it in the future: the 'Super SO model' and the 'Local SO model'. The key question is whether it would be easier to manage seams within a balancing area or seams between balancing areas. The main challenge with the Super SO model would be that a global optimum, considering all voltage levels and local issues, is difficult to achieve. Even though the Local SO model might be more pragmatic, the main challenge with this model would be implementing it in a way that limits fragmentation of balancing markets, which would have severe implications for efficiency and competition.

Keywords

Distributed Energy Resources, Electricity Balancing Markets, Power Market Design, Power Market Regulation, Power Systems Governance, Distribution System Operator, Energy Communities

Note

Several paragraphs in Section 4 of this Report are based on a previous publication: Schittekatte, T., Reif, V., Meeus, L., 2021. Welcoming new entrants into European electricity markets. Energies 14, 4051. https://doi.org/10.3390/en14134051. We would like to thank Jean-Michel Glachant, of the Florence School of Regulation, Leonardo Meeus, of the Florence School of Regulation and Vlerick Business School, and Anselm Eicke, of MIT Energy Initiative and Hertie School, for their valuable feedback on a draft of this Report. The Report has received funding from Grid Singularity GmbH. It reflects the opinions of the authors and any mistake remains the authors' responsibility.

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Abbreviations

AC: Alternating Current
ACER: European Union Agency for the Cooperation of Energy Regulators
aFRR: automatic Frequency Restoration Reserves
BA: Balancing Authority
BRP: Balance Responsible Party
BSP: Balancing Service Provider
CACM: GL Capacity Allocation and Congestion Management Guideline
CEC: Citizen Energy Community
CEER: Council of European Energy Regulators
DER: Distributed Energy Resource
DLMP: Distribution Locational Marginal Prices
DSO: Distribution System Operator
EB GL: Guideline on Electricity Balancing
ENTSO-E: European Network for Transmission System Operators for Electricity
EIM: Western Electricity Imbalance Market
ERCOT: Electric Reliability Council of Texas
EU: European Union
FCP: Frequency Containment Process
FCR: Frequency Containment Reserves
FRCE: Frequency Restoration Control Error
FRP: Frequency Restoration Process
FRR: Frequency Restoration Reserves
FERC: Federal Energy Regulatory Commission
GB: Great Britain
kW: Kilowatt
IDGCT: Intraday Gate Closure Time
ISO: Independent System Operators
ISP: Imbalance Settlement Period
LFC: Load-Frequency Control
LMP: Locational Marginal Prices
mFRR: manual Frequency Restoration Reserves
MW: Megawatt
NEMO: Nominated Electricity Market Operator
P2P: Peer-to-Peer
PF: Power Factor
PJM: Pennsylvania, New Jersey and Maryland
PV: Photovoltaic
PX: Power Exchange
RCC: Regional Coordination Centres
REC: Renewable Energy Community
RES: Renewable Electricity Sources
RR: Restoration Reserves
RSC: Regional Security Coordinators
RTO: Regional Transmission Operator
SO: System Operator
SO GL: Guideline on Electricity Transmission System Operation
TSO: Transmission System Operator
V2G: Vehicle to Grid
VPP: Virtual Power Plant
UK: United Kingdom
US: United States

1. Introduction

This Report analyses how electricity balancing can be organised in a future with greater penetration of distributed energy resources (DERs). In today's European power systems, electricity balancing is defined as all actions and processes through which transmission system operators (TSOs) continuously ensure the maintenance of system frequency within a predefined stability range. DERs are defined as assets directly connected to the distribution network or located behind the meters of consumers connected to distribution networks. They include small-scale photovoltaics (PV), rooftop PV, wind parks and other distributed generation, thermal and electrical energy storage and the management of more flexible and price-responsive electricity demand (Burger and Luke, 2017). Greater penetrations of DERs can create challenges to balancing, while, at the same time, DERs can also help to balance the system more cost-effectively.

Currently, participation of DERs in electricity balancing markets, whether individually or aggregated, is still somewhat limited. A recent overview of entry barriers in the different Member States of the European Union (EU) can be found in SmartEn (2021a). The European Network of Transmission System Operators for Electricity (ENTSO-E) and the major associations of European distribution system operators (DSOs) – CEDEC, E.DSO, Eurelectric and GEODE – acknowledge that increasingly relying on intermittent renewable electricity sources (RES) to achieve our climate goals, while, at the same time, decommissioning conventional power plants, requires the development of new approaches to system operation and to the sourcing of ancillary services from DERs (CEDEC et al., 2021). Article 2(48) of Directive (EU) 2019/944 defines 'ancillary services' as a range of functions which system operators contract in order to guarantee system security. Ancillary services include balancing and various other services, such as reactive power provision and black-start capability, but not redispatch. In this Report, when we use the term 'system services' we mean ancillary services and redispatch. As DERs are, in general, relatively flexible, i.e. able to adjust the volumes of electricity withdrawn from or injected into the grid at short notice, they are considered very suitable to provide all types of system services.

Over recent years, electricity balancing markets have been harmonised and are in the process of being integrated across borders, as is discussed in Meeus et al. (2020). In the debate among practitioners and academics, most attention has been devoted to reducing entry barriers to the participation of DERs in balancing markets. For recent overviews and case studies, see, for example, Poplavskaya & de Vries (2019) and Schittekatte et al. (2021b). These studies take the current organisation of balancing markets, i.e. the roles and responsibilities, as given. However, with increasing participation of DERs in wholesale markets, local energy markets and system service markets, it becomes harder to separate market and grid operation. Therefore, in this Report we go one step further. We analyse whether the current organisation of the balancing mechanism is future proof. We discuss the extent to which effective interaction with DERs requires the re-organisation of the balancing system.

The Report is structured as follows. First, in Section 2 we describe the basic working of electricity balancing and provide a brief history of how electricity balancing has evolved over the years. Readers familiar with electricity balancing can directly proceed to the following three sections. In these three sections, we discuss in more depth the organisation of balancing mechanisms and the impact of increased participation of DERs. In all three sections, we apply the same multidimensional analytical framework, that consists of the following dimensions, which are the most relevant to the organisation of the balancing mechanism:

1. Coordination between the electricity balancing market and grid operation
    a. Consideration of the network in the area spanned by a balancing market operator
    b. Consideration of the network between the areas of different balancing market operators
2. Coordination between the electricity balancing market and wholesale markets
3. Non-discriminatory conditions for entry in electricity balancing markets
4. Non-discriminatory exposure to imbalance prices

In Section 3, we introduce the framework for analysing the organisation of the balancing mechanism and apply it to how electricity balancing is organised today in the EU and the United States (US). In Section 4, aided by the same framework, we discuss challenges in electricity balancing with greater penetration by DERs. In Section 5, we introduce and discuss two alternative setups for electricity balancing. Finally, we end the Report by offering some conclusions.

2. Basics and a brief history of electricity balancing

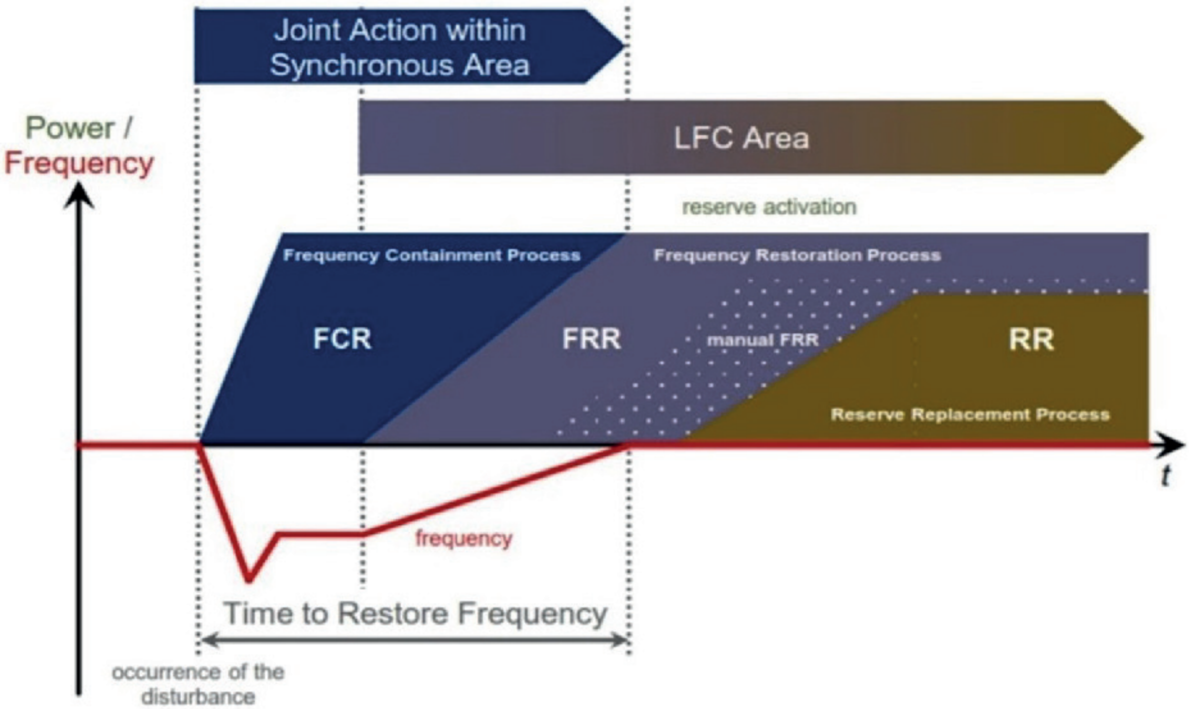
This section consists of three parts[1]. First, we describe the load-frequency control (LFC) process that lies at the heart of matching supply and demand for electricity in real time. Then, we discuss the four main building blocks of the balancing mechanism. Last, we provide a brief history of how electricity balancing gradually became more market-based and introduce the main provisions in EU legislation that were vital in this evolution.

2.1 The load-frequency control process

In a power system, injection into the grid must equal withdrawal from the grid at all times while respecting all grid (thermal, voltage and stability) security limits. If electricity injections and withdrawals deviate from each other, the frequency starts to depart from its reference value, which is 50 Hz in Europe and 60 Hz in the US. A deficit of injections with respect to withdrawals results in a frequency drop, while a deficit of withdrawals with respect to injections results in a frequency increase. If the frequency deviates too much from its reference value, protection devices start to disconnect generation and load. Such disconnections can lead to a cascading failure that can result in a system-wide blackout. TSOs put in place LFC procedures, often referred to as 'electricity balancing', to manage real-time power balances for each LFC area.

There are several types of reserves that meet different operational needs. In practical terms they differ mainly in response time and maximum duration of delivery. The activation of different reserves after a frequency drop/spike is shown in Figure 1.

Figure 1: A frequency drop and the reserve activation structure (ENTSO-E, 2018)[2]



1 Some elements in this section rely on Section 6 of Schittekatte et al. (2020) and Section 4 of Schittekatte et al. (2021b).

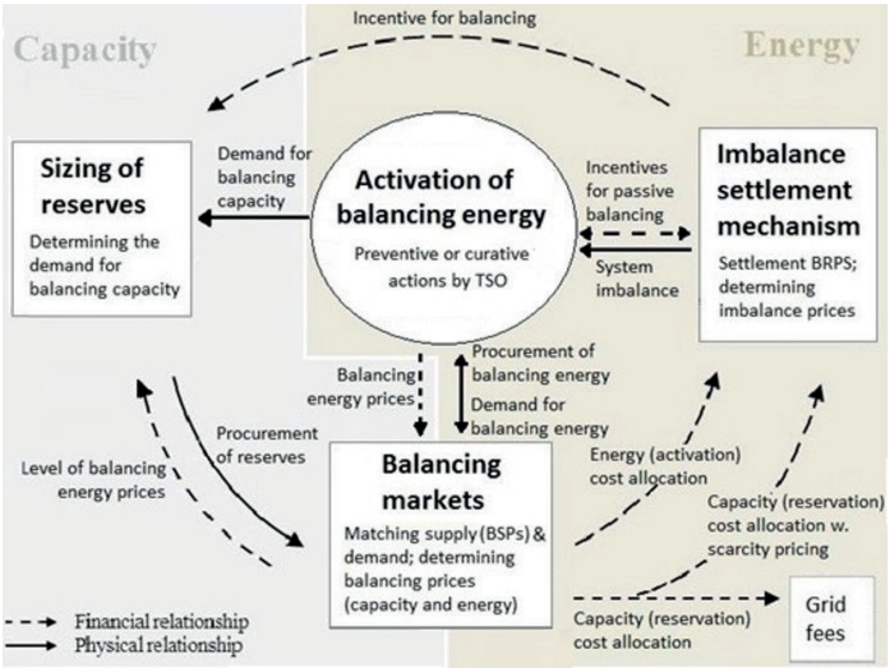
2 Three remarks should be added to this figure: (a) the activation process shown is the typical activation process for a TSO with a reactive approach to the activation of balancing energy; (b) FCR is assumed to be fully replaced by FRR; (c) inertia, the first source of energy limiting frequency drop, is not depicted in the figure. Inertia is an inherent physical property of e.g. rotating generators and motors. Inertia slows down a frequency drop/spike immediately after a sudden mismatch of injections and withdrawals, and does not need any control signal.

