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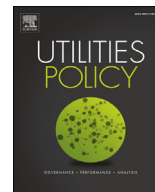
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The electricity balancing market: Exploring the design challenge



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ABSTRACT

In the unbundled national electricity markets in Europe, the balancing market is the institutional arrangement that deals with the balancing of electricity demand and supply. This paper presents a framework for policy makers that identifies the relevant design variables and performance criteria that play a role in the design and analysis of European balancing markets. We outline the full extent of the design challenge through a discussion of trade-offs among performance criteria, uncertain effects of design variables, and the many inter-linkages between the balancing market and the electricity market at large. Policy makers can address the balancing market design challenge by adopting a structured approach in which design variables, performance criteria, market conditions, system developments, and resultant market incentives are explicitly considered.

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1. Introduction

The topic of electricity balancing market design has been given relatively little attention by academic researchers, despite its crucial role in both power markets and power system operations. Electricity must be ‘consumed’ as soon as it is produced, because it cannot be stored easily. Balance management is a power system operation service vital for ensuring security of supply through the continuous, real-time balancing of power demand and supply. At each point in time, total production must be equal to total consumption in order to stabilize system frequency; it is therefore also called frequency control. If the system runs out of balance, power stability and quality will deteriorate, which may trigger the disconnection of system components, and ultimately, power blackouts. In vertically integrated electricity systems, it is relatively easy to maintain the system balance, but unbundling in European energy markets, which was initiated by Electricity Directive 96/92/EC, has separated the power transmission segment from power generation and supply. This has made balance management a much more difficult task, and necessitated the provision of incentives to ensure that electricity market participants schedule electricity production and consumption and stick to these schedules, and

provide balancing services to the System Operator. However, in countries without an unbundled, competitive electricity market, the design task has been less urgent and simpler, and there we can refer to a ‘balancing model’ or ‘balancing approach’ (Energy Community Regulatory Board, 2012). As unbundling took a different pace in European countries, national policy makers made their own choices in setting the detailed balancing market rules, based on national power system and market conditions and national and individual objectives.¹

The balancing market is the institutional arrangement that establishes market-based balance management in an unbundled electricity market.² It can be considered the last in a sequence of electricity markets, after year-ahead, month-ahead, day-ahead and intra-day markets (ERGEG, 2009). However, the design of the balancing market is more intricate, as it lies at the junction of financial transactions (the power market) and physical exchanges

¹ No documentation has been found of the decision making on early national balancing market legislation. Two balancing market experts from TenneT indicated that these have likely been relatively simple, implicit and internal processes. For example, the initial Dutch balancing rules have been developed by looking at the Swedish design and adapting for the differences in generation mix, and by aiming for appropriate incentives to market players (personal communication, Frank Nobel and Fijko Wenting, Arnhem and Heteren, summer 2015).

² In the draft Network Code on Electricity Balancing, the balancing market is defined as ‘the entirety of institutional, commercial and operational arrangements that establish market-based management of the function of Balancing’, with ‘Balancing’ being defined as ‘all actions and processes, on all timelines, through which TSOs ensure, in a continuous way, to maintain the system frequency within a predefined stability range’ (ENTSO-E, 2014a).

Abbreviations: BRP, Balance Responsible Party; BSP, Balancing Service Provider; SO, System Operator; STU, Schedule Time Unit.

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(the power system).

In this paper, we aim to provide an overview of the decisions and evaluation criteria that play a role in balancing market design, by presenting a design framework to support policy makers (national governments, regulators, and System Operators). Furthermore, we elaborate by delineating the scope of the design challenge, which also underpins the value of the framework. The focus of this paper is on European markets that include a voluntary power exchange and bilateral markets, rather than a centralised power pool as common in the United States (Stoft, 2002). The topic of harmonizing and integrating national balancing markets is out of the scope of this analysis. The paper builds upon the research by van der Veen (2012).

In Section 2, we present literature on European balancing market design. Section 3 provides the developed balancing market design framework. The scope of the design challenge is discussed in Section 4 by drawing attention to the performance criteria trade-offs, the impact of design variables, and the inter-linkage of the balancing market with the electricity sector. This leads to a set of design principles for policy makers. Finally, Section 5 gives the conclusions of this work.

2. Literature review

In this section, we describe the balancing market design literature that formed a basis for the development of our framework. This requires the use of some key terms that are explained in the design framework in Section 3.

Vandezande et al. (2008) have provided a first overview in literature of balancing market design options. The authors make a high-level distinction between design aspects related to procurement of balancing services and design aspects related to delivery and settlement. Three categories of design options are included under procurement of balancing services: balancing service definitions, times and methods of procurement, and methods for remuneration. Delivery and settlement includes four design options: gate closure times, settlement periods, methods of imbalance volume calculation, and methods of imbalance pricing. Herewith, the authors present a logical, high-level classification of design options related to service types, used methods for the main balancing market activities, time aspects, and pricing aspects.

Rebours et al. (2007) and Rebours (2008) describe eight fundamental issues in the design of ancillary service markets (of which balancing service markets form a subset). However, these issues are oriented towards mandatory power pools such as the PJM market in the U.S., and concern design principles rather than design options. Most identified design options in these sources are also given by Vandezande et al. (2008), with the exception of three variables: the scoring of balancing service offers (which deals with the order of selection of balancing bids), the allocation method used for allocating procurement costs, and the publication of market data.

