Designing Multinational Electricity Balancing Markets

Designing Multinational Electricity Balancing Markets

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It is done, four and a half years work on a PhD research ('promotieonderzoek' in Dutch), with this dissertation ('proefschrift') as the final result. This may sound like a long period, but my experience is that time has flown by. Looking back, I see how much I have learnt in the process. In particular, I know now how to prevent blackouts.

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Reinier van der Veen

Delft, July 2012

1 Introduction

The main topic of this thesis is the possible internationalization of electricity balancing markets. To provide a proper introduction to this, the more general topics of balance management, the balancing market, balancing market design and balancing market integration will be outlined in section 1.1, within the larger picture of power system operation, the liberalized electricity market, electricity market design, and electricity market integration, respectively. After that, the research topic of balancing market internationalization is introduced in section 1.2, followed by the research scope in section 1.3 and the research question in section 1.4. Next, the relevance of the research is explained in section 1.5. In section 1.6, the applied research methods are given. Last, section 1.7 provides a short readers' guide.

1.1 Background

1.1.1 Power system operation and balance management

Electricity is a peculiar commodity: It must be 'consumed' as soon as it is produced, because it cannot be stored[1]. Due to this property, the provision of electricity requires balance management. Balance management is the power system operation service that involves the continuous balancing of power demand and supply in a power system, which is necessary to safeguard the security of electricity supply from producers to consumers through the electricity network. At each point in time the total production needs to be equal to the total consumption in order to keep the system frequency stable; 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 power system components, and ultimately, power blackouts.

The System Operator (SO) is responsible for power transmission and system operation within a power system, which includes balance management. Other system operation services are voltage control and black-start capability. System operation services can be distinguished from transmission services that deal with the physical transportation of

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[1] It can be stored in another energy form, but this brings about energy conversion losses, and is costly on a large scale.

electricity through the network. System operation services have public good characteristics, because they benefit all system users (producers and consumers), while system users cannot be denied the service (non-excludability), and the entry of a new system user does not reduce the benefits for other users (non-rivalry) (Laux-Meiselbach, 1988).

With regard to security of supply, one can distinguish between long-term security and short-term (operational) security. Balance management is first and foremost concerned with operational security of supply. After all, balancing power supply and demand is a real-time process. The subject of ensuring an adequate amount of generation capacity to meet demand at all times, generation adequacy, is a long-term security aspect that can be considered to be a precondition for balance management. The contracting of balancing resources in order to ensure sufficient real-time balancing capacity has a wider time span, but in view of the goal of such contracting, and considering that a contracting period is typically not longer than one year, we consider this aspect of balance management to concern the operational security of supply as well.

1.1.2 The liberalized electricity market and the balancing market

In the last decade of the 20th century and the first decade of the 21st, a lot of electricity systems moved from a public monopoly to a deregulated electricity market with private, competing energy companies. The liberalization of electricity markets, enforced by the Electricity Directive 96/92/EC in Europe, has introduced competition in generation, trade and retail. From the perspective of balance management, however, the most important development is the unbundling of generation and transmission, introducing competition between generators and making a separate System Operator responsible for power transmission and system operation[2]. Before this unbundling, the public network company had full control over generation planning and dispatch, which enabled an economically optimal balance planning and real-time system balancing. After the unbundling, private generation companies emerged, with freedom of connection, transaction, and dispatch. This has made balance management a much more complex task. Without the control over generation by the System Operator, the market participants need to be stimulated to supply balancing resources and to limit imbalances through rules and regulation. We define the balancing market as an institutional arrangement that establishes market-based balance management in a liberalized electricity market.

In a liberalized (unbundled) electricity market, a lot more institutional provisions are needed for the 'public good' of balance management. First, the size of system balances must be limited, and the SO must be able to anticipate on system imbalances. This requires a balancing market to have an administrative system of balance planning and settlement, where market parties submit energy schedules and are penalized for schedule deviations. Second, there must be enough balancing resources available to the SO to restore the system balance at all times. For this, it is possible that the SO owns balancing resources itself, but these would then either be left unused for electricity generation, which means inefficient resource utilization and expensive balance management, or the SO would act as a market player, which would create opportunities for favoring the own generation units. In a balancing market, the SO needs to procure balancing resources from the mar-

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[2] A Transmission System Operator (TSO) owns the transmission network, whereas an Independent System Operator (ISO) does not. This issue is not relevant here; hence the use of the general term 'System Operator'.

ket. Therefore, it operates a real-time market for balancing energy, and a tender for the contracting of reserve capacity in order to ensure a minimum availability of balancing resources. With such a balancing market, it is much more difficult to maintain the system balance in an economically efficient way without jeopardizing system security than before the unbundling. Both the effectiveness and efficiency of balance management have become dependent on the incentives that the market receives, and the degree to which it responds desirably to those incentives. The SO can merely propose the 'rules of the game' for balancing market parties that shape these incentives to policy makers. In short, liberalization has required more regulations and provisions for balance management, whereas the certainty about the performance of balance management has decreased.