From the moment the frequency drops/spikes, frequency containment reserves (FCR) are almost instantaneously activated to stabilise the drop/spike. FCR are the fastest type of reserves and are operated using a joint process involving all TSOs in a synchronous area. Within a couple of minutes, the frequency restoration process (FRP) starts. The FRP is operated for each LFC area. First automatic frequency restoration reserves (aFRR) and later manual frequency restoration reserves (mFRR) are activated to relieve FCR and aFRR respectively. The aFRR are activated automatically by a controller operated by the TSO, while the mFRR are activated on specific manual requests from the TSO. FRR aim to restore the frequency to its nominal value. Finally, after about 15 minutes or more, replacement reserves (RR), the slowest type of reserves, can support or replace FRR. Not all TSOs make use of RR[3].

2.2 The main building blocks in current electricity balancing mechanisms

The organisation of the electricity balancing mechanism consists of more than the LFC process that manages the activation of balancing energy. We consider three additional building blocks: balancing markets, the imbalance settlement mechanism and the sizing of reserves. The different building blocks are financially or physically interlinked as shown in Figure 2.

Figure 2: The four building blocks in the balancing mechanism and their relationships (adapted from Hirth and Ziegenhagen, 2015)



The TSO operates the balancing capacity and balancing energy markets, and acts as the single buyer in these markets. On the supply side, Balancing Service Providers (BSPs), market participants with reserve-providing units or reserve-providing groups, offer balancing services to TSOs. The amount of balancing capacity procured is determined during the balancing reserve sizing process. The activation strategy for balancing energy cleared in balancing energy markets can influence the demand for balancing energy and prices. The amount of balancing energy activated depends on the system imbalance. A system imbalance occurs when the aggregate of (contractual) positions, meaning the energy volume of Balance Responsible Parties (BRPs) declared to the TSO at intraday gate closure, differs from the total allocated volume attributed to the BRPs. The allocated volume means an energy volume physically injected into/withdrawn from the system and attributed to a BRP. A BRP is a market party or its representative responsible for imbalances. A BRP can be an individual gener-

3 All balancing processes follow similar principles in terms of general roles, responsibilities and requirements, although slight differences due to product specificities and timing exist among different reserve types.

ator or industrial consumer connected to the transmission grid, a retailer or a portfolio of generators/consumers (balancing group). BRPs are subject to imbalance prices, which (ideally) reflect the cost of activating balancing energy to address system imbalances. Imbalance prices should incentivise BRPs to be balanced in moments of stress, and (in some cases) can even encourage BRPs to help the system by being out of balance in the opposite direction to the system imbalance. This is referred to as passive balancing. Balancing capacity costs can be recovered via the imbalance settlement or, alternatively, via transmission tariffs paid by all grid users.

It should be noted that the way balancing mechanisms are designed strongly influences trade in other short-term markets. For example, high imbalance prices encourage rebalancing by trading in the intraday market. Also, high reserve requirements or an overlap between the balancing market and other short-term markets can reduce the supply in short-term markets. In this Report, we focus mostly on the organisation of balancing markets and the imbalance settlement mechanism.

2.3 A brief history of electricity balancing markets in the EU and key legislation

Balancing energy markets, i.e. marketplaces where balancing products are procured by the TSO from BSPs, were gradually introduced and refined. At the start of the market-building process, most national balancing markets were technical mechanisms based on long-term bilateral deals between conventional generators and the TSO. The 2005/2006 Sector Inquiry conducted by the European Commission found that balancing markets were not functioning well in most Member States. Concentration in balancing markets was found to be even higher than in the underlying wholesale markets due to high entry barriers. Examples of concentration levels in (upward and downward) balancing energy markets in three Member States are shown in Figure 3 (European Commission, 2007).

Figure 3: Volumes supplied (MWh) by generators aggregating secondary and tertiary reserves between January 2003 and January 2005. Adapted from European Commission (2007)

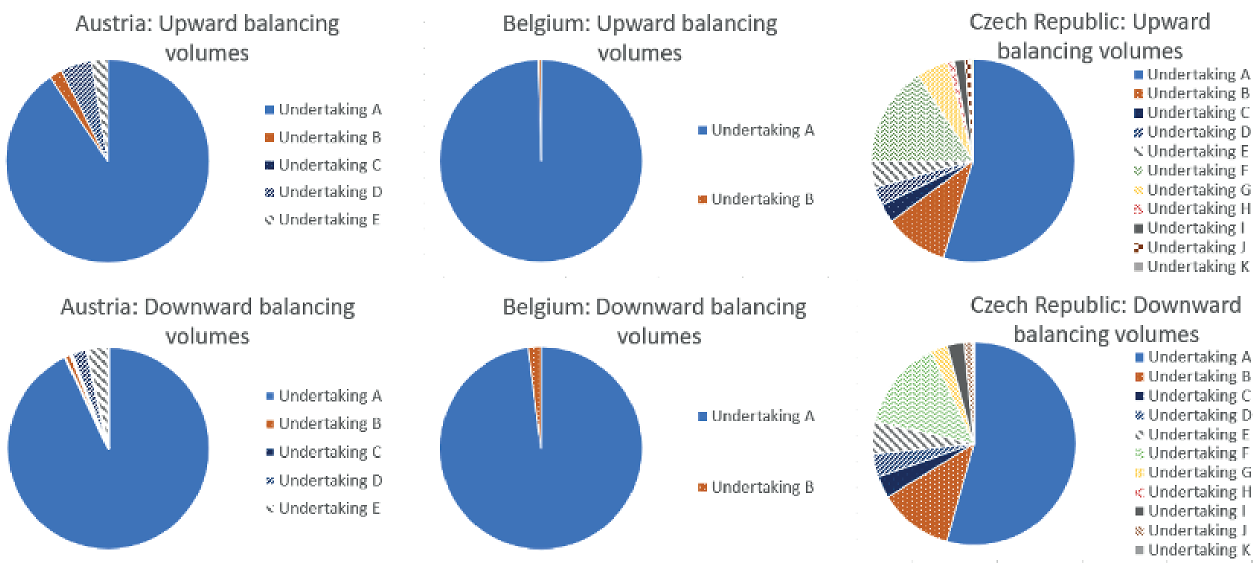


Figure 2 shows that, in both Austria and Belgium, between 2003 and 2005, one BSP supplied about 90% or more of the activated upward and downward balancing energy[4]. In the Czech Republic, there were more BSPs active in the market, yet the dominant BSP supplied more than 55% of all balancing energy. The high concentration levels gave generators scope for exercising market

4 As a reference, Brijs et al. (2017) provides data about the total amount of balancing energy over total consumption. For Belgium, France, Germany and the Netherlands the yearly amount of balancing energy equals about 1-2% of annual consumption. This proportion has generally been reducing over the years due to many factors, among which improved trading possibilities in intraday markets, balancing market design improvements, cross-border coordination and forecast improvements. For the German case see e.g., Ocker and Ehrhart (2017).

power or effectively ruled out the implementation of (short-term) market-based arrangements in the balancing timeframe.

The adoption of the Third Energy Package in 2009 and the subsequent adoption of electricity network codes and guidelines – especially Commission Regulation (EU) 2017/2195 establishing a Guideline on Electricity Balancing (EB GL) and Commission Regulation (EU) 2017/1485 establishing a Guideline on Electricity Transmission System Operation (SO GL) – created the framework of technical, operational and market rules which have since governed the functioning of balancing markets and facilitated their harmonisation. The EB GL primarily harmonises market arrangements related to balancing: the design of balancing markets and the imbalance settlement mechanism. However, as balancing happens in real time, balancing market arrangements cannot be fully decoupled from system operation and system security. Therefore, the SO GL is also relevant when discussing balancing. This guideline primarily addresses the sizing of reserves and the activation strategy for balancing energy in real time.

The integration of balancing markets across borders to reduce the level of concentration, despite being deemed an effective solution, was not expected to happen quickly. The slow pace of balancing market integration was due to large differences between national balancing market designs and strong dependency on (national) operational practices. Balancing markets and products first had to be harmonised. Currently at the EU level there is one standard balancing energy product for aFRR, two standard balancing energy products for mFRR and one standard balancing energy product for RR[5]. At the national level, TSOs are allowed to introduce also specific products, but approval by the national regulator is needed. Furthermore, to reduce concentration levels in the short term, harmonisation allowed the entry of new market players. Balancing market entry has proven to be much more complex than in the wholesale markets. In this regard, Regulation (EU) 2019/943 on the internal market for electricity, which was part of the Clean Energy Package, stated that a new Network Code (NC) could be developed in the area of demand response (DR), including rules on aggregation, energy storage and demand curtailment. It can be expected that this new NC, which has been recently confirmed in the priority list for new network codes for 2020-2023 (European Commission, 2020), will remove many of the current entry barriers[6]. Figure 4 gives a brief graphical overview of the relevant EU packages, including network codes and guidelines.

Figure 4: EU Packages including Network Codes (NCs) and Guidelines (GLs) relevant to electricity balancing.

5 There is typically no balancing energy product for FCR. FCR are only marketed as symmetric balancing capacity products, i.e. they are able to increase and reduce electricity injection/withdrawal during a certain time period. As activation of FCR can happen in both directions, the volume of energy activations is netted out.

6 Additional relevant references in this regard are, among others, the ASSET study on demand-side flexibility on behalf of the European Commission (Küpper et al., 2020), the reaction of the Council of European Energy Regulators (CEER) on the ASSET study (CEER, 2021), and a position paper of SmartEn (2021b) on the topic.

3. The organisation of balancing in practice and theory

This section consists of three parts. First, we discuss how balancing markets are currently organised in the EU[7] and we compare this with the equivalent arrangements in the US. Second, we introduce the analytical framework that is used throughout this Report. Third, we illustrate the framework by applying it to the current organisation of the EU and US balancing mechanisms.

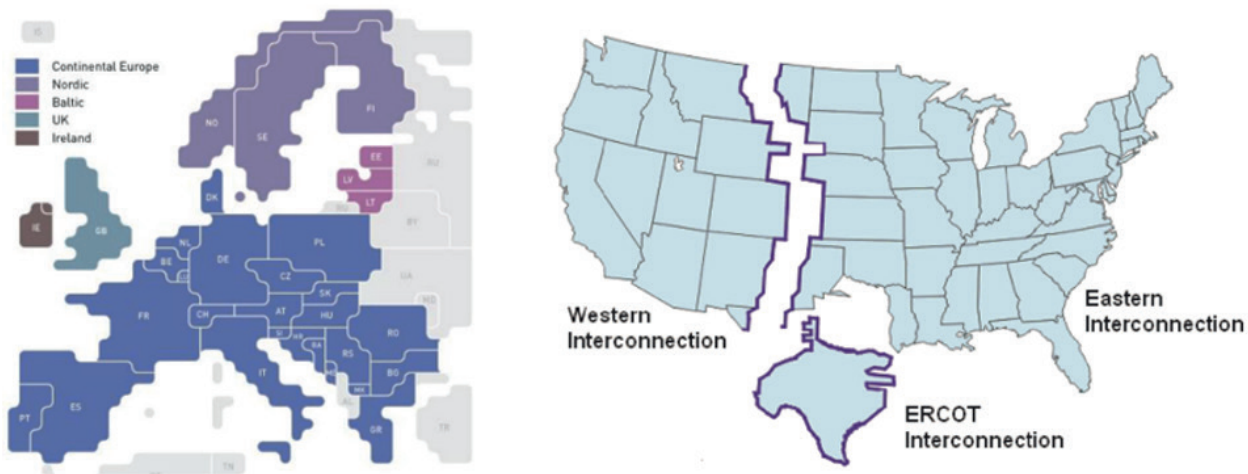
3.1 Balancing organisation in practice: the European Union and the US

This section has three parts. Each part discusses the geographical areas relevant to different dimensions of balancing: the physically relevant area, the relevant area for operations and the relevant area for trade. In this Report, the relevant areas for operations and trade are the most important.

3.1.1 Physics: Over what area is the frequency common?

The frequency of an alternating current (AC) power grid regulated by the electricity balancing mechanism is the same, in each time instance, over a synchronous area. Currently, there are five synchronous areas covering the European Union, Norway, Switzerland and the United Kingdom: Continental Europe, the Nordics, the Baltics (part of the Russian synchronous area), Great Britain and Ireland/Northern Ireland (Figure 5, left). For example, in the case of the Continental European synchronous area and under the assumption that there are no network constraints, a drop in frequency due to a generator in Portugal tripping can lead to a disconnection of devices in Bulgaria. In the US there are currently three synchronous areas: the Western, Eastern and Texas interconnections (Figure 5, right).