Next, Abbasy (2012) describes the time-related design choices playing a role in balancing service market design under the common variable ‘timing of balancing service markets’. This variable includes two main aspects: timing of bid procedure, which involves the frequency of bidding and the gate opening and closure times of balancing service markets, and timing of market clearance, which concerns both the frequency of clearance and the coordination with clearance of other (short-term) electricity markets.

Several reports on balancing markets and balancing market integration by the former market-oriented organisation of European Transmission System Operators (ETSO) describe numerous design variables (ETSO, 2005, 2006, 2007). A large part of these consists of design options also covered by Vandezande et al. (2008).

Four new variables identified in these reports are the balancing service requirements, reserve volume requirements (i.e., the amount of balancing capacity demanded by the System Operator), a planned balance for the energy schedule (i.e., matching schedules for production and consumption), and the allocation of the net income for the SO of balance settlement (imbalance payments minus remuneration of procured balancing services).

Finally, a survey of European TSOs about the current national balancing market design by ENTSO-E, the European Network of Transmission System Operators for Electricity, provides a comparative overview for twenty-seven ENTSO-E member countries (ENTSO-E, 2014b). The covered design options are in line with the literature. The survey reveals the wide variety of choices made across Europe for each particular design variable. For example, automatic Frequency Regulation Reserves are settled pay as bid in seven countries, with a marginal price in seven other countries, and with a regulated price in four countries.³

Balancing market performance criteria are not well described in the literature. Often, these criteria are considered implicitly, or constitute lower-level indicators that cover the relevant balancing market objectives only partially. Importantly, Frontier Economics and Consentec (2005) have mentioned three high-level performance criteria: economic efficiency, security of supply, and integration implementation costs. Furthermore, Vandezande (2011) positions a cost-reflective balancing market design as a precondition for the efficient functioning of electricity markets, putting forward the criterion of cost-reflectivity.

3. Balancing market design framework

Using the literature described in Section 2 as a starting point, we have developed a balancing market design framework.⁴ It consists of three parts: a reference model, a performance criteria set, and a design space. The reference model introduces and defines the balancing market concepts. The performance criteria set offers a set of high-level balancing market performance criteria, while the design space lists the relevant balancing market design variables. Herewith, the design framework can support policy-making by aiding in the establishment of a common understanding of the design task, and in the consideration of all relevant design options and decision criteria. Additionally, it may facilitate further research on the role of the balancing market.

3.1. Reference model

In the reference model the structure of the balancing market is defined. A balancing market consists of three main phases (balance planning, balancing service provision, and balance settlement) and concerns three main actors (the System Operator (SO), Balancing Service Providers (BSPs), and Balance Responsible Parties (BRPs)). In the balance planning phase, BRPs submit energy schedules to the SO on the day before delivery, stating planned energy generation and consumption for each Schedule Time Unit (STU) within the day of delivery. In the balancing service provision phase, BSPs submit balancing service bids to the SO, which are procured by the SO in price order to secure the system balance. In the balance settlement phase, energy imbalances (schedule deviations) of BRPs and

³ In fact, it appears that for many variables some of the TSOs were not even able to indicate their design choice, and for some variables one of the design options is vaguely called ‘hybrid’, which emphasizes the multitude and intricacy of existing balancing markets in Europe.

⁴ The framework is one of the main products of a PhD research on balancing market design (van der Veen, 2012). A more extensive description can be found in the dissertation.