1.1.3 Electricity market design and balancing market design

The balancing market is a part of the overall electricity market. The overall electricity market actually exists of a sequence of markets, including year-ahead, month-ahead, day-ahead and intra-day markets. See Figure 1.1. Furthermore, a distinction can be made between power exchanges and bilateral markets. The real-time balancing energy market, often called 'balancing mechanism', can be considered the last electricity market on which energy can be traded. Therefore, its function is very different: It serves to procure energy that corresponds directly to the real-time adjustment (regulation) of generation and consumption, in order to maintain the system balance. As a result, balancing energy can only be provided by generation and consumption resources that are technically capable of providing balancing energy. The real-time balancing energy market has two features that distinguish it from other electricity markets. First, it is a single-buyer market with the System Operator as the single buyer, instead of a two-sided auction. Second, the demand is determined by the system imbalance volume, which is small but highly volatile, and must be met.

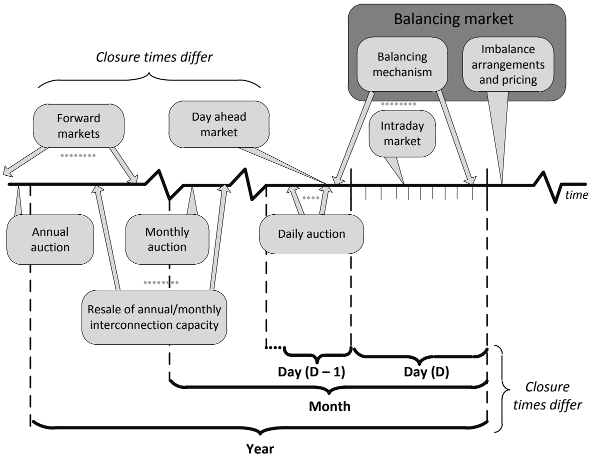

Figure 1.1 – Time sequence of electricity markets (ERGEG, 2009)

However, the balancing market is more than the real-time market. It also includes energy scheduling and imbalance settlement (called ‘imbalance arrangements and pricing’ in Figure 1.1). This part of the balancing market concerns the entire market, as all production and consumption should be scheduled and settled.

An important high-level power market design variable is the number and types of electricity markets (bilateral vs. exchange, long-term vs. short-term). Other important variables are the voluntariness of bidding, the frequency of bidding, the time unit for market clearing, gate opening and closure times, participation and bidding requirements, and pricing mechanisms for the different markets. Considering balancing market design variables, the equivalent high-level variable is the number and types of balancing service markets, where a distinction can be made between reserve capacity and balancing energy markets, upward and downward regulation markets, and market for different service classes (see chapter 3). The other power market design variables mentioned are also relevant to the design of the balancing service markets. On top of that, however, a lot of design variables exist related to balance planning and settlement.

Wrapping up, it can be said that the balancing market lies at the junction of financial transactions (the energy market) and physical exchanges (the power system). Balancing service market design appears to be similar to power market design, despite the fact that the System Operator is the single buyer in balancing service markets, but the inclusion of balance planning and settlement makes balancing market design a more complex topic. This complexity lies in the large number of design variables and in the different goals of (economically) efficient and (technically) effective balance management.

1.1.4 Electricity market integration and balancing market integration

The European Commission (EC) strives towards the creation of a single European electricity market, with the overall goals of increased transparency, equality between market players, and enhanced competition in mind. To this end, different Electricity Regional Initiatives (ERIs) have been set up, in which the integration of day-ahead and intra-day markets on a regional level has been started up. A recent development has been the coupling of the day-ahead markets of the Netherlands, Belgium, France, Luxembourg, Germany and the Nordic region at the end of 2010 and the start of 2011, which was an extension of the France-Belgium-Netherlands Trilateral Market Coupling project from 2006. Balancing market integration is seen as a logical follow-up step after day-ahead and intra-day market integration. The EC, regulators and SOs have recently began to think about this option, and it will be covered in the regional Balancing Network Code that ENTSO-E will develop after 2012 (ENTSO-E, 2011c).