Figure 5: Synchronous areas in Europe (ENTSO-E, 2014) and the US (Kaplan, 2009)



3.1.2 Operations: Over what area are balancing processes performed?

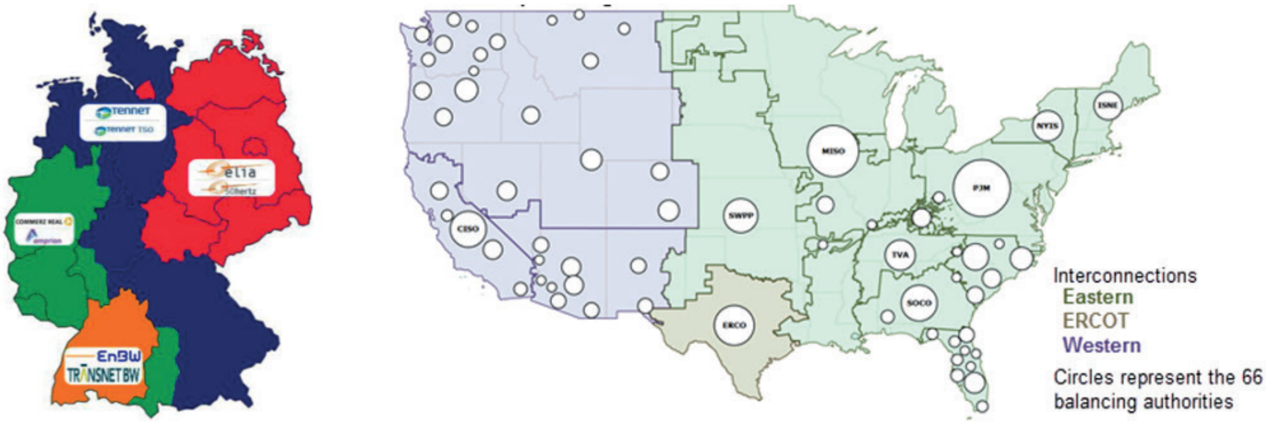
The geographical area over which the frequency containment process (FCP) is operated is the synchronous area. The geographical area over which the frequency restoration process (see also Figure 1) is operated is called the LFC area. In more technical terms, the FRP aims to restore the frequency to its nominal value by regulating the frequency restoration control error (FRCE), i.e. the difference between the reference and the real-time power balance for each LFC area, towards zero. The exact delineation of LFC areas differs across the different synchronous areas in Europe.

7 In this section, reference to the European Union (EU) is meant to include Norway and Northern Ireland, which, while not being EU Member States, follow the EU internal electricity market rules.

In theory, the LFC area can be as large as the synchronous area. Indeed, in the case of both the British and Irish synchronous areas, the LFC area corresponds to the synchronous area operated by National Grid ESO, and Eirgrid and SONI jointly respectively (Eirgrid and SONI, 2020). In the Nordics, a new balancing model is currently being implemented. The demand for balancing energy is determined for each bidding zone, each corresponding to one LFC area, but optimisation of balancing energy activation is done for the whole synchronous area (Svenska Kraftnät et al., 2018). Finally, in Continental Europe, each LFC area corresponds to the control area of a TSO (ENTSO-E, 2021a). For example, Figure 6 (left) shows the four German LFC areas, each operated by a TSO. With several LFC areas within a synchronous area, frequency control is managed by monitoring power flows over the LFC area borders: the actual power flows between LFC areas are compared to the scheduled flows (calculated based on exchanges in the day-ahead and intraday markets) to find the FRCE in each LFC area. Finally, the Baltics are currently mostly dependent on the Russian Federation for electricity balancing processes as they are part of the Russian Synchronous area. They are awaiting synchronisation with Continental Europe.

In the US, electricity balancing processes are organised by balancing authorities, which are the entities responsible for maintaining the energy load-resource balance within specific geographical areas. In the parts of the US where the power sector is liberalised, the Independent System Operator (ISO) or the Regional Transmission Operator (RTO) is the balancing authority. In other parts, the vertically integrated utility is the balancing authority. The Texas Interconnection is a special case with one balancing authority, the Electric Reliability Council of Texas (ERCOT), covering the entire synchronous area. In the other synchronous areas, there are several balancing authorities. Figure 6 (right) shows the balancing authorities in the US.

Figure 6: The German LFC areas (Wikiwand, 2017) and the US balancing authorities (EIA, 2016)



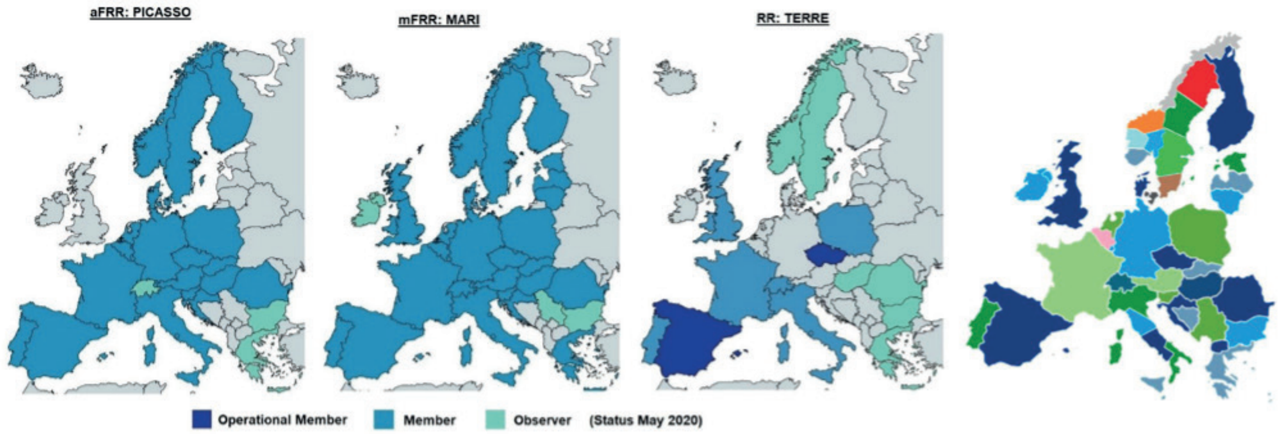
3.1.3 Trade: Over what area is balancing energy traded and how is it priced?

In Continental Europe, balancing energy markets are currently still national and organised by each TSO, but European balancing energy platforms are being set up[8]. In simplified terms, in the EU balancing platforms, all balancing offers by BSPs are forwarded by the national TSOs to a common order list and each LFC area (often operated by one TSO) represents a demand for balancing energy. Imbalance netting and coordination between the balancing needs in different LFC areas avoids counteracting activations (IGCC, 2020). The balancing platforms are organised jointly by the relevant TSOs. In Figure 7 (left), the three EU platforms for balancing energy are shown: PICASSO for aFRR, MARI for mFRR and TERRE for RR. At the time of writing, only TERRE is operational. Note that each of these balancing energy platforms spans several synchronous areas.

8 Except for the four German TSOs, which are currently procuring balancing energy commonly across their control areas.

In terms of pricing, the spatial granularity of balancing energy and imbalance prices is the bidding zone, often corresponding to a national territory, as is shown in Figure 7 (right). This means that two BSPs physically located in the same bidding zone will receive the same balancing energy price when they provide the same balancing energy product during the same market time unit. In addition, two BRPs physically located in the same bidding zone will be subject to the same imbalance price. When the EU balancing platforms are in place, the balancing energy prices for standard products paid out to BSPs will converge between two bidding zones if there is no (near) real-time congestion between these zones. Imbalance settlement prices, while they reflect the costs of balancing actions, may not necessarily fully converge in such a situation as the methodology for the exact calculation of the imbalance settlement price is determined at the national level[9].

Figure 7: The three European balancing energy platforms for aFRR, mFRR and RR and the current bidding zone configuration (Schittekatte et al., 2020).



Even though they are not completely the same, what are referred to as balancing energy markets in the EU can be compared to real-time markets in the US[10]. A US real-time market typically has a temporal granularity of 5 minutes and is used to trade differences between what was procured in the day-ahead market and real-time energy demand. Real-time markets are organised for each ISO/RTO in the parts of the US where the power sector is liberalised. As is shown in Figure 8 (left), there are seven ISOs/RTOs in the US (CAISO, ERCOT, SPP, MISO, PJM, ISO-NE and NY-ISO). In the Eastern Interconnection there is currently very limited integration of real-time markets across ISOs. In the Western Interconnection, the Western Electricity Imbalance Market (EIM) has been in place since 2014. Currently, the EIM coordinates real-time trading across the nine participating States as is shown in Figure 8 (middle)[11]. Market participants can voluntarily bid in this centralised market balancing supply and demand in real time.

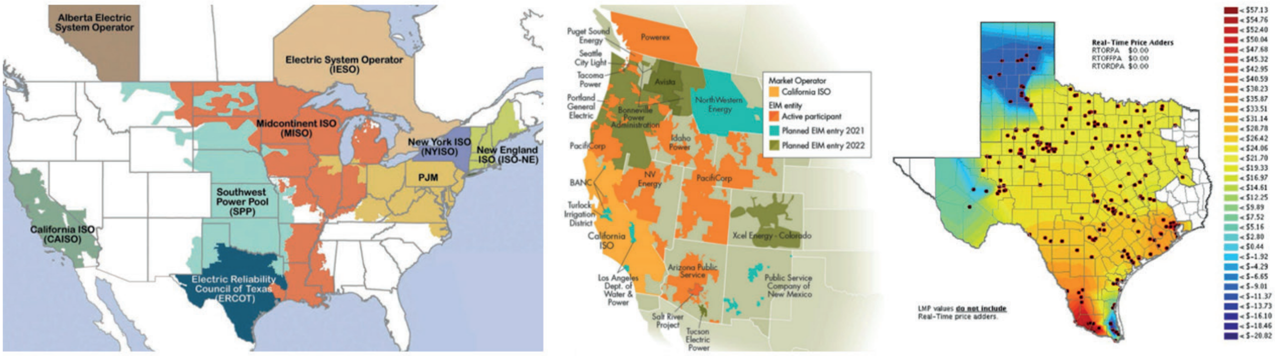
An important difference to the EU is that real-time markets operated by ISOs/RTOs calculate nodal prices. This means that, in the case of network congestions, there can be different real-time prices in different transmission nodes in an area spanned by an ISO/RTO. Figure 8 (right) gives an example of nodal real-time prices in ERCOT.

9 Even though the main features of the imbalance settlement need to be harmonised (Art. 52 (2) of the EB GL).

10 See Papavasiliou et al. (2021) for a more in-depth comparison of the real-time market in the US and the balancing market in the EU. The same paper also outlines the approximate steps that would turn the current EU balancing market into a real-time market as in the US.

11 No common day-ahead market is in place across these states and also vertically integrated monopolies take part in this integrated real-time market.

Figure 8 Left: ISO/RTOs in the US (Kaplan, 2009). Middle: the Western Electricity Imbalance market (CAISO, 2021). Right: Illustration of nodal real-time prices in ERCOT (ERCOT, 2020)



3.2 Balancing organisation in theory: an analytical framework with four criteria

In theory, the LFC area could be as large as the synchronous area, as in the cases of Great Britain, Ireland and Texas, but also as small as, for example, part of a distribution network connecting a community of smart buildings. In the former extreme, the LFC process is operated by one ‘synchronous system balancing operator’. This operator is the single buyer in a balancing energy market spanning the entire synchronous area and possibly beyond (as in the case of the EU balancing platforms). In the latter extreme, thousands of ‘local balancing operators’ locally oversee supply and demand balancing. Under the condition of optimal coordination with each other, each local balancing operator can organise its balancing market and balancing energy can seamlessly flow from one local LFC area to another. Alternatively, the local balancing operators can jointly organise one balancing energy market with multiple buyers.

The previous paragraph has indicated that a balancing setup is currently in place that can often be situated between these two extremes. For example, in Continental Europe, the LFC area is often a country, and the national TSO is in charge as the balancing operator. Balancing prices are also determined for each country[12]. Examples are Belgium, France, the Netherlands, Poland and Spain. In the US, several balancing authorities span several states, as in the case of the Pennsylvania, New Jersey and Maryland (PJM) ISO, while others span no more than a few towns. The current setups are driven by legacy situations and path dependency, rather than a well-thought-through design choice. The main reason for a national LFC process in Europe is that reliable electricity supply conditional on a well-functioning balancing mechanism is a matter of national political concern. Therefore, the (national) TSO is endowed with this task. In terms of pricing, the electricity networks within countries were generally well-developed while the grid between countries often constituted bottlenecks. As such, having a uniform balancing energy and imbalance price for each country, i.e. a bidding zone equalling the national territory, did not lead to gaming or other issues. In addition, only transmission-connected grid users were considered to be potential BSPs. There was no need for balancing price differentiation between voltage levels.