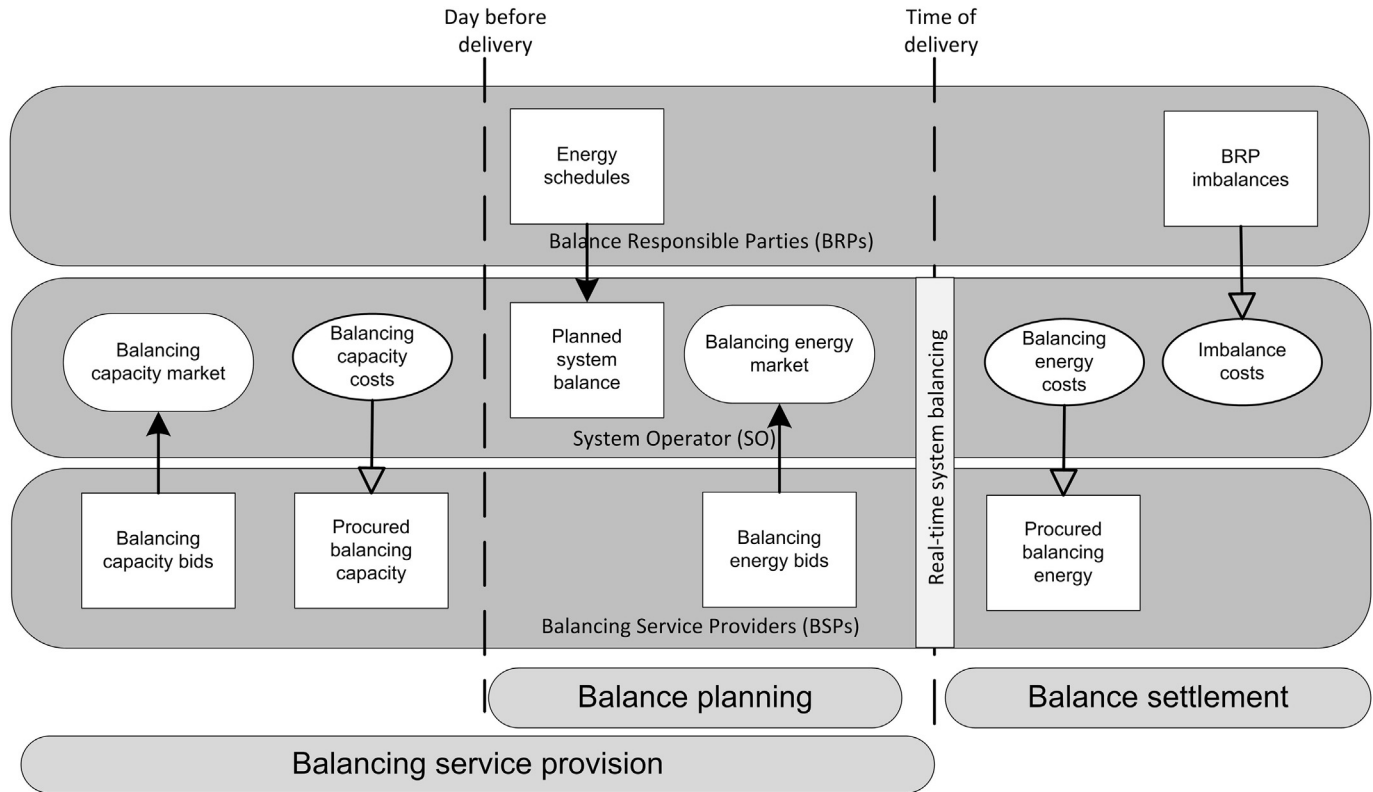


Fig. 1. Basic structure of the balancing market, ordered by time of occurrence (horizontal) and by actor (vertical). Balancing Service Providers (BSPs) are remunerated for balancing services provided to the System Operator (SO). The balancing energy costs are allocated to the Balance Responsible Parties (BRPs) in the form of imbalance costs. Shown are information flows (black arrowhead) and money flows (white arrowhead) between different actors.

activated balancing energy are settled on a STU basis. BSPs who provided upward regulation receive the upward regulation price if marginal pricing is used, or the bid price in case of pay-as-bid pricing (in euro/MWh). BSPs who provided downward regulation pay the downward regulation price, or the bid price.⁵ BRPs with a shortage pay the short imbalance price for each MWh of deviation, and BRPs with a surplus receive the long imbalance price. Imbalance prices are based on the regulation prices or costs, and thus reflect real-time system balancing costs; these costs are allocated to the BRPs, which face a proportionate incentive to balance their energy portfolio. A schematic of the balancing market structure is shown in Fig. 1.

Balancing services consist of two main types: balancing energy (the real-time adjustment of balancing resources⁶ to maintain the system balance) and balancing capacity (the contracted option to dispatch balancing energy during the contract period). Selected bids in the balancing capacity market are transferred to the balancing energy market. Furthermore, one can also differentiate between upward regulation and downward regulation, and between Frequency Containment Reserve (FCR), Frequency Regulation Reserve (FRR), and Replacement Reserve (RR),⁷ which vary in function and activation method.

⁵ Providers of downward regulation who are saving fuel costs thanks to ramping down of their power plants will still profit if they pay less than their fuel costs. If the downward regulation price is negative, the providers actually receive this price.

⁶ Balancing resources are the physical generation resources (power plants) and consumption resources (adjustable load) that have the flexibility and capability to provide balancing services.

⁷ These terms have been adopted more recently by ENTSO-E. Previously, the terms primary, secondary and tertiary control (reserves), respectively, were used.

3.2. Performance criteria set

The performance criteria set includes the high-level criteria with which the performance of balancing markets can be evaluated. Two fundamental balancing market requirements are economic efficiency and security of supply. We have formulated four criteria that correspond with economic efficiency and three performance criteria that correspond with security of supply as well as two market-facilitation criteria.

The short definitions of the performance criteria are as follows.

3.2.1. Security-of-supply criteria

- *Availability of balancing resources* is the availability of resources for meeting reserve requirements and resolving system imbalances in real-time.
- *Balance planning accuracy* is defined as the accuracy with which energy schedules reflect actual energy exchanges, i.e., the accuracy with which the system balance is planned.
- *Balance quality* is the effectiveness of maintaining the control area balance, i.e., keeping to scheduled cross-border exchanges, and maintaining system frequency, i.e., keeping to nominal system frequency (which is 50 Hz in Europe).

3.2.2. Economic efficiency criteria

- *Cost allocation efficiency* concerns the efficiency with which the balancing service costs are allocated to the market, i.e., whether market parties pay for balance management to the degree that they benefit from it (or have caused the need for it).

- *Utilisation efficiency* is defined as the economic efficiency of the utilisation of available balancing resources, i.e., the degree to which the least and cheapest balancing resources are used to maintain the system balance.
- *Price efficiency* involves the cost-reflectivity of balancing service prices paid to BSPs.
- *Operational efficiency* concerns the economic efficiency of handling the transactions related to the administrative processes in the balancing market, including those of energy schedule and balancing service bid submission and balance settlement.

3.2.3. Market-facilitation criteria

- *Transparency* concerns the information availability, symmetry and clarity on balancing market design and performance.
- *Non-discrimination* involves the equality of balancing market rules and conditions for different market parties (BRPs and BSPs).

The performance criteria included are in alignment with the objectives stated in the Framework Guidelines⁸ (ACER, 2012). Furthermore, a survey conducted among balancing market experts confirmed the importance of these criteria (van der Veen, 2012).

3.3. Design space

The design space provides a comprehensive and high-level overview of (national) balancing market design variables, grouped by market phase. Short definitions of the design variables are provided below.