Although the found literature did often not explicitly mention the goals pursued with balancing market integration (see chapter 2), it is generally expected to significantly improve competition in balancing service markets, which is equivalent to expectations about electricity market integration. However, balancing market integration is also expected to increase security of supply, due to a larger availability of balancing resources.

With regard to the integration content and required efforts, electricity market integration basically requires the coupling or merging of the power exchanges of different countries, including the algorithms used to optimally allocate the available interconnection capacity simultaneously with the matching of the supply and demand bids submitted to the power exchange(s) (implicit auctioning). Balancing market integration establishes the cross-border exchange of balancing services, which requires harmonization of balancing service market variables. This may also be necessary to couple power exchanges, but to a lower extent. Moreover, in order to safeguard security of supply, the balancing service exchange must be properly scheduled, operated and controlled in the framework of balance management. As argued by Frontier Economics and Consentec (2005) for intra-day and balancing markets, the facilitation of cross-border trade becomes 'more challenging, and the arrangements potentially more complex and costly than those required to integrate forward markets'.

A simpler feature of balancing market integration is that balancing service traders will not be required to purchase interconnection capacity; the SO will just check its availability. This is possible because the activation of balancing energy bids takes place in real-time, at which point the actual power flows and available transfer capacity are known. Furthermore, multiple degrees (designs) of balancing market integration are possible, whereas electricity market integration is more straightforward. This thesis will demonstrate that the choice of balancing market integration design has a large effect on balancing market performance.

As a final observation, the establishment of balancing market integration appears more similar to electricity market integration than power market design appears to balancing market design, because balance planning and settlement do not play a large role in balancing market integration. Still, balancing market integration is less straightforward than electricity market integration due to the technical implications for system balancing, the need for harmonization of market designs, and the larger number of integration options.

1.2 Research topic: Balancing market internationalization

Next to electricity market integration, which is generally aimed at to improve economic efficiency, electricity market harmonization is a second international development that receives attention in Europe, with the aim of increasing transparent and non-discriminatory markets. This distinction can also be made for balancing markets, and that is why the overall research topic of this thesis is balancing market internationalization. Balancing market internationalization is the (possible) development from national to multinational balancing markets, which may involve either harmonization or integration, or both.

Balancing market harmonization is the streamlining of national balancing market designs, i.e. setting the balancing market design variables to equal values, with transparency and non-discrimination as primary goals. It will not create interaction between different national balancing markets, but it will reduce the barriers for participation in foreign electricity markets, and for balancing market integration as well.

Balancing market integration is the introduction of market arrangements for the exchange of balancing services between national balancing markets, with economic efficiency as the primary goal and security of supply as a secondary goal. Therefore, this introduction will create interaction between balancing markets.

An important difference between harmonization and integration is that a minimum degree of harmonization appears a requirement for integration, whereas full harmonization could be realized without any integration. This also implies that the realization of integration is constrained by existent designs, which calls for a step-wise integration. With harmonization, on the other hand, few limitations appear to exist. The most advanced form of balancing market internationalization (excluding the merging of control areas) would include both full integration of balancing service markets and the harmonization of overall balancing market designs, which would create a complete level-playing field for market parties across country borders.

The above shows that the distinction between balancing market harmonization and balancing market integration is a relevant one; it enables the consideration of two different internationalization trends that contribute to different primary goals, but are still intertwined developments. Furthermore, harmonization can be linked to the national design perspective (even though the scope is international), because it involves the equalization of design variable values in different countries. Similarly, integration can be linked to the multinational design perspective, because it revolves around new, regional (multinational) design variables. We make use of these links in the structuring of the thesis by the combined consideration of the subjects of national balancing market design and balancing market harmonization, and of multinational balancing market design and balancing market integration (see section 1.7).

1.3 Research scope

The scope of the research is **design and decision making for balancing market internationalization**. Thus, we look at balancing market internationalization from a design perspective and from a decision-making perspective. This implies that the policy makers on balancing market design are the ‘problem owner(s)’. These are the national governments, regulators, and System Operators. Furthermore, the focus on the balancing market implies that the day-ahead and intra-day market are not included in the research scope. Therefore, the interrelations between short-term markets and balancing markets are not considered, and thus the effects of balancing market internationalization on short-term markets are not either. Finally, the focus on balance management implies that congestion management is also outside the research scope.