In theory, the geographical scope of the LFC area spanned by the balancing operator does not even matter; it can be either of the extremes or any setup between them. In practice, the context will determine the optimal choice of LFC area and subsequently who should be in charge of the balancing process. We identify four criteria that can play a role in this decision:

12 With the major exceptions in Continental Europe of Germany, which is covered by the control areas of four TSOs, and Italy, which is divided in seven bidding zones.

1. Coordination between the electricity balancing market and grid operation
    a. Consideration of the network constraints within the LFC area
    b. Consideration of the network constraints between the LFC areas of different balancing operators
2. Coordination between the electricity balancing market and wholesale markets
3. Non-discriminatory conditions for entry in balancing energy markets
4. Non-discriminatory exposure to imbalance prices

The first criterion relates to how balancing is coordinated with other system services (most importantly, congestion management), while the second criterion relates to how balancing markets are coordinated with preceding wholesale markets. The third criterion relates to the provision of balancing energy by BSPs (the supply side). Conversely, the fourth criterion deals with the settlement of imbalances by BRPs (the demand side, indirectly represented by the TSO).

3.3 Application of the multidimensional framework to the current organisation of balancing in the European Union and the US

In this subsection, we illustrate these four criteria by discussing the current balancing setups in the EU and the US (ISO/RTO system). A summary is provided in Table 1 in Subsection 3.3.5. In this subsection we mostly focus on transmission network and transmission-connected grid users. In Section 4 of this Report, we discuss the impact of future increased penetration of DERs on the current organisation of electricity balancing.

3.3.1 Coordination between the electricity balancing market and grid operation

Consideration of network constraints within the LFC area

Since balancing energy markets are zonal in the EU, network constraints within a zone are not considered when clearing the balancing markets and/or determining the imbalance prices. Therefore, it can happen that, near to real time, several BSPs are excluded from delivering balancing energy as their actions would violate network constraints. In addition, BRPs might see an opportunity to deviate from their schedules based on an imbalance settlement price that does not reflect the actual real-time needs of the grid (for a discussion, see Chaves-Ávila et al., 2014).

Zonal pricing means that coordination between congestion management and balancing is crucial. In this regard, several approaches currently exist in the EU. Poplavskaya et al. (2020) derive three stylised interaction models based on case studies of Germany, France and the Netherlands. The three models are: a separate balancing market and cost-based redispatch (Germany); a separate balancing market and market-based redispatch (the Netherlands); and joint balancing and redispatch markets (France). Each interaction model has pros and cons. There is no legislation at the EU level prescribing one model or another. However, it is relevant in this regard that Regulation (EU) 2019/943, in its Article 13(2) and (3), requires redispatch to be market-based unless it can be shown that this would lead to inefficiencies. In addition, it is important to note that Article 30(1)(b) of the EB GL states that activation of balancing energy bids activated also for purposes other than balancing affects the balancing energy price, while it also ensures that at least balancing energy bids activated for internal congestion management do not set the marginal price of balancing energy[13]. In practice, coordination between balancing and redispatch will always be imperfect. The zonal balancing market setup is reasonable if there is no structural congestion within bidding zones. However, this condition no longer holds in several EU Member States (see Table 1 in ACER and CEER, 2021 for the remedial action volumes in each country)[14].

13 The methodology for pricing balancing energy – and cross-zonal capacity used for the exchange of balancing energy or operating the imbalance netting process – was adopted by the EU Agency for the Cooperation of Energy Regulators (ACER, 2020).

14 Creating a nodal balancing market while keeping the wholesale markets (day-ahead and intraday) zonal is not a solution. Introducing different spatial granularity for each market segment is expected further to increase the (already existing) potential for gaming.

In contrast, in the organised markets in the US, network constraints within an area spanned by a balancing authority are optimally considered in the real-time market by the use of nodal pricing.

Consideration of network constraints between LFC areas

While, in the EU, the networks in LFC areas are imperfectly coordinated with balancing markets, significant progress has been made in the way in which network constraints between LFC areas are considered. From the operational perspective, relevant entities are the Regional Coordination Centres (RCCs). RCCs were introduced by the Clean Energy Package and are tasked with several duties related to the coordination of system operation and capacity calculation at the regional scale. At the time of writing, six Regional Security Centres (RSCs), the predecessors of RCCs, are operational across the EU. Currently RCCs are not assigned responsibilities related to real-time system operation and thus the load-frequency process, even though there have been discussions in the past on whether this should be the case (Roques and Verhaeghe, 2016). The operational protocols between TSOs operating their LFC areas in the same synchronous area are described in the SO GL.

In terms of trading, European balancing market platforms spanning a large number of EU countries are currently being set up (see Figure 7). Establishment of these European balancing platforms is prescribed in the EB GL. Experience with several cross-border balancing pilot projects in the last decade inspired the implementation of the European platforms. In practice, BSPs will still submit balancing energy bids to their connecting TSOs. These TSOs will then forward the bids to the European platforms. An important provision in this regard is Article 29 of the EB GL, which gives TSOs the right to not forward these bids to the European platform (so-called 'filtering'). More precisely, it is stated that TSOs have the right to declare balancing energy bids unavailable for activation by other TSOs because they are restricted due to internal congestion or due to operational security constraints (a need for 'guaranteed (own) volumes') in the connecting TSO scheduling area.

Similarly to the EU, in the US there are operational protocols to be followed by the balancing authorities that are part of the same synchronous area. An entity called the reliability coordinator is the highest level of authority responsible for the reliable operation of a reliability coordinator area, which spans several balancing authorities (NERC, 2016). The reliability coordinator may direct a balancing authority in its reliability coordinator area to take whatever action is necessary to ensure reliability. In terms of trading, integration of real-time markets between different organised ISO markets has been minimal. An exception is the Western EIM facilitating real-time trading between several balancing authorities across nine states.

3.3.2 Coordination between the electricity balancing and wholesale markets

In the EU, the imbalance price, which reflects balancing actions, can be interpreted as the 'real-time' energy price, as physical deviations from market positions are settled at this price. Following this logic, all preceding electricity markets can be considered to be forward markets propagating the imbalance price backwards. The reference forward markets are the day-ahead market and, increasingly, the intraday market, jointly referred to as wholesale electricity markets. In the EU, balancing markets are operated by TSOs, while the day-ahead and intraday markets are operated by power exchanges. Power exchanges that are certified to conduct cross-border transactions are called Nominated Electricity Market Operators (NEMOs). Within one country several NEMOs can be competing, or one NEMO can be the designated monopolist[15]. In this sense, in the EU, wholesale markets and balancing markets (resulting in the formation of the imbalance price) are rather weakly linked.

An important issue related to coordination between balancing and wholesale markets is that in many EU Member States portfolio bidding is (still) in place (for a recent overview, see p.6 of ENTSO-E, 2021b). Portfolio bidding means that bids in the wholesale market do not refer to a specific generation or demand unit, but to a portfolio of units. It is up to the market party to schedule its individual units to comply, in aggregate, with the position of the portfolio. This also means that deviations from market positions by individual plants can be compensated by other plants in the same portfolio.

15 For a discussion on the governance of power exchanges in Europe, see, e.g., Meeus (2011) and more recently Meeus and Schittekatte (2020).

Neuhoff et al. (2016) stress that TSOs have no visibility of the reserve capability within portfolios. As there can be intra-zonal congestion, TSOs continue to acquire at all times reserve and response to avoid the risk of potential imbalances. Last, currently there is no co-optimisation of energy and reserves in place. It is up to the market parties to estimate the opportunity cost of not selling energy in the wholesale market when submitting bids to offer balancing capacity (Ehrhart and Ocker, 2021).

In the organised markets in the US, the ISO operates both the day-ahead and the real-time markets together, composing a two-settlement system. Therefore, there is stronger interlinkage between these two markets. No portfolio bidding is allowed. Instead, unit-based bidding is in place. Finally, the day-ahead clearing co-optimises energy trade and reserves.

3.3.3 Non-discriminatory conditions for entry in balancing energy markets

Following the prescriptions in the EB GL regarding the use of standard products to be traded on European platforms for balancing, a total of four standard balancing products have been introduced (one aFRR product, two mFRR products and one RR product). The main characteristics of these products (e.g. minimum and maximum size, full activation time, minimum duration, etc.) are the same for all countries participating in the balancing platform. Only a small set of characteristics can be decided at the national level (often) within certain predetermined boundaries (e.g. ramping and deactivation periods). TSOs also have the right to propose specific (national) products if they can prove the need for them. Besides product design, progress has also been made regarding other design elements in balancing markets and relevant regulations that needed to be revised to reduce discrimination between traditional BSPs (e.g. thermal units) and new BSPs (e.g. RES and industrial demand). Examples, such as the requirement to have asymmetric products, maximum lead time for balancing capacity auctions, pricing rules, etc., are described in Schittekatte and Meeus (2018).

In the US, as there is limited integration between the different organised markets, there is less need to establish harmonised product definitions, again with the Western EIM being an exception.

3.3.4 Non-discriminatory exposure to imbalance price

Progress has also been made in terms of harmonisation of regulations on the imbalance price in the EU. Calculation of the imbalance price is still left to national TSOs, even though certain principles need to be respected. The idea is for the imbalance price better to reflect balancing energy costs, rather than being ‘an administratively-determined penalty’ to punish BRPs for being out of balance. The most important principle is that single pricing became the default pricing rule in the EB GL. Under the single pricing rule, a BRP which is out of balance in the opposite direction to the system imbalance receives the same imbalance price that another BRP must pay for being out of balance in the same direction as the system imbalance (thus aggravating the system imbalance). The imbalance pricing rule is discussed in more depth in Subsection 4.4.1. Furthermore, currently, as the EB GL prescribes, the imbalance settlement period (ISP) in the EU is converging towards 15 minutes[16]. A shorter ISP better reflects system conditions and rewards flexibility, while a longer ISP socialises a larger share of the balancing costs.

Furthermore, an important proportion of RES generators were originally exempted from balance responsibility in the EU. These exemptions have gradually been lifted and currently they only cover smaller RES generators, as is described in Schittekatte et al. (2021b). The resulting improved functioning of intraday markets has been very important to allow market parties to trade away their imbalances and limit their exposure to the imbalance price. Trading in intraday markets is possible until the intraday gate closure time, which, depending on the country, can be up to 5 minutes before delivery.

Quite unlike the EU, the real-time market in the US is a two-sided market where supply and demand are subject to the same price for the provision and consumption of real-time electricity. Imbalances are settled at the real-time price, which has 5-minute granularity. There is no intraday market in the organised markets in the US, even though proposals to introduce intraday auctions are currently being discussed (see, e.g., Herrero et al. (2018)).

16 Several exemptions are possible, as is discussed in Schittekatte et al. (2020).

3.3.5 Summary table

In Table 1 we summarise our assessment of the organisation of balancing as it is currently done in the EU and the US using the four identified criteria. It is not obvious which approach outperforms the other. Each has its advantages and particular challenges. However, Table 1 clearly confirms that the current setups are driven by path dependency, rather than well-thought-through design choices.

Table 1: Assessment of the current organisation of electricity balancing in the EU and the US

		EU	**US (organised ISO/RTO markets)**
1/Coordination between balancing and the network	1.a. within the LFC area	○ Sub-optimal coordination between balancing and redispatch	○ Optimal coordination via nodal pricing
	1.b between LFC areas	○ A (minor) role for RCCs ○ European balancing energy platforms	○ A (minor) role for reliability coordinators ○ Limited integration of real-time markets, with the Western EIM being an exception
2/ Coordination between balancing and wholesale markets		○ Different entities in charge (TSOs vs PXs) ○ (Possible) portfolio bidding ○ No co-optimisation	○ The same entity (ISO) in charge of both ○ Unit-based bidding ○ Co-optimisation
3/ Non-discriminatory conditions for entry in balancing energy markets		○ Significant harmonisation via EB GL ○ 4 standardised products for the European balancing platforms	○ Limited harmonisation across organised markets, with a possible exception in Western EIM
4/ Non-discriminatory exposure to imbalance prices		○ Partial harmonisation of the imbalance settlement rule (single pricing) ○ Evolution towards 15-minute settlement ○ Fewer types of grid users exempted from balancing responsibility ○ Increased trading opportunities in the intraday market	○ A true two-sided (real-time) market ○ 5-minute settlement ○ No or limited role for an intraday market

4. Challenges in balancing with increased DER participation

In this section, we discuss the participation of DERs in electricity balancing. We organise the discussion according to the analytical framework that was introduced in the previous section. In the first two subsections, we divide the discussion between the current arrangement and future challenges. In the other two subsections, we divide the discussion between ongoing reforms and specific regulatory issues. We end the section with a summary table.