3.3.1. General variables

- *Schedule Time Unit (STU)*: The main time unit in the balancing market, which divides balance responsibility between the SO and the BRPs (i.e., the market). It is the time period over which energy schedules and balancing service bids are specified. An alternative term is '(imbalance) settlement period'.
- *Publication of national information*: The decision regarding which balancing market information is distributed to the market, in what form, and how often. A distinction can be made between information on the market design itself and market results (data on balancing service bid volumes and prices, and imbalance volumes and prices).

3.3.2. Balance planning variables

- *Zonal vs. nodal responsibility*: The geographical aggregation level at which BRPs must submit energy schedules. If BRPs must submit energy schedules for each network node, and are penalised for deviation per node, 'nodal balancing' is applied. If energy schedules are at the level of geographically defined subsystems of the control area, 'zonal balancing' is applied.

⁸ The Framework Guidelines stipulate that European balancing rules should pursue the objectives of operational security, competition, non-discrimination, transparency, efficiency, and social welfare, promote cross-border exchanges, and facilitate wider participation of demand response and renewable energy sources (ACER, 2012). The last two objectives are not directly covered in our criteria set, as they do not measure the performance of balancing markets. However, they do contribute to higher efficiency and effectiveness of balancing, by increasing the availability of balancing resources.

- *Responsibility for renewable generation*: The distribution of balance responsibility for renewable generation between the market (BRPs) and the SO. Balance responsibility for renewable generation may lie completely or partially with the SO, or renewable producers may have the same balance responsibility as conventional producers.
- *Net vs. separate positions*: The definition of existing BRP balances. If separate production and consumption positions exist, BRPs have to submit separate energy schedules for production and consumption that are settled separately. If a 'net position' applies, there is only one type of scheduled position that includes both generation and consumption.
- *Final gate closure time*: The time at which the energy schedules of BRPs become final, typically around 1 h before the time of delivery. Between the initial and final gate closure time, BRPs can submit adapted energy schedules to the SO, which replace the last submitted version.
- *Initial gate closure time*: The time at which BRPs must submit an initial energy schedule to the SO.⁹ Often, this is right after day-ahead market clearing, for all the STUs on the day of delivery.
- *BRP accreditation requirements*: The requirements a market party must meet to become authorised by the SO as a Balance Responsible Party. These usually concern a certain financial security, and the technical capability to exchange information with the SO in the right data format and in a timely fashion.

3.3.3. Balancing service provision variables

- *Balancing service classes*: The main classes of balancing services, which have different functions and technical characteristics. ENTSO-E distinguishes between Frequency Containment Reserves, Frequency Regulation Reserves, and Replacement Reserves, for which different procurement and control requirements are stipulated (ENTSO-E, 2013).
- *Reserve requirements*: The control area requirements for procurement of balancing capacity, including requested volumes and technical characteristics of the balancing resources. These are specified separately for each of the balancing service classes.
- *Control system*: The control system used for activation of balancing energy, concerning the use of manual vs. automatic control, and decentralised vs. centralised control. In continental Europe, Frequency Containment Reserve (primary control) is a decentralised automatic service that is activated in a matter of seconds, Frequency Regulation Reserve (secondary control) is a centralised and often automatic service that is activated by means of Load-Frequency Control in a matter of minutes, and Replacement Reserve (tertiary control) is a centralised and often manual service that is activated within minutes up to hours (UCTE, 2009).
- *Methods of procurement*: The main methods used to procure balancing services. Balancing services are often provided by BSPs to the SO through bidding in balancing service markets. Different balancing service markets may be installed for different service classes and types. Alternatively, balancing services could be acquired by SOs through bilateral contracting, through an obligation for BSPs to provide balancing services, or the SOs may own balancing resources themselves.
- *Timing of balancing service markets*: This variable encompasses the timing of bid procedures (time horizon of markets), and the

⁹ With an initial energy schedule submission the SO obtains information to plan the system balance and possibly energy transports well in advance, and has more time to check the consistency of the energy schedules.

timing of market clearance (frequency and coordination with other markets). The timing of bid procedures involves the opening and closure times of balancing service bid submission, relative to the market clearing times. The timing of market clearance consists of the frequency of balancing service market clearance and the coordination with the clearance of day-ahead and intra-day markets (Abbasy, 2012).

- *Balancing service pricing mechanisms:* The pricing mechanisms used for settlement of selected bids in the different balancing service markets. Two market-based pricing mechanisms are pay-as-bid pricing and marginal pricing, where selected bids are remunerated with the price of the last activated bid in price order. In case of regulated pricing, the prices are partially or fully determined by price regulations.
- *Activation strategy:* The strategy or procedure applied by the SO regarding the activation of balancing service bids, including order of activation (the degree to which the SO deviates from merit order) and time of activation (proactive vs. reactive).
- *Bid requirements:* The requirements that balancing service bids must meet. These may contain requirements about bid price, volume, grid location, response speed, regulating speed, activation time, activation duration, and activation method, among others.
- *BSP accreditation requirements:* The requirements a market party must meet to become an authorised Balancing Service Provider. These concern the technical pre-qualification of balancing resources, and the capability to exchange information with the SO.