The general focus will be on **Europe**. This is due to the aim of the European Commission to create a single European electricity market, which puts forward the relevance of the research topic for Europe. Furthermore, Europe consists of a lot of countries with each their own balancing market design, which complicates the realization of internationalization, and makes its impact on the performance of the different balancing markets much more uncertain. Balancing market integration in Europe has only been realized in the Nordic region, and in Germany for the four large control areas. The focus on Europe implies that the context of the research on balancing market design in this thesis is formed by electricity markets consisting of voluntary power exchanges and bilateral markets, rather than one centralized power pool (cf. Stoft (2002)).

Furthermore, the analysis of impact of internationalization will for an important part be carried out for the **case study of Northern Europe**, i.e. the Netherlands, Germany and the Nordic region (Norway, Sweden, Finland, and Denmark). There are multiple reasons for this. First of all, a case study will enable a detailed impact assessment of balancing market internationalization, taking into account the specific situation (systems, designs, and performance) in the involved countries. Second, it may serve as a reference case for estimating the impact of other balancing market internationalization cases. Third, the case study will illustrate the execution of the design and analysis processes that are part of the overall decision-making process, which contributes to the formulation of design recommendations on internationalization. Finally, the case study of Northern Europe will provide an answer to a fundamental question from the research project 'Balance Management in Multinational Power Markets' of which this research has been a part, i.e. what is the value of balancing market integration for Northern Europe.

The main perspective used throughout the research is the **system perspective**. This fits with the role of the government, regulator, and/or the System Operator as the 'problem owner(s)'. These actors also strive for effective and efficient balance management, because it is in their interest that the electricity system and the balancing market as a whole perform well[3]. Also, we take a national perspective rather than a regional (multinational) perspective, because balancing market internationalization will not change the fact that each nation has its own power system and control area(s), and thereby separate regulations and provisions for balance management. Moreover, the main decision makers will defend the interest of national electricity markets, as a result of which successful decision making depends on the impact on the national markets, rather than on the region as a whole.

Last of all, the research presented in this thesis focuses on **the role of the Balance Responsible Party (BRP)**. This is motivated by the division of subjects between researchers within the research project 'Balance Management in Multinational Power Markets', but also by the larger obscurity of the role of the Balance Responsible Party, compared to that of the Balancing Service Provider. Besides, as the BRPs basically determine the demand for balancing services as a result of their balance planning activities, this role is a very important one.

1.4 Research question

The main research question is:

> *To what extent can the design and decision making on multinational balancing markets in Europe improve balancing market efficiency without endangering security of supply?*

Three sub-questions are:

- What are the main design options and performance criteria for national and multinational balancing markets?
- What is the impact of harmonization and integration on the performance of national balancing markets in Europe?

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[3] In view of the role of the SO, its main interest will be security of supply.

- How should decision making on balancing market internationalization in Europe be approached to successfully design and realize multinational balancing markets?

High balancing market efficiency and operational security of supply are the two fundamental requirements for balancing markets. A multinational balancing market is defined as the whole of the institutional arrangements on balance management present for a group of countries having implemented some form of balancing market internationalization. Remember, however, that a national perspective is adopted, which means that the effects on efficiency and security of supply of the involved national balancing markets are studied[4].

The decision-making process consists of the design, analysis and final decision-making processes on balancing market internationalization. The design process is crucial, because the formulation and selection of alternative designs determines whether all important and promising internationalization options are considered for implementation. The analysis approach and the content of the analysis process directly affect the main input for the final decision making.

1.5 Relevance

In general, balance management is necessary to ensure operational security of supply, and a balancing market is necessary to secure effective and efficient balance management in a liberalized electricity market, which makes balancing market design a relevant power market design topic. In addition, a lot more design options arise from the need for planning, real-time balancing, and settlement, which have as of yet been left relatively unexplored. This mismatch between relevance and attention may be caused by the newness of the topic, and by the satisfactory initial balancing market designs that have been installed. In view of the large number of design options, the uncertainty of effects and the uncertainty of what defines a well-performing balancing market in the first place, a systematic evaluation of main multinational balancing market design options is an extensive and complicated task. It is the aim of this research to provide such a systematic evaluation.

The practical relevance of the research is represented by the formulation of a decision-making process design that can be used by decision makers regarding balancing market harmonization and integration. This possible development has in Europe only been realized by the Nordic region and by Germany for its different control areas, but in the light of the creation of a single European electricity market further integration is studied and planned by the European Commission, regulators and TSOs (see chapter 2). Generally, integration is considered to reduce balancing costs and increase security of supply. In the thesis, recommendations on the design of multinational balancing markets will be given for the case study of Northern Europe, and for European balancing markets in general.