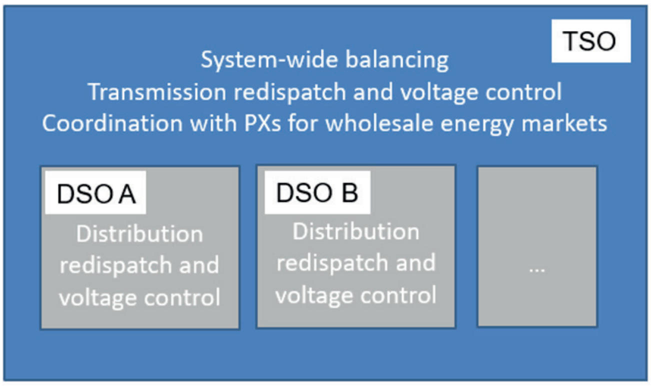
4.1 Coordination between the electricity balancing market and grid operation

In this subsection we do not distinguish between coordination between balancing markets and grids within and between LFC areas since, at least for now, consideration of the grid within a LFC area is the most relevant for DERs.

4.1.1 Current arrangements

Figure 9 summarises the current division of system operation tasks between TSOs and DSOs. TSOs are responsible for system-wide balancing, redispatch and voltage control at the transmission level and coordination with power exchanges regarding wholesale energy markets[17]. As was mentioned in Subsection 3.3.1, balancing and redispatch can be integrated or separate. Currently, market-based procurement of reactive power (to stabilise voltage) is somewhat limited (Anaya and Pollitt, 2020)[18]. DSOs are in charge of redispatch and voltage control within their grids. Currently, market-based redispatch at the distribution level through so-called flexibility markets is limited to a few innovative projects (Radecke et al., 2019; Schittekatte and Meeus, 2020)[19]. However, these projects are quickly expanding as Article 32(1) of Directive (EU) 2019/944 mandates DSOs to introduce market-based procurement of flexibility. Voltage issues are currently mostly resolved by investments by DSOs or managed via connection agreements limiting the values of power factors (PFs) according to grid connection network codes and financial incentives. Voltage control markets for distribution grids are currently limited to pilots (Bridge WG, 2019).

Figure 9: The current division of tasks between TSO and DSOs



This current role division implies that TSOs must coordinate with DSOs when resources connected to the distribution grid are activated in balancing markets. The activation of DERs for balancing purposes could create issues in the distribution grid. Recital (8) of the EB GL states that a level play-

17 Voltage control services are needed when there are sudden changes in demand. This is because the amount of reactive power changes, which affects the voltage and quality of supply.

18 In the early nineties, an academic debate developed on whether nodal prices should include not only prices for active power but also for reactive power. Hogan (1993) showed that not having a nodal structure for reactive power prices can lead to sub-optimal incentives. Kahn and Baldick (1994) demonstrated that such problems would be very rare and therefore it would not be worth having a nodal reactive power price structure. In the implementation of nodal prices in practice, the latter authors' advice was followed.

19 For a more conceptual discussion and some examples from the US, consult Tabors et al. (2017).

ing field should be in place for all market participants, including demand-response aggregators and assets located at the distribution level, to offer balancing services and ensure adequate competition. Two provisions in the SO GL are relevant in this regard, one having to do with prequalification and the other with the real-time delivery of active power.

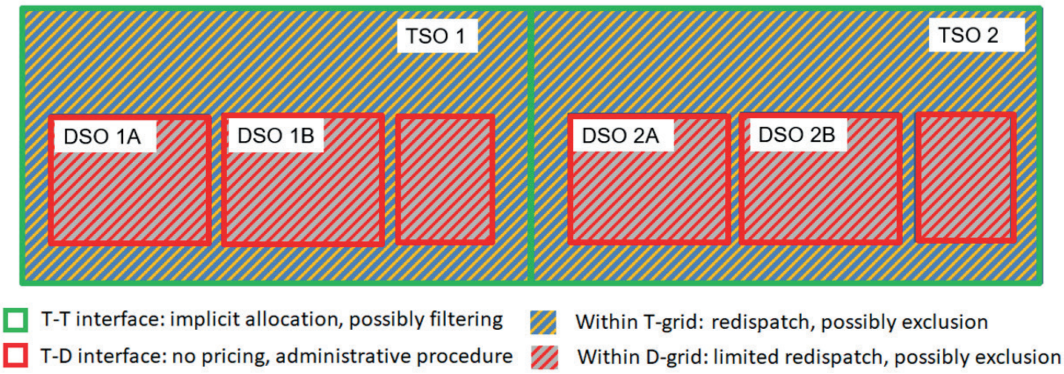
First, the SO GL, in its Article 182(3), specifies that the prequalification process for balancing resources connected to the distribution level should rely on rules concerning information exchanges and the delivery of active power reserves between the TSO, the reserve-connecting DSO and any intermediate DSO[20]. Each reserve-connecting DSO and each intermediate DSO, in cooperation with the TSO, should have the right, during the prequalification process, to set limits to or exclude the delivery of active power reserves located in the distribution system. The reasons for limitations or exclusion should be technical, such as the geographical location of the reserve-providing units and reserve-providing groups (SO GL, Article 182(4)).

Second, each reserve-connecting DSO and each intermediate DSO can set temporary limits to the delivery of active power reserves before their activation. Procedures need to be agreed upon with the respective TSO (SO GL, Article 182(5)). In this regard, Article 15(3) of the EB GL states that each TSO may, together with the reserve-connecting DSOs within the TSO's control area, jointly draw up a methodology for allocating the costs resulting from the exclusion or curtailment of active power reserves connected at the distribution level.

These two provisions could become an important constraint on the participation by DERs in balancing markets. There is no pricing of the transmission-distribution interface. Instead, prequalification and possible exclusion by the DSO of a BSP with 'badly located' resources from providing balancing services are dealt with administratively. In addition, it is not explicitly stated that DERs are to be compensated when excluded from participation in balancing markets due to grid issues at the prequalification or delivery stage. If compensation were in place, it would not be clear to whom its costs should be allocated.

In fact, regarding participation in European platforms for balancing energy, DERs need to pass through two 'filters' (after passing the prequalification requirements). First, the DSO may restrict delivery as is described above. Second, the TSO to which the DSO is connected may have reasons to not forward the balancing bid to the European platforms, as is described in Subsection 3.3.2. Even though it is not extensively documented, it can be expected that in most DSO grids congestion issues are still relatively limited. However, this is not expected to remain the case. Figure 10 provides a summary of current issues in coordination between grid (transmission and distribution-level) operation and balancing.

Figure 10: Current issues in coordination between grid operation and balancing



20 No formal definition of 'intermediate DSO' has been found.

4.1.2 Future challenges

The costs of distribution grids are a larger share (typically 30-40%) of the total costs of power delivery than the costs of transmission grids (typically 5-10%). These numbers underline the importance of efficient operation of distribution grids to achieve decarbonised power systems at least costs, especially because massive investments in distribution grids are expected to accommodate the electrification of transport and heating (Eurelectric and E.DSO, 2021)[21].

Well-functioning DSO redispatch and voltage control require detailed visibility of the DSO network. Potter et al. (2021) argue that current voltage control practices in the distribution grid are quickly becoming inadequate, especially with the increased penetration of DERs. The same authors argue that voltage control is a bigger issue in distribution grids due to their topology and other grid characteristics. It is believed that there are significant gains to be achieved by introducing a market mechanism.

It is recognised that DERs can (competitively) solve grid issues. However, a more important interaction between active and reactive power delivery at the distribution level makes the introduction of a market mechanism more difficult compared to the transmission level. Therefore, the distribution grid requires a more integrated approach to grid operation (see e.g. Zubo et al.). With more structural congestion at the distribution level and more DERs willing to participate in balancing markets, more conflict between TSOs and DSOs in activating the available resources can be expected, due to the lack of visibility of the DSO network by the TSO. Such a situation could lead to more instances of exclusion of DERs from balancing markets, resulting in an under-utilisation of the capacities of DERs and possibly costly compensation for the excluded DERs. Another possibility is that, when DERs are not excluded from balancing markets, unanticipated thermal and/or voltage issues may emerge in the distribution grid. This could possibly lead to costly remedial actions, a higher need for grid investments and gaming by DERs[22]. It is important to add that Håberg (2019), who extensively studied the filtering mechanism currently in place at the transmission level, states that "*regardless of its implementation, the concept of pre-filtering bids is found to be fundamentally inefficient, detrimental to market participants and incapable of preventing congestion in certain cases.*"

4.2 Optimal coordination between electricity balancing and wholesale markets

4.2.1 Current arrangements

As was mentioned in Subsection 3.3.2, reservation of balancing capacity and clearing of wholesale markets happen sequentially in the EU. This is different to the power markets in the US, where reservation of balancing capacity and clearing of wholesale markets are co-optimised. One difficulty for renewables and demand response, therefore also for DERs, is the estimation of the opportunity cost when participating in auctions for balancing capacity. This difficulty is exacerbated when there is a long time lag between auctions for balancing capacity and clearing of wholesale markets. Progress has been made in this regard with two provisions in Regulation (EU) 2019/943. First, Article 6(9) states that contracts for balancing capacity cannot be concluded more than one day before the provision of the balancing capacity and the contracting period shall be no longer than one day. Derogations are possible to ensure security of supply or to improve economic efficiency. Second, Article 6(2) states that the price of the balancing energy bid is not to be predetermined in the balancing capacity contract[23]. Besides BSPs contracted in the balancing capacity market, other BSPs without contracted balancing capacity may also bid in the balancing energy market (EB GL, Article 16(5)). Allowing so-called 'free bids' in balancing energy markets is an important provision to allow easier entry by DERs.

21 Eurelectric & E.DSO (2021) estimate that European distribution power grids will require an investment in the order of 375-425 billion euros in 2020-2030 in the EU27+UK. This implies an increase of about 50-70% in annual investment compared to the average year in the period 2015-2019.

22 See Beckstedde et al. (2021) for examples of possible gaming strategies when there is congestion at the transmission and distribution levels.

23 Exceptionally for specific balancing energy products, the TSO can request this rule to not be applied.

Regarding wholesale markets, currently DERs can participate directly or via aggregators. The minimum bid size varies from one bidding zone to another, but is generally not seen as a barrier (Epex Spot, 2021).[24] The wholesale market has the same spatial granularity as the balancing energy market, i.e. bidding zones often correspond to national territories. Schedules resulting from positions in wholesale markets are the basis for the imbalance settlement.

4.2.2 Future challenges

Smeers et al. (2021) assess the distortions created by having sequential balancing capacity and wholesale markets and state that the case for co-optimisation in a future decarbonised electricity system appears overwhelming. Already some proposals to improve coordination between the balancing capacity market and the wholesale market are close to implementation in the Nordic region (ENTSO-E, 2019). Smeers et al. (2021) highlight that the most important barriers to moving towards a co-optimised approach are institutional in nature. It can be expected that overcoming these barriers would ease the participation of DERs in balancing capacity and subsequently balancing energy markets.

A possibly more urgent challenge is the expectation that DERs, either directly or via aggregators participating in existing wholesale markets, will increasingly be facing market access issues due to congestion. We can already see the establishment of local energy markets or peer-to-peer (P2P) markets at the level of distribution grids, with some schemes aiming to reflect local grid issues in their market clearing. Glachant and Rossetto (2021) discuss these emerging markets and document real-world examples, including community trading within regulatory sandboxes. It is currently an open issue how local energy markets, whether they are organised as P2P or not, will interact with existing wholesale and balancing markets. One particular concern is the mismatch in terms of spatial granularity between local energy markets and balancing markets. Balancing markets would have to reduce their spatial granularity to limit inconsistencies that would allow for gaming or other issues. Furthermore, more DER activity in wholesale or local energy markets would lead to more positions being considered in the imbalance settlement mechanism.

4.3 Non-discriminatory conditions for entry in balancing energy markets

Balancing energy markets have been gradually opened to new entrants. However, the detailed rules on non-discriminatory entry in electricity balancing markets and the remaining barriers to such entry vary quite substantially from one country to another (see, for example, the yearly monitoring reports by SmartEn (2021a)). Therefore, it is hard to split this discussion into current and future challenges. Instead, we divide this subsection into ongoing reforms in market and product design to address barriers against DERs entering balancing markets and the regulatory frameworks for new entrants.