3.3.4. Balance settlement variables

- *Allocation of balancing capacity costs:* The method used to allocate the balancing capacity costs. These costs are usually allocated to all system users through adaptation of the system services tariff. Alternatives are an additional price component in the imbalance price, a separate fee structure for BRPs, and the assignment of reserve obligations to market participants.
- *Allocation of balancing energy costs:* The method used to allocate the balancing energy costs. Imbalance settlement serves to allocate the balancing energy costs to the BRPs in proportion to their energy imbalances. An alternative may be to recover a part of the balancing energy costs through the system services tariff¹⁰.
- *Imbalance pricing mechanism:* The pricing mechanism used to determine the short and long imbalance prices. A main design choice for this variable is whether these prices are identical ('single pricing') or not ('dual pricing'). Other design choices concern the balancing costs or prices on which the imbalance prices are based, whether price components are added, and whether the imbalance pricing rules are dependent on certain criteria reflecting the system balance quality.
- *Penalty for non-delivery:* The penalty that BSPs pay for not delivering requested balancing energy.¹¹
- *Allocation of net settlement sum:* The allocation of net income or expenditure from balance settlement (imbalance payments

minus remuneration of procured balancing services) at the system level. Possible allocation methods include the adaptation of the system services tariff, adaptation of imbalance prices, separate fees for BRPs, or allocation to the SO as income.

- *Timing of settlement:* The frequency and time of settlement of procured balancing services and BRP imbalances. The frequency of settlement determines the periods over which costs are aggregated and settled in one transaction, and the time of settlement determines the time lapse between the end of the aggregation period and the financial settlement.

3.3.5. Example of design: The Netherlands

To give an actual example, we describe here the Dutch balancing market in terms of the design variables described. This information has been extracted from Autoriteit Consument en Markt (2014a,b) and TenneT (2010, 2012a,b).

The Netherlands makes use of a *Schedule Time Unit* of 15 min. Regarding the *publication of national information*, the Dutch TSO TenneT provides the bid prices at certain spots in the bid ladder of the next day (100 MW, 300 MW, and 600 MW in both directions) on its website. A minute-to-minute indication of the bid price of the last activated bid and the minute-to-minute dispatched balancing energy volumes are also provided there. Regarding *zonal vs. nodal responsibility*, the balance responsibility applies to the Netherlands as a whole, and *responsibility for renewable generation* lies fully with the market (BRPs). Concerning *net vs. separate positions*, there is a net balance for BRPs that includes both production and consumption. The *initial gate closure time* is 2:00 p.m. on the day before delivery (for all STUs of the next day). The *final gate closure time* is at 10:00 a.m. on the day after delivery, which means that so-called 'ex-post trading' can take place, i.e., BRPs 'trading away' imbalances with each other after real-time. The *BRP accreditation requirements* include required expertise and technical, administrative and organisational facilities, and a signed agreement concerning financial accountability and security.

The *balancing service classes* defined in the Netherlands are primary power, regulating power, reserve power, and emergency power. Primary power is activated automatically and within seconds based on frequency deviations. Regulating power can be activated automatically and fully within 15 min, and is used to remove the Area Control Error of the Netherlands. Reserve power is not activated automatically, and/or is activated fully in more than 15 min. Emergency power is a last-resort service (interruptable load), and is activated manually. Regarding *reserve requirements*, 101 MW of primary control capacity have been contracted in 2014 (this was the first year such capacity was contracted and remunerated). The TSO plans to reserve 215 MW of regulating power and 350 MW of emergency power (only upward) for 2016, partly through annual contracts and partly through quarterly contracts.¹² The *control system* applied is the Load Frequency Control system that is central to balance management in the synchronous zone of continental Europe. Concerning *methods of procurement*, balancing capacity is contracted bilaterally. Contracted regulating bids are put into the main balancing energy market, the 'regulating and reserve market'. This market may both include regulating power bids and reserve power bids. For power plants with a nominal capacity larger than 60 MW it is mandatory to have the technical capability to provide primary power, and all connected parties with more than 60 MW capacity (per connection) are obliged to offer all available up- and down-regulation capacity into this market.

¹⁰ In essence, imbalance settlement can be considered an indispensable part of the balancing market, as market participants must have an incentive to deliver the energy that they sold in the market, and thus should be charged for imbalances.

¹¹ If the SO adjusts the energy schedules of corresponding BRPs based on requested balancing energy, non-delivery will be subject to imbalance settlement. In such systems, the penalty for non-delivery would be an additional penalty. In order to verify balancing energy delivery, the SO must receive measurement values of balancing resources with intervals of several seconds, as STU values are insufficient (Lampropoulos, 2014).

¹² <http://www.tennet.eu/nl/nieuws/article/oproep-voor-de-levering-van-regelvermogen-en-noodvermogen-in-2016-1.html>, accessed on May 29, 2015.

Furthermore, concerning the *timing of balancing service markets*, TenneT contracts primary control capacity on a weekly basis. Regulating power is contracted annually, but the market for regulating and reserve power operates on a 15-min basis. On the day before delivery, the bids must be submitted before 2:45 p.m. After that, bids can be adapted up to 1 h before the STU of delivery. The *balancing service pricing mechanism* applied in this market is marginal pricing; the set prices are called 'regulation prices'. Contracted balancing capacity is settled by pay-as-bid pricing. Next, regarding the *activation strategy*, bids are activated in price order to restore system balance. TenneT applies a reactive strategy, in which bids are activated in response to actual system imbalances rather than in anticipation to expected ones. Furthermore, multiple bids can be activated in parallel. The *bid requirements* for regulating power include a regulating speed of at least 7%/minute, a bid volume between 4 and 999 MW, and a bid price between –100,000 and 100,000 euro/MWh. There are no additional *BSP accreditation requirements*.