The scientific relevance consists of the definition of the concepts of the national and multinational balancing markets and of standard terminology, the formulation of the important design variables and performance criteria for the design and analysis of balancing markets, the creation of insights into the functioning of balancing markets, insights into

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[4] As the boundaries of the national balancing market correspond with the control area boundaries, and as these boundaries are often retained after balancing market internationalization, the 'multinational balancing market' will still consist of national balancing markets (see section 3.1).

the impact of individual design variables on performance, insights into the impact of alternative options for balancing market harmonization and integration, and findings on the dependency of this impact on external power system and market conditions.

1.6 Methodology

The research takes a design approach, which materializes into the formulation of design variables and performance criteria for national and multinational balancing markets. Next, the effects of design variables on the performance criteria are assessed, thereby analysing the impact of balancing market harmonization and integration. Due to the large number of variables and the high-level and varying nature of the performance criteria (technical, economic, institutional), the overall impact assessment of design variables will take the form of a qualitative multi-criteria analysis. This analysis enables the consideration of all variables and criteria, allowing for a comprehensive evaluation of the impact of balancing market design and internationalization. As an input for the multi-criteria analysis, a system analysis of the balancing market is carried out, exploring the interactions between design variables, system factors, and performance criteria. In addition, some important design variables are studied by means of Agent-Based Modelling (ABM), enabled by the more quantitative nature of those variables. ABM is a suitable modelling paradigm for the analysis of balancing markets, because it can take into account the interaction between individual behaviour and system-level performance that is core to the functioning of balancing markets (see subsection 4.4.3 for more information about the use of ABM). Finally, the case study of Northern Europe within the overall impact assessment supports the drawing of conclusions on the potential impact of balancing market internationalization.

1.7 Readers' guide

Chapter 2 - Literature study In Chapter 2, first the balancing market rules and regulation in Northern Europe are described, based on national documents about the specific balancing market designs, which supports the case study analysis of Northern Europe. Also, designs in other countries are briefly explored. Next, a literature study on national and multinational balancing market design is presented, from which the most important balancing market design variables are identified. This study covers the scientific literature on balancing market design options and the literature on the balancing market integration possibilities in Europe, which forms an important input for the design framework in the next chapter.

Chapter 3 - Balancing market design framework The balancing market design framework consists of three main parts: a reference model, an evaluation set and a design space, applying to national and multinational balancing markets. The reference model introduces the concept and elements of the national and multinational balancing market, and introduces standard terminology on balancing market design in a multinational context. The evaluation set consists of high-level performance criteria that can be used to assess the impact of balancing market design changes, including balancing market internationalization. The design space includes the most important design variables for national and multinational balancing markets. Herewith, the design framework provides highly useful tools for the balancing market design process.

Chapter 4 - Analysis of national balancing market design and harmonization In this chapter, a system analysis of balancing markets is carried out first, followed by an indication of the importance of the different balancing market design variables and performance criteria defined in the last chapter. Then, the variable of the imbalance pricing mechanism is analysed by means of Agent-Based Modelling. Furthermore, a qualitative multi-criteria analysis of the impact of individual national design variables is performed, considering the influence of contextual factors. Then, the impact of harmonization is assessed for the case study of Northern Europe. Finally, conclusions are drawn on the general impact of balancing market harmonization.

Chapter 5 - Analysis of multinational balancing market design and integration In this chapter, the impact of individual multinational design variables is estimated in a qualitative multi-criteria analysis. After that, the impact of the main cross-border balancing arrangements is estimated by using the same analysis tool. Next, the impact of the arrangements is analysed for the case study of Northern Europe applying Agent-Based Modelling. All this finally leads to a general conclusion on the impact of balancing market integration.

Chapter 6 - Synthesis This chapter synthesizes and interprets the results of the last two chapters. First, drivers and barriers to balancing market harmonization and integration are described. Then, the generated insights on balancing market design and on balancing market internationalization are given. Last, design recommendations are specified for internationalization in general and for Northern Europe in specific.

Chapter 7 - Decision-making process of internationalization A decision-making process design for balancing market internationalization is presented in this chapter, offering a structured approach to System Operators, national regulatory authorities and legislators to go through the design, analysis and final decision phases of the decision-making process. The balancing market design framework, applied analysis approaches and obtained design recommendations resulting from this research form useful inputs in this process design.

Chapter 8 - Conclusions and recommendations