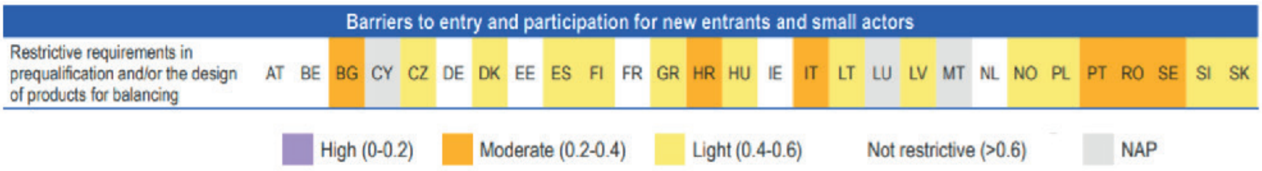
4.3.1 Ongoing reforms: balancing market and product design-related barriers against DERs

Besides the yearly reports by SmartEn, another important report in this regard is the market monitoring report by ACER and CEER. In their latest edition, ACER and CEER (2021) include, for the first time, a detailed assessment of how easy it is for new entrants and small actors to enter and participate in electricity markets. One dimension in this assessment is whether there are restrictive requirements for prequalification and/or the design of balancing products. ACER and CEER analyse the extent to which some product requirements and design features of the current national balancing markets are still not in line with the European target model (in this context, the EB GL) and how they may represent a barrier. They find that some product specifications and features of balancing markets, which were originally designed in a context of centralised production, limit the participation of demand-side response, decentralised production and energy storage. Figure 11 provides an

24 For example, when trading in the day-ahead and intraday markets via EPEX Spot, the minimum bid is 100 kW (Epex Spot, 2020) and aggregation is generally allowed. Also, (closer to real-time) balancing and congestion management markets are typically more interesting markets to participate for DER than wholesale markets.

overview of the results of this assessment. Several countries, such as Austria, Belgium, Germany, Estonia, France, Ireland and the Netherlands are very positively assessed. Barriers are found to be more severe (or moderate) in Bulgaria, Croatia, Italy, Portugal, Romania and Sweden.

Figure 11: Barriers to entry and participation by new entrants and small actors in each Member State (ACER and CEER, 2021)



Source: ACER calculations

Note: NA (not available) refers to Member States where it was not possible to assess the barrier due to insufficient data available. NAP (not applicable) refers to Member States where the barrier does not apply, e.g. if no capacity market was operational, if there were no price interventions in the retail price settings, etc.

The balancing market design and product design parameters that are the focus of the assessment conducted by ACER include long delivery periods and large minimum capacities required in the prequalification process, long validity periods of balancing energy bids, long balancing capacity contracts, large minimum bid sizes, restrictions on the participation of aggregators and the obligation to provide symmetric balancing capacity[25]. Moreover, long procurement lead times (as was discussed in the previous subsection) and regulated or pay-as-bid pricing may also hinder participation by new entrants and small actors.

Schittekatte et al. (2021b) show that the entry of new entrants in balancing markets has happened gradually. First large-scale RES and industrial demand entered. Several barriers against them needed to be lifted, of which the majority were identified by ACER and CEER. In this regard, Schittekatte et al. (2021b) discuss in more depth the barriers related to minimum bid sizes, the length of balancing capacity contracts and symmetric procurement of balancing capacity and energy. Not long afterwards DERs, often via aggregators, also entered balancing markets in several countries. The same barriers that were relevant for large-scale RES and industrial demand often also limit participation by DERs. However, additional barriers need to be removed. Again, many of these barriers are included in the recent analysis presented in the report by ACER and CEER (2021). In this regard, Schittekatte et al. (2021b) discuss barriers related to the possibility of using aggregated offers and bids, the right to pool-based pre-qualification, the design of baselines and penalties for non-availability of balancing energy for which a reservation payment has been earned.

4.3.2 Regulatory framework on new entrants in balancing markets

Another challenge regarding participation by DERs in balancing markets is the development of proper regulatory frameworks for new players that facilitate the entry of DERs in these markets. These frameworks should not impede or distort the entry of these players in balancing markets. We focus on active customers, independent aggregators and energy communities.

First, an active customer is defined in Directive (EU) 2019/944 as "*a final customer, or a group of jointly acting final customers, who consumes or stores electricity generated within its premises located within confined boundaries or, where permitted by a Member State, within other premises, or who sells self-generated electricity or participates in flexibility or energy efficiency schemes, provided that those activities do not constitute their primary commercial or professional activity." An active customer, directly or via aggregation, has the right to enter in balancing markets.* ACER and CEER (2021) report that in 2020 only Denmark, France, Hungary, Italy, Spain and Slovenia had adopted all the main relevant provisions in their national legislation. Furthermore, it is stated that active custom-

25 Examples of restrictions on the participation of aggregators are when load aggregators cannot be prequalified as reserve-providing groups and when stringent restrictions on the size of the physical units that can be aggregated are imposed.

ers are eligible to participate directly in day-ahead, intraday and balancing markets in nine Member States (Germany, Denmark, Estonia, France, Hungary, Ireland, Italy, Romania and Slovenia). Portugal allows their participation in its day-ahead and intraday markets, but not in balancing markets.

An issue that is particularly relevant to the participation of active consumers with DERs in any electricity market is network charges and levies. Volumetric network charges and levies (in €/kWh) can distort market price signals. Currently, many Member States are reforming their distribution network charging design. A recent overview can be found in the best practices report by ACER (2021). The charging of levies as part of the electricity bill is under discussion in many EU Member States, one factor accelerating these reforms being the high electricity prices in autumn 2021 (see, e.g., Lempriere, 2021). Non-cost reflective network charges and high volumetric levies particularly impact the business case for electricity storage. ACER and CEER (2021) report that, in 2020, Austria, Estonia and Romania had yet to remove double charges (including network charges) for active customers owning an energy storage facility, and that Finland had eliminated double taxation, but not double network charges.

Second, independent aggregators are aggregators that engage in the aggregation of consumers, but which are not affiliated to those consumers' suppliers. Even though in principle suppliers can provide aggregation services, they have been relatively slow in taking on this role. Traditional suppliers are inherently reluctant to offer demand response programmes, as these services impact their core business of selling volumes of energy and they are often vertically integrated with generation (see, for example, Bray and Woodman, 2019; Burger & Luke, 2017; and He et al., 2013)[26]. Therefore, the concept of independent aggregators emerged. ACER and CEER (2021) find that France, Germany, Hungary and Slovenia are the only Member States where independent aggregators can participate in all market timeframes. An important regulatory challenge in the EU relates to the specific case of independent aggregators is their interaction with suppliers and their contracted consumers. Suppliers purchase a certain amount of electricity in advance to cover the consumers' expected load and are responsible for having a balanced position in real time. In most cases, independent aggregators sell a reduction in consumption compared to the baseline in a given electricity market, such as the balancing energy market. Consequently, the actions of independent aggregators can cause an imbalance in the portfolio of suppliers, and suppliers have also asked for compensation for their forgone revenue.

In most EU Member States with an existing regulatory framework for independent aggregation, a perimeter correction has been proposed to solve the imbalance issue, as is described in Schittekatte et al. (2021a)[27]. The foregone revenue issue is more controversial. In this regard, Article 17 of Directive (EU) 2019/944 states that Member States shall enable demand response through independent aggregation. More specifically, Member States may require independent aggregators to pay suppliers financial compensation, but the compensation must not create a barrier to market entry by independent aggregators. Schittekatte et al. (2021a) describe how the EU Member States that are most advanced in developing regulatory frameworks for independent aggregators have introduced compensation mechanisms reflecting energy sourcing costs. Examples are Belgium, France, Germany (not yet implemented), Slovenia (not yet implemented) and Switzerland[28]. In contrast, in the US the Federal Energy Regulatory Commission (FERC) orders that demand response should not pay compensation, but it should be paid at full wholesale market prices when a net benefit test is passed (FERC, 2011). Order 745 was disputed (as is described in Chen and Kleit, 2016; Panfil, 2015). However it was upheld by the Supreme Court (Supreme Court of the United States, 2016).

26 An important evolution is that, as aggregators have been challenging suppliers, a significant number of prominent European supply companies have either engaged in aggregation themselves, have set up an aggregator or have acquired an aggregator. At least 35% of the 26 aggregators identified in a review provided in Poplavskaya and De Vries (2020) have been acquired or spun off by large utilities in the last few years. With more and more independent aggregators being operated by companies with a supplier-side business, the previously discussed issues between independent aggregators and suppliers might become less critical in the EU. This evolution does not mean that the establishment of a proper regulatory framework on independent aggregators is not urgent.

27 Alba et al. (2021) warn that sub-optimal telemetry readings and the rebound effect might lead to issues with the proposed perimeter correction.

28 ACER and CEER (2021) state that, except for France, Italy, Slovenia and Romania, no Member State currently has a method in place for calculating financial compensation to suppliers or BRPs during activation of demand-side response via independent aggregators.

Third, energy community initiatives unite grid users selling, sharing or trading electricity among themselves. Communities can focus on different activities and be subject to different governance models. ACER and CEER (2021) report that Citizen Energy Communities (CECs) are only eligible to participate in day-ahead, intraday and balancing markets in five Member States (Germany, Denmark, France, Hungary and Ireland). CECs are defined in Directive (EU) 2019/944 as legal entities that have voluntary and open participation and are effectively controlled by members or shareholders that are natural persons or local authorities, including municipalities and small enterprises. The primary purpose of a CEC is to provide environmental, economic or social community benefits to its members or shareholders or to the local areas where it operates, rather than to generate financial profits. CECs may engage in generation, including from renewable sources, distribution, supply, consumption, aggregation, energy storage, energy efficiency services and charging services for electric vehicles, and provide other energy services to their members or shareholders[29]. Besides CECs, Renewable Energy Communities (RECs) are also defined in Directive (EU) 2019/944. The difference between a CEC and a REC is that, in a CEC, members do not have to be in close proximity to one another; a CEC can be 'virtual' with dispersed members over a larger region. If there is proximity and if all electricity generation assets are renewable-based, the CEC is a REC. However, RECs are not always a subgroup of CECs. RECs can also engage in collective investments in other energy carriers, e.g. renewable gas, while CECs are limited to electricity. For a broader discussion of energy communities, see Verde and Rossetto (2020). Please note that it remains up to the individual Member States to develop the concrete regulatory framework for CECs and RECs, which must respect the principles and boundaries of the EU Directive.

Schittekatte et al. (2021b) note that, besides CECs and RECs, other types of energy communities are also entering electricity markets, often first as BSPs. One example of this is the 'sonnenCommunity'. Sonnen GmbH started as a German producer of intelligent energy storage systems and evolved into a fully integrated hardware company, aggregator and supplier. Members of the sonnenCommunity can use their batteries to become part of a battery pool by providing a small share of their individual storage capacity to the public power grid for a few minutes a week to buffer short-term peaks or, for example, participate in balancing markets. In return, the battery owners who have the sonnenFlat tariff can receive financial compensation in the form of cost-free energy up to a certain amount of kWhs (Sonnen, 2021). Another example is the electric car manufacturer and technology firm Tesla Motors Limited, which the British energy regulator, Ofgem, granted an electricity generation licence in 2020 (Ofgem, 2020). Tesla entered the market to develop Virtual Power Plants (VPPs) in Great Britain and other countries by using a real-time trading and control platform which aggregates its own car fleet and other possible DERs. The trading and control platform, called Autobidder, allows the participation of an asset in various electricity markets (so-called 'value stacking'), including balancing markets. More recently Tesla has joined up with electricity supplier Octopus Energy to offer an energy tariff tailored to homes with solar panels and batteries (Octopus, 2021). Households opting for this tariff automatically join Tesla's UK VPP. Octopus, meanwhile, has launched its own Octopus Electric Vehicle solution in the UK, which consists of a bundle offer for leasing an electric car and charging infrastructure, and a suitable tariff (Octopus EV, 2021). In this way, Octopus implements vehicle-to-grid (V2G) feeding to support grid stability in Great Britain.

In the near future, more hardware companies are expected to follow suit. Examples could be manufacturers of smart home systems such as Google with Nest, Amazon with Amazon Echo and smaller players such as Thermovault. A particular challenge related to these new players that (re-) integrate several activities is lock-in. As He et al. (2013) describe, hardware manufacturers may make the switching of aggregators by consumers more difficult. Hardware manufacturers might have privileged access to consumer information, and in some cases might impede data access by other aggregators. The lock-in effect and the uneven access to data might lead to dominant positions in the interface between DERs and the balancing markets. These issues are not new, yet they are reinforced with integrated hardware companies and energy communities. Another challenge is that,

29 Regarding network charges for energy communities, CEER (2019) explains that Member States generally do not apply network charges for electricity exchanged without the use of the public grid. However, this question becomes trickier when consumers share or trade electricity at the local level, but using the public grid. Several Member States allow or are considering allowing a (minor) discount on network charges for electricity shared via local energy communities.

under the current market rules, having multiple suppliers for one connection point would require a duplication of meters and other administrative barriers. This issue is further discussed in Subsection 4.4.2.

Finally, as was already briefly touched on in Subsection 2.3, Article 59(1)(e) of Regulation (EU) 2019/943 states that a new network code can be developed in the area of demand response, including rules on aggregation, energy storage and demand curtailment. It can be expected that this new network code, which has recently been confirmed in the priority list for new network codes for 2020-2023 (European Commission, 2020) will further mitigate the barriers discussed in this section.

4.4 Non-discriminatory exposure to the imbalance price

Article 5(1) of Regulation (EU) 2019/943 mandates that all market participants are financially responsible for imbalances they cause in the electricity system. However, for certain installations, including small-scale RES installations with an installed electricity capacity of less than 400 kW, Member States may provide derogations and allow a grandfathering clause[30]. In practice this means that many DERs are currently exempt from balancing responsibilities.