In the Netherlands, *allocation of balancing capacity costs* occurs by adaptation of the system services tariff. The *allocation of balancing energy costs* occurs through imbalance settlement. The Dutch *imbalance pricing mechanism* is quite elaborate. In principle, single imbalance pricing is applied, but depending on the 'regulation state' dual pricing may be applied (based on both the regulation prices). Roughly, dual pricing is applied to STUs in which both upward and downward regulation has been activated. In addition, a so-called incentive component is added to the short imbalance price and subtracted from the long imbalance price if two conditions with regard to the number and size of involuntary energy exchanges with foreign countries are met. This component is determined weekly, does not change by more than 2 euro/MWh, and cannot be lower than zero. Also, the imbalance price is set 10% higher than the regulation price if emergency power has been activated in the STU. There is no *penalty for non-delivery* for BSPs. Activated balancing energy is automatically rewarded by the SO, and the energy schedules of the corresponding BRPs are adapted accordingly, which means that non-delivery creates a BRP imbalance. Finally, the *allocation of the net settlement sum* occurs through adaptation of the system services tariff, and the *timing of settlement* is weekly.

4. Discussion

In this Section, the scope of the balancing market design challenge is outlined in more detail, by discussing three relevant aspects. First, we show that various trade-offs exist between performance criteria (Section 4.1). Then, we elaborate on the uncertain impact of design variables (Section 4.2). Third, we consider the fact that the balancing market is embedded in the overall electricity market (Section 4.3). This allows us to draw a richer picture of the challenges involved in balancing market design, and formulate design principles for policy makers (Section 4.4).

4.1. Performance criteria trade-offs

Here we provide a short overview of the full range of trade-offs that exist among the balancing market performance criteria identified in Section 3.2. The trade-offs can be ordered in three classes: trade-offs among security-of-supply criteria (security trade-offs), trade-offs among security-of-supply and economic efficiency criteria (security-efficiency trade-offs), and trade-offs among market-facilitation criteria and security or efficiency criteria (facilitation trade-offs).

Regarding *security trade-offs*, balance planning accuracy can be traded off against availability of balance resources and balance

quality. If the SO can procure more and quicker resources from the market, this can improve the score on the last two criteria, but it may also reduce balancing planning accuracy, as it results in lower possibilities of, and incentives for, portfolio balancing. Portfolio balancing is the BRP activity of balancing the energy portfolio in order to minimise imbalance costs, and involves generation and load forecasting, short-term market trading, and so-called 'internal' balancing (i.e., the real-time adjustment of generation and consumption within the BRP portfolio). Lampropoulos (2014) states that 'passive contribution' (voluntary contribution to system balancing by BRPs) may result in substantial reductions of balancing energy demand.¹³ On the other hand, it also reduces the supply of balancing services to the SO. Thus, the effect of portfolio balancing on availability of resources is not straightforward. Balance quality may be affected if BRPs overreact to system imbalances and create frequency overshoots.

Regarding *security-efficiency trade-offs*, portfolio balancing again plays a key role in the evaluation of balance planning accuracy vs. utilisation efficiency. Improving the opportunities for portfolio balancing (e.g., by setting the final gate closure time closer to the time of delivery) or the incentives for portfolio balancing (e.g., by applying an imbalance pricing mechanism that results in higher imbalance prices) improves the accuracy of system balance planning, but may cause inefficient real-time balance management. Inefficiencies may for example be caused by BRPs withholding balancing resources for internal balancing, the use of more expensive resources, and the regulation (ramping) of resources in opposite directions at the same time.¹⁴ Furthermore, realising a higher balance planning accuracy by creating overly strong imbalance prices will affect cost allocation efficiency. Also, striving for a high balance quality by dispatching quicker but more expensive resources may improve balance quality, but damages utilisation efficiency. Price efficiency may be compromised by a higher degree of balancing resource contracting and longer contract periods (motivated by the objective of high resource availability), because the higher resource demand and uncertainty of resource value will lead to higher (risk) premiums in the balancing capacity prices.

Facilitation trade-offs exist in relation to the performance criteria of transparency and non-discrimination, but they are more difficult to make explicit. Non-discrimination is realised by creating a level-playing field for the market participants. Policy makers may aim to design the balancing market such that, for example, small, renewable or demand-side market participants are not at a disadvantage in playing the role of BSP and BRP, but if they create exceptions for such participants they thereby introduce discrimination. The introduction of equal balancing rules and conditions for all market participants would not only contribute to non-discrimination, but also to market transparency and operational efficiency, as the regulatory regime is simplified. Other effects are less clear. For example, on the one hand, equal rules may lead to a higher number of market participants who together increase the supply of, and reduce the demand for, balancing resources. On the other hand, equal rules may also give such strong incentives to renewable energy producers that they balance their energy portfolio less efficiently and effectively than would the SO. Furthermore, the simplification of balancing rules for the reason of operational efficiency or transparency may be at the expense of the

¹³ Passive contribution is enabled by single imbalance pricing, which gives BRPs the opportunity to profit from imbalance settlement by having a BRP imbalance that is opposite to the system imbalance.

¹⁴ Costs of portfolio balancing are not reflected in the balancing service and imbalance prices, but are nevertheless part of the costs of balance management, which in the end consumers pay for as well.

security or economic efficiency of balance management. For example, increasing the length of the STU may reduce transaction costs but also balance planning accuracy, and reducing the number of balancing service markets increases transparency but could damage price efficiency and balance quality.

As a last remark, between some performance criteria there is a synergy rather than a trade-off. This is especially true for the relations between utilisation efficiency, price efficiency, and cost allocation efficiency, and the relations between non-discrimination, transparency, and operational efficiency.