This notwithstanding, retailers or other market parties, e.g. aggregators managing or marketing a pool of DERs (including DERs exempt from balancing responsibility), will be balance responsible. In addition, the threshold for balance responsibility might be decreased over time. Therefore, there is value in limiting imbalance volumes and their costs. As the detailed rules and barriers related to non-discriminatory exposure to the imbalance price also vary quite substantially from one country to another, it is again hard to divide the discussion into current and future challenges. Instead, we divide this subsection into measures related to lowering the volume and cost of imbalances and the appearance of new linkages between balancing and retail markets.

4.4.1 Ongoing reforms: lowering the volume and cost of imbalances

A difference in real time between the volume allocated to a BRP and its contractual position for a given ISP is often unavoidable. First, we discuss the role of liquid intraday markets allowing BRPs to trade away their imbalances near to real time, which requires real-time information about the state of the system. Second, we discuss revisions of the imbalance settlement rules which aim to improve reflection of the cost of balancing in the imbalance settlement price.

Regarding intraday markets, the length of the products traded is crucial. In this regard, Regulation (EU) 2019/943 requires market participants to be provided with the opportunity to trade energy in time intervals at least as short as the ISP in both day-ahead and intraday markets. Ocker and Ehrhart (2017) argue that the introduction of an intraday auction with 15-min products in Germany in 2014 helped to allow more precise scheduling of RES and other generation technologies, which led to a significant reduction in overall balancing costs. Another important parameter is the intraday gate closure time (IDGCT). The closer IDGCT is to real time, the better market participants will be able to trade away their imbalances on the intraday market using more updated forecasts. These trades contribute to increased liquidity in the intraday market and better deployment of flexible resources. This is especially relevant for RES, but also for all types of DERs, as their production and consumption schedule might vary at short notice. The Capacity Allocation and Congestion Management Guideline (CACM GL) requires the cross-zonal IDGCT to be at most one hour before the start of the relevant market time unit, while the intra-zonal (in most cases, national) IDGCT can be different and much closer to real time. Currently, gate closure in intra-zonal intraday markets can be up to five minutes before delivery, as is the case in the Netherlands and Belgium (NordPool, 2021). In addition, transparent 'near real time' information about the system state is of importance, since it allows market participants to estimate potential imbalance settlements and therefore incentivises market participants to balance their positions in intraday markets. DERs or energy communities can even use this near-real-time information to be out of balance in the direction that reduces the

30 The 400 kW threshold applies if the renewable generator is commissioned before 1 Jan 2026. Afterwards, only RES with an installed electricity capacity of less than 200 kW can be exempted.

system imbalance. This passive balancing might be an easier revenue opportunity for these players than 'active' provision of balancing energy via organised balancing energy markets with predefined products in place. The possibility of engaging in passive balancing depends on national regulations and the design of the pricing rule in the imbalance settlement mechanism, as is discussed next[31].

Regarding the imbalance settlement mechanism, most discussion has revolved around the application of single versus dual imbalance pricing. Under dual pricing, when the individual imbalance of a BRP is in the same direction as the system imbalance, so it contributes to the system imbalance, the imbalance settlement is linked to the cost of balancing energy. However, the price a BRP sees when its individual imbalance is in the opposite direction to the system imbalance and so helps to restore system balance is often linked to or capped by a reference or day-ahead market price. It is generally accepted in the academic literature that single pricing is the superior method as it provides an incentive for BRPs to support system balance (Meeus et al., 2020; Neuhoff et al., 2015; Newbery, 2006; Schittekatte et al., 2020). From the perspective of smaller players, dual pricing is discriminatory as it treats larger players preferentially because they can aggregate imbalances in their portfolio to lower their total balancing costs (Neuhoff et al., 2015). Moreover, one could argue that dual pricing creates a penalty for random imbalances, which do not necessarily put the system in danger. This is particularly relevant for DERs. More precisely, imagine a grid user with random uncontrollable imbalances fluctuating around zero which are completely uncorrelated with the system imbalance. At the same time, the system imbalance is also randomly fluctuating around zero. In this case, under single pricing the total imbalance cost of this BRP will net out, while under dual pricing the total imbalance cost will be positive. This issue has been settled in the EB GL, Article 52 of which states that single pricing should be applied. However, under certain conditions, a TSO may propose that the regulatory authority implement dual pricing.

4.4.2 Novel links between balancing and retail markets

New entrants that enter electricity wholesale markets via electricity retail markets impact the current arrangements regarding the balance responsibility of engaged active consumers with DERs. More precisely, in the context of local (physical) energy communities and P2P trading, participating consumers typically still need a separate contract with a traditional supplier in addition to a contract with the local energy community or the P2P exchange. Similarly, a hardware company acting as a supplier might supply consumer assets used to provide demand response, such as an electric vehicle or a heat pump, but not the residual (inflexible) load. Watson et al. (2020) conducted survey experiments in Great Britain and found high social acceptability of multiple supplier models. Importantly, consumers are more likely to engage with local energy in a multiple supplier model.

Electricity supply has been open to competition in the EU since the entry into force of the Second Energy Package. However, the conditions that an electricity supplier must meet to obtain a supplier licence have always been very strict. Examples are obligations related to reporting and billing, public service obligations and balance responsibility. The allocation of these obligations might change with these new entrants. In this regard, the Clean Energy Package paves the way for a split-supply model, i.e. consumers being able to engage with multiple suppliers, by stating, in Article 4 of Directive (EU) 2019/944, that '*Member States shall ensure that all customers are free to purchase electricity from the supplier of their choice and shall ensure that all customers are free to have more than one electricity supply contract at the same time, provided that the required connection and metering points are established*'. CEER (2019) explains that there is currently no general framework stating how responsibilities should be shared among multiple suppliers.

In addition, several practical issues arise. In particular, there is the cost of equipping consumers with additional smart sub-metering devices. In this regard, the Elia Group (2021) states that the re-

31 Eicke et al. (2021) find that market parties strategically deviate from balanced positions in Germany even though this practice is forbidden by national regulation. The authors interpret the balancing system as a fictitious marketplace for imbalance energy and find that in the German case there is a decrease in demand for imbalance energy of 2.2 MW for each increase in the imbalance price of EUR 1 per MWh. Therefore, they emphasise that it is very important for imbalances to be properly priced to make sure that 'passive balancing actions' are also beneficial from a system point of view.

quirement to have multiple meters leads to hurdles for both flexibility providers and consumers which often outweigh the benefits brought by new services. They propose what they call a 'consumer-centric' market design. This proposal avoids the need for multiple meters for each connection point.

Practically, it proposes introducing 'exchange of energy blocks', which would allow the decentralised exchange of energy on a 15-minute basis between consumers and various suppliers and service providers. A hub would record the energy block offtakes and injections occurring at the consumer's access point, making it possible to determine the contribution by each provider in relation to the consumer's residual consumption[32]. The same proposal also argues that, to unlock all DER flexibility, the physical balancing obligation for all connection points in the portfolio of a BRP needs to be further eased to enable passive balancing.

Implementation of the consumer-centric market design proposal by the Elia Group (2021) and other technical solutions enabling this design are already in a mature development stage. Any of these approaches, be they hardware- or software-based, will result in a significant increase in data exchange and metering.

4.5 Summary table

Table 2 provides a summary of this section. It can be seen that greater penetration by DERs in the balancing mechanism challenges all the dimensions of our analytical framework. As is also argued by Burger et al. (2019), keeping the current organisation of the balancing mechanism in place is not unreasonable in the short term. However, in the medium to long term, this model is expected to reach its limits due to increased shares of DERs and accompanying coordination issues between DSOs and the TSO. We argue that for that time horizon more fundamental reforms need to be considered. We discuss these reforms in the next section of this Report.

32 From a technical point of view, it should be noted that the regulated platform which would support the exchange of energy blocks is a software-based solution not requiring any certified metering.

Table 2: Assessment of challenges for balancing markets with increased DER penetration

	Current arrangements	**Future challenges**
1/Coordination between balancing and the network	○ No pricing of the transmission-distribution interface ○ Prequalification and possible exclusion by DSOs of balancing provision by BSPs with 'badly located' resources are dealt with administratively. ○ Double 'filtering' of DSO-connected BSPs when EU platforms will be operational	○ With more DERs (competitively) delivering balancing energy and solving congestion and voltage issues, the interaction between active and reactive power delivery requires a significant increase in the capability to monitor real-time flows in the distribution grid. ○ Sub-optimal TSO-DSO coordination will lead to: · under-utilisation of DERs, and/or · increased grid and gaming issues
2/ Coordination between balancing and wholesale markets	○ Imperfect coordination between wholesale markets and balancing capacity markets. ○ Balancing and wholesale markets have the same zonal, relatively crude, spatial granularity.	○ An increase in costs due to lack of co-optimisation. ○ The development of local markets (incl. P2P) requires balancing markets to evolve; if not, differences in spatial granularity between electricity transactions and balancing are created, possibly leading to gaming opportunities and other distortions.
	Ongoing reforms	*Specific regulatory challenges*
3/ Non-discriminatory conditions for entry in balancing energy markets	○ Mitigation of market- and product design-related barriers for DERs to enter balancing markets progressing (e.g. product design, minimum bid size, symmetrical products, auction lead time etc.)	○ Regulatory frameworks for new players need to be set up at Member State level to enable the entry of DERs in balancing markets (e.g., active consumers, independent aggregators, and energy communities). ○ A general issue is the design of network charges and taxation. ○ There are also issues specific to each new entrant.
4/ Non-discriminatory exposure to imbalance prices	○ Measures to lower the volume and cost of imbalances for DERs are gradually being implemented (e.g. products in intraday markets and the imbalance settlement pricing rule).	○ Novel links between balancing and retail markets are appearing (multi-supplier models) leading to a need for adjustments in the regulation of retail markets. ○ A potential significant increase in the amount of imbalance measurements and positions.

5. Alternative setups for electricity balancing

The previous sections have treated the current organisation of balancing mechanisms as given. However, as was illustrated in Section 3, the current setup is driven by path dependency, rather than a well-thought-through design choice. (Often) having one TSO managing the balancing mechanism in each country, with a uniform balancing energy price and imbalance price, has been working relatively well in a context in which BSPs are only connected to the transmission grid and there is limited intra-zonal congestion. We have argued that already today, and especially in the future, the context is changing. As was discussed in Section 4, the new context will lead to new opportunities and challenges with increased participation by DERs in the balancing mechanism. Our analytical framework has shown that a greater penetration of DERs challenges all dimensions of the current setup. In the medium to long term this model is expected to reach its limits.

In this section, we discuss alternative setups for the organisation of the balancing mechanism. We consider two extreme visions with the current setup being somewhere in the middle. This section is divided into two parts. First, we introduce the two alternative setups. Afterwards, we briefly discuss the main challenges and opportunities the two setups bring using a simplified version of our previously introduced analytical framework.

5.1 Descriptions of the two alternative setups

Discussion on alternative setups for the balancing mechanism is not completely new. Two important studies in this regard are a report by De Martini and Kristov (2015) and a paper by Burger et al. (2019). Both focus on the US.

De Martini and Kristov (2015) discuss how penetration by DERs impacts DSO functions such as real-time operation, infrastructure planning and maintenance, and interconnection of loads and resources[33]. Two future grid operation models are envisioned: the 'Total TSO model' and the 'Independent DSO model'. In the Total TSO model, all operational and market functions that are increasingly needed at lower voltage levels with higher shares of DERs are allocated to the TSO. This does not mean that there would no longer be a role for the DSO in the power system. The DSO could retain ownership of distribution assets and, possibly, some of the basic planning and operational functions. In the implementation of the Independent DSO model, three stages are foreseen. The first stage relates to how most of the DSOs' functions are managed today. In the second stage, the central feature of the Independent DSO is leveraging the value of DERs to provide services to support distribution system operation and to defer or avoid distribution system upgrades. It could be argued that some DSOs in the EU, and to a more limited extent in the US, are already entering this stage. In the third stage of the Independent DSO model, the DSO also organises local energy markets, settles intra-DER transactions and is the only entity in charge of physical coordination of DER schedules. In this stage, the DSO itself functions as an aggregator at the transmission-distribution interface.

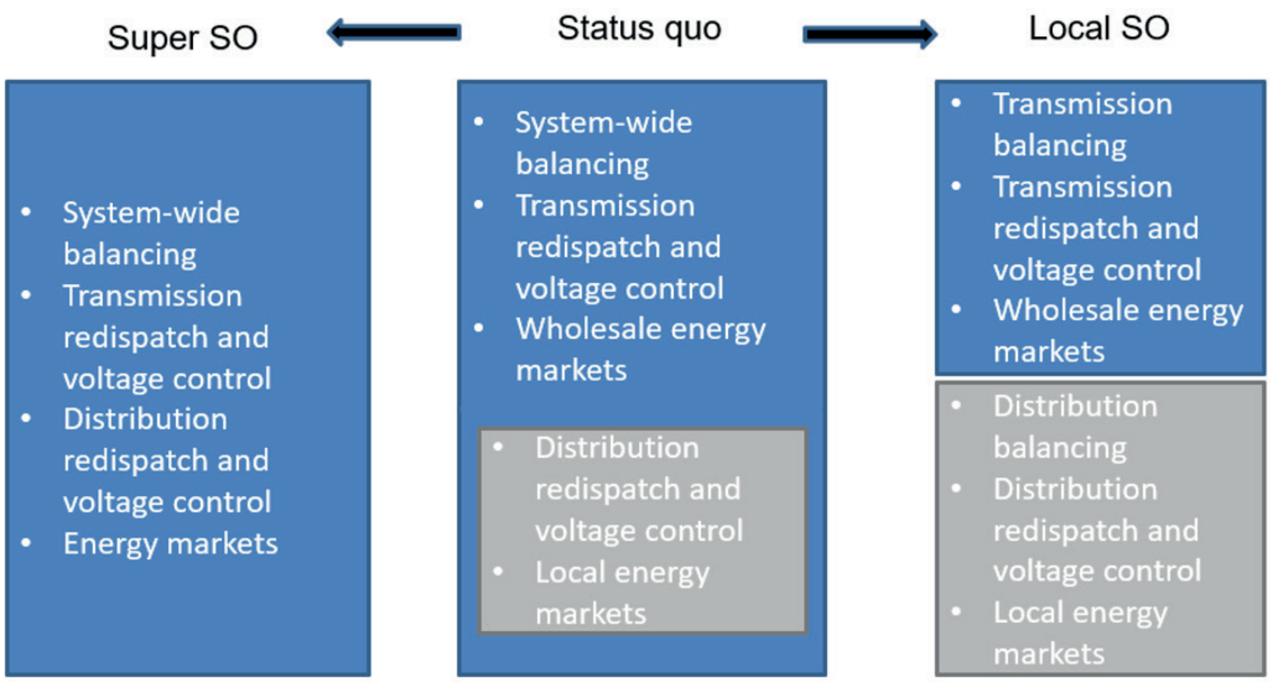
Similarly, Burger et al. (2019) distinguish two basic models for the future organisation of grid operation besides the typical setup that is currently in place, which is labelled a 'Hybrid Model'. These authors call one extreme case the 'Enhanced Bulk BA Model' and the other the 'Enhanced DSO Model'. In the Enhanced Bulk BA Model, the DSO would provide the TSO with all necessary information regarding the status of the distribution network. The DSO would hand over responsibility for ensuring the feasibility of power flows and power balancing at the distribution level to the TSO. The TSO would be in charge of balancing, overseeing all BSPs at all voltage levels and having visibility of all power flows. In the Enhanced DSO Model, the DSO would have sole responsibility for distribution-level balancing. Burger et al. (2019) explain that, in this model, similarly to the Independent DSO model foreseen by De Martini and Kristov (2015), the DSO would act as a sort of 'local system aggregator' at the transmission-distribution interface. More accurately described, the DSO would collect all information about DER bids and provide the TSO with an aggregate demand or supply bid for energy and ancillary services while checking the feasibility of the potential power flows under a

33 The same authors have also summarised the report in a shorter paper (Kristov et al., 2016).

range of different assumptions regarding potential transmission-level power flows and prices. The DSO would also oversee the real-time dispatch of DERs and be in charge of settling imbalances. The TSO would need little to no information about the distribution grid and the DERs' capabilities. Burger et al. (2019) explain that the Enhanced DSO Model could be interpreted as a decomposition of the power system into the transmission and distribution levels with TSO and DSO scheduling problems being solved independently and coordinated to reach a globally optimal (or near-optimal) solution[34]. The same authors calculate that the expenses of the PJM ISO account for roughly 0.7% of total system costs and these costs might not increase substantially with the size of the market. Therefore, they argue that if an 'Enhanced DSO' model were to be implemented, a minimum scale would be required to avoid duplication and to deal with the increasing complexity of its functions.

The two extreme setups proposed in De Martini and Kristov (2015) and Burger et al. (2019) are similar. Other relevant contributions are papers by Bahramirad et al. (2016) and Apostolopoulou et al. (2016), who propose more concretely how the division of roles between the TSO and the DSO should look if balancing were transferred to the DSO. In this Report, as is shown in Figure 12, we focus our discussion on the same two alternative models for the organisation of balancing. We label the alternatives the 'Super SO model' and the 'Local SO model'. The 'Super SO model' would involve balancing and all other grid-related services at all voltage levels being bundled as one task, requiring full visibility of the grid. In the 'Local SO model', instead, operational and market functions at different voltage levels are performed separately. In this model, flows over the numerous different LFC area borders would need to be monitored and coordinated[35]. Here we focus on the division or bundling of grid operation and market functions and not necessarily on the corporate structures that would be optimal to implement these functions. Similarly, we do not discuss the degree of separation (unbundling) between the different functions that would be appropriate[36].

Figure 12: Alternative setups for organising system services and energy markets[37]



34 An example of such an algorithm is proposed in Caramanis et al. (2016).

35 The MIT Utility of the Future report (MIT Energy Initiative, 2016) argues that that the "natural boundary" would be between meshed and radially-operated portions of the network, but that this boundary is not necessarily the way that transmission and distribution networks are divided between TSOs and DSOs.

36 For a discussion on whether or not to bundle grid ownership and operation, see Pollitt (2012).

37 (Wholesale and local) energy markets can be organised directly by the System Operator (as in the US for wholesale markets) or facilitated by the 'Super' or Local System Operator by forwarding information about grid constraints to a third-party power market operator (as in the EU for wholesale power markets).

5.2 Assessments of the two alternative setups

In this section, we discuss both alternatives. We simplify our analytical framework by merging the first two dimensions and the last two dimensions.

5.2.1 Coordination between balancing, grid service and wholesale markets

In theory, real-time locational marginal prices (LMPs) for active and reactive power applied at the transmission and distribution levels in both day-ahead and real-time would be able to coordinate wholesale markets, balancing markets and grid operation. This is referred to as Distribution Locational Marginal Prices in, e.g., Caramanis et al. (2016), Bai et al. (2018) and Papavasiliou (2018). It is expected that in practice the computation of such prices would be very challenging. Therefore, it is appropriate to look at second-best solutions. The Super SO model and the Local SO model setups that we introduced in the previous subsection are examples of second-best solutions.

The Super SO model would rely on a single entity to perform the market and grid operation functions that are currently carried out by different entities, as is illustrated in Figure 12. The vertical coordination challenge is therefore largely internalised by that entity, while there would continue to be a horizontal coordination challenge between adjacent Super SO entities if several of them were to operate in a single synchronous system, like the TSOs and LFC areas we know in the current setup. By internalising a large part of the coordination challenge, the Super SO model could outperform the Local SO model. However, it has also been argued that it is unrealistic for this entity to be able to reach a global optimum due to computational complexities. To avoid such issues, the Super TSO can opt for the use of heuristics to come to feasible coordination or internally set a more layered optimisation[38]. De Martini and Kristov (2015) even discard this model, which they refer to as the 'Total TSO Model'. Besides computational complexity, they also argue that a single entity would be more vulnerable in terms of reliability[39].

The Local SO model would rely on strong coordination between local system operators. They would coordinate vertically across the distribution-transmission network interface in a way that could be similar to the coordination we know among TSOs for their transmission-transmission network interfaces. The management of this vertical interface would be market-based and as transparent as possible. The local dimension of balancing responsibility does not mean that the size of balancing markets is reduced. Local balancing markets would be accessed locally, but they would still coordinate to reach a more global optimum. This coordination would certainly be constrained by the available network capacity. In the case of optimal coordination, if the local balancing market were uncompetitive due to a limited number of players at a certain moment, it would be merely a physical reality due to a concentrated market behind a (temporary) physical constraint. In the Super SO model, this local market concentration would still be there. The only difference would be that in the Local SO model the constraint would be situated between LFC areas instead of within an LFC area. Burger et al. (2019) are, however, somewhat sceptical about whether coordination between SOs at different voltage levels would work well. They refer to the limited success of inter-ISO balancing in the US and are also wary of the coordination required if balancing and grid-related functions were divided over the transmission and distribution grid.

It can also be expected that the way the coordination between balancing, grid services and wholesale markets is organised will also affect the opportunities for DERs to participate in these different markets (individually or via aggregators or energy communities). A trade-off emerges when considering the two models: on the one hand, due the internalisation of market and grid operation functions for a large area by one entity, the Super SO model would facilitate DERs to compete in wholesale

38 Layered optimisation could eventually lead to a setup very similar to the Local SO model but not necessarily. In the Local SO model, the boundaries of the different layers are fixed externally while under the Super SO they are decided on internally.

39 De Martini and Kristov (2015) cite contributions by studies on ultra-large-scale systems and system architecture (e.g. Feiler et al., 2006) to argue that the complexity associated with the Super SO model makes the system more fragile and vulnerable to relatively small or local disturbances.

markets and wider system service markets, wherein DERs would compete with generation, storage and demand units at all voltage levels. On the other hand, due to stronger emphasis on the coordination of grid and market functions at local level, under the Local SO model, more revenue opportunities for DERs might be developed and exploited at lower voltage levels, potentially at the expense of the possibility for DERs to compete in the provision of wider system services. Thus, the consideration that must be made is where the most added value from the participation of DERs in balancing, grid services and wholesale markets lies. Whether it is in adding competitive pressure in markets accessible to resources connected at all voltage levels under the Super SO model, or whether it is in trading in more local energy markets and allowing for, or improving, the provision of grid services at lower voltage levels under the Local SO model.

5.2.2 Non-discriminatory conditions for entry in balancing energy markets and exposure to the imbalance price

There is always tension between standardisation and innovation. This is also the case of balancing market entry conditions and the imbalance prices that apply to DERs. In what follows, we claim that this trade-off might play out differently depending on the market model we choose.

The Super SO model would lend itself to more standardisation, possibly at the cost of innovation. Even though the Super SO could continue to experiment with different entry conditions for DERs, it might not have the incentive to do so. Regarding the imbalance settlement, in the Super SO model it would remain similar to the current model, but with a significant increase in the volume of data exchange, as there might be several imbalance positions to account for for each meter.

The Local SO model would make differentiation of conditions for entry in balancing markets between BSPs at the transmission and distribution levels more straightforward, but there would be a higher risk of creating an uneven playing field. What is key in the Local SO model is that no incompatible products are traded in different LFC areas, leading to market fragmentation due to issues with balancing energy trading at the transmission-distribution interface. In this regard, a certain degree of harmonisation in terms of product design would be needed. In the Local SO model, the SO at the transmission level (possibly the TSO) would take care of settling transmission-connected assets, while settling imbalances of distribution-connected assets would be a task for the local SO. The Local SO would have to coordinate closely with retailers.

6. Conclusions

This Report has discussed how electricity balancing can be organised in a future with much greater penetration by DERs. Rather than focussing on entry barriers and taking the organisation of the balancing mechanism as given, we argue that the feasibility of solutions for optimal participation by DERs in the balancing mechanism is conditional on the organisation of the balancing mechanism. We formulate three conclusions.

First, the current organisation of balancing mechanisms in the EU is a legacy situation, rather than a well-thought-through design choice. Different alternative setups are possible in theory and their performance in practice depends on the context. We have introduced a multidimensional analytical framework and illustrated it by comparing the current setup in the EU with that in the US.

Second, in the medium to long term it will become increasingly challenging to operate the balancing mechanism cost-effectively without adjusting its organisation. We have illustrated this point by using the analytical framework to highlight the challenges that the balancing mechanism in the EU is currently facing with increasing shares of DERs.

Third, we have discussed the implementation of two extreme alternatives for the future organisation of the balancing market: a 'Super SO model' and a 'Local SO model'. The main question is whether it would be easier to manage seams within a balancing area or seams between balancing areas. The main challenge with the Super SO model is that a global optimum that takes into account all local issues would be difficult to achieve. It could be imagined that this model might facilitate DERs to compete in wholesale markets and wider system service markets with generation, storage of demand units at all voltage level. Even though the Local SO model might be more pragmatic, the main challenge with this model is implementing it in a way that limits fragmentation of balancing markets, which would have severe implications for competition. However, under the Local SO model, more revenue opportunities for DERs might be developed, and exploited, at lower voltage levels. In that regard, note that the Local SO model might lead to more experimentation, which could be beneficial, but could also be costly if local balancing practices are not standardised once experience shows what works best.

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Research Project Report
Issue 2022/02
February 2022

doi:10.2870/95157
ISBN:978-92-9466-182-1
QM-07-22-092-EN-N

Publications Office
of the European Union

Co-funded by the
Erasmus+ Programme
of the European Union