4.2. Impact of design variables

For many of the balancing market design variables the different possible values (settings) can have widely diverging effects. In addition, most variables affect multiple performance criteria. To illustrate, we focus on the potential impact of three important design variables on performance.

The determination of the *Schedule Time Unit* divides balance responsibility between the System Operator and the Balance Responsible Parties. Smaller STUs will give stronger incentives to BRPs to balance their energy portfolio, as deviations from scheduled energy exchange during the STU will even out to a lesser degree. As a result, power imbalances on the system level will be smaller, which leads to a lower activation of balancing energy bids. However, this leads in turn to lower imbalance prices, which weakens the incentives to BRPs again. Thus, the STU certainly has an impact on balance planning accuracy, but its nature is uncertain. Furthermore, the changes in BRP portfolio balancing will change the amount of offered balancing energy: Intra-day trade commits flexible resources, and balancing resources are kept by BRPs for 'internal balancing'. Because intensified portfolio balancing will thus both decrease the demand for and supply of balancing energy services, the effects of the STU on availability of balancing resources and price efficiency are not straightforward. Frunt (2011) finds in an analysis on the effect of the STU on imbalances that the total balancing effort of BRPs and the SO combined increases with an increasing STU, and that this combined effort stabilises for STUs of 1 h and smaller (to about 2% of the yearly energy consumption). This suggests that the value of both these criteria will decrease for larger STUs. However, as the BRP portfolio balancing replaces more efficient centralised active balancing by the SO, a smaller STU may reduce the utilization efficiency. Also, a smaller STU raises the transaction costs, because energy schedules and balancing energy bids are submitted more frequently.

The *timing of balancing service markets* is about the timing of balancing service bid procedures and balancing service market clearances. The timing of balancing service markets has a large impact on the bidding behaviour of Balancing Service Providers. If balancing capacity markets are cleared yearly, only BSPs with balancing resources that are available across one whole year can offer balancing resources, which is a substantial entry barrier for smaller market participants and reduces the offering of balancing capacity (i.e., utilization efficiency). As a result the price efficiency will be low as well, and this is aggravated by the fact that BSPs must predict the opportunity costs of balancing capacity procurement for up to one year in advance. An advantage of long-term procurement is a higher degree of certainty with regard to the availability of balancing resources. In case of a daily balancing capacity market, the coordination of timing of the balancing capacity market clearance with the day-ahead market clearance becomes an issue. Abbasy et al. (2010a) found that a balancing capacity market clearance after the day-ahead market clearing will lead to the lowest prices in both markets and highest balancing capacity volumes, although this could result in a lower balancing resource

availability. Furthermore, the frequency of clearing of balancing energy markets also affects price efficiency. In case of marginal pricing, a higher clearing frequency is likely to result in lower balancing energy prices. However, if the market prices become too low for BSPs to cover their costs, they may start to submit higher bid prices, limiting this effect. Finally, a bid deadline that is well before the clearing time will increase the uncertainties on profits and reduces the possibilities to participate in other markets, which is likely to lead to higher bid prices. An example is given by the comparison of the monthly secondary control reserves market in Germany and the Dutch balancing energy market over the year 2009,¹⁵ made by Abbasy et al. (2010b). They observed significantly higher balancing energy prices (relative to intra-day prices) in Germany, and attributed this to the monthly procurement and corresponding fixation of the balancing energy bid ladder in Germany, which added to market uncertainties and opportunity costs for German BSPs.

The *imbalance pricing mechanism* is the main design variable determining the strength of the incentives that BRPs receive to balance their energy portfolio. van der Veen et al. (2012) presented an analysis of the impact of various imbalance pricing schemes, taking into account the effects on BRP behaviour. The imbalance pricing mechanism was found to exert a greater impact on the actual imbalance costs paid by BRPs than on their portfolio balancing strategies, because all schemes give the general incentive to end up with a positive imbalance rather than a negative,¹⁶ due to which BRPs usually end up with a small positive imbalance. Single pricing led to the lowest actual imbalance costs, suggesting that this mechanism results in the highest cost allocation efficiency. Another positive effect is that it does not discriminate against small players, because the relatively higher imbalances of small BRPs are offset by the profits of being in the right direction, which happens more often for small BRPs (van der Veen et al., 2012). However, this option provides weaker incentives for balance planning accuracy, which may be problematic for systems in which balancing resources are lacking.

From a wider perspective, and considering the entire balancing market design space and performance criteria set, we note that the balance planning variables generally impact on the criterion of balance planning accuracy, as they influence the BRPs task of energy portfolio balancing. By contrast, the balancing service provision variables affect availability of balancing resources, utilisation efficiency and price efficiency. Furthermore, the settlement variables affect cost allocation efficiency, and also balance planning accuracy, because the way the costs are distributed determines the incentives for BRPs to balance their energy portfolio. The main variable affecting the criterion of transparency is the publication of national information. Non-discrimination is affected by responsibility for renewable generation (as distinct balancing rules for renewables are a form of market discrimination) and net vs. separate positions (as a net position puts small players at a disadvantage, among others (NordREG, 2008)). Balance quality is mainly influenced by the choice of control system and activation strategy. Operational efficiency changes when the number of transactions changes, and the Schedule Time Unit and the timing of balancing service markets play a substantial role here.

¹⁵ In the German market in 2009, reserve capacity and balancing energy for secondary control were procured in a single tender, which was held on a monthly basis. Bids were selected based on the capacity price, but real-time activation was based on the energy price. The selected bids formed the energy bid ladder, which was fixed for the entire month (Amprion, EnBW, TenneT Germany, and 50Hertz, 2011; Riedel and Weigt, 2007).

¹⁶ This results from the up-regulation bid prices having a higher mark-up (compared to the day-ahead market price) than the down-regulation prices.

All in all, we have found various indications that balancing market design choices influence performance along multiple criteria. Moreover, the effects are not obvious, as the mechanisms taking place within the balancing market include feedback loops between individual and system imbalance volumes and imbalance costs (concerning BRPs) and between the volumes and prices of offered balancing services and the volumes and prices of procured balancing services (concerning BSPs).

4.3. Inter-linkage with the electricity sector

Because the balancing market is embedded in the electricity market, power system and market conditions have a large influence on the effects of balancing market design variables. Here we address these influences for various (high-level) conditions.

First of all, the *power system size* has an influence on the impact of balancing market design options. Both the amount of balancing resources and the system imbalances will be higher in larger power systems, but system imbalances may be relatively smaller, if the various causes of imbalance are independent. Second, the *national electricity generation characteristics* influence offered balancing services, balancing costs, and system imbalances because they determine the amount of available balancing resources and the minimum level of balancing prices (which is the marginal costs of flexible power plants), and they affect the demand for system balancing (due to the unpredictability of generation, and through the level of inertia from power plants (Fruent, 2011)). Similarly, *consumption characteristics* are influential because the predictability of consumption affects the demand for balancing services, and because the eligibility of load resources as balancing resources affects the availability of these resources. The availability of *transmission capacity* determines the occurrences of internal congestions, which affects the availability of balancing resources for system balancing. This may be because resources are located in a congested area, or because they are used for redispatch (congestion management). Regarding the *day-ahead market and intra-day market design* a relevant sub-condition is the time unit used in those markets compared to the STU; if these are equal, BRPs are able to balance their energy portfolio by trading in those markets more accurately than if the time unit is larger than the STU. The short-term market gate closure times are influential as well, as they affect the accuracy of forecasting of generation and consumption.

Importantly, the fact that the balancing market is intertwined with the rest of the electricity market also means that balancing market design cannot be considered in isolation from overall electricity market design. Therefore, current structures may limit the design options for balancing markets and adaptation of the balancing market design may require adaptation of other aspects of electricity markets or power systems. Another implication is that possible balancing market designs must also be evaluated against higher-level electricity market objectives and performance criteria, such as the pursuit of renewable energy targets (ENTSO-E, 2011).

4.4. Design challenge and principles

In view of our analysis, we can mark the contours of the balancing market design challenge. First of all, the design framework presented in Section 3 shows that there are many design options, as well as many ways to assess performance, depending on the importance given to each of the criteria. Secondly, from Section 4.1 we take away that multiple trade-offs exist between performance criteria, which requires policy makers to prioritise criteria, but also to carefully evaluate the double-edged effects that design choices may have. Furthermore, the impact of many design choices is uncertain and depends on market participant responses in terms

of altered balance management practices, and because of the complex interactions among individual practices and system-level prices and costs, as illustrated in Section 4.2. This complexity is enlarged by the existing inter-linkages between the balancing market and the rest of the electricity market, as treated in 4.3. Power system and market conditions influence the effects of balancing market design choices. But, as such choices also affect overall electricity market performance, consideration of broader objectives may change the assessment of balancing market design options yet again.

In sum, the scope of the balancing market design task is vast and intricate. The design challenge for policy makers is to deal with the complexity and uncertainties in a practical way, without ignoring vital elements of balancing markets and their functions.

We suggest the following design principles to address this challenge:

- a. Reach agreement on key balancing market criteria and variables
- b. Start from power system and market conditions
- c. Consider future power system and market developments
- d. Strive for appropriate incentives to market participants
- e. Reduce uncertainties through in-depth analysis and monitoring of performance

Policy makers should start with creating a common understanding of the balancing market design problem, and narrow the scope of the design task through principle *a*. Principles *b* and *c* will further limit the scope by ruling out design options that are incompatible with current or future (desired) conditions, and identifying the options that provide appropriate incentives to BRPs and BSPs under these conditions (principle *d*). 'Appropriate incentives' are those that will trigger market behaviour that leads to efficient (low-cost) and effective (secure) balance management.¹⁷ To find out which designs provide such incentives, empirical analysis of current balancing markets and simulations are useful (principle *e*).

Our framework can support the balancing market design process by facilitating a systematic approach, in which all design options and performance criteria are consciously considered. Therefore, the framework may be most useful at the start of policy-making process, when prioritising the design variables and performance criteria. However, because all variables and criteria play a role in the balancing market, we recommend using the framework as a reference throughout the design process. Furthermore, the framework can help structure further research on balancing market design.

5. Conclusions

In the unbundled electricity markets in Europe, the balancing market is the institutional arrangement required to maintain the balance between electricity demand and supply. Several design variables and performance criteria play a role. The framework presented in Section 3 takes these into account to provide a systematic and structured approach to the design and analysis of balancing markets. In view of the wide variety of design options, the trade-offs among performance criteria, uncertainties about the effects of design options, and the inter-linkages between the balancing market and the overall electricity market, policy makers

¹⁷ We borrow this term from the EU electricity directive 2009/72/EC, which stipulates that 'appropriate incentives should be provided to balance the in-put and off-take of electricity and not to endanger the system' (European Commission, 2009).

face a substantial design challenge. This challenge can be met by addressing key criteria and variables, by considering system and market conditions and expected future developments, and by identifying the design options that provide appropriate incentives to market participants given all of these considerations.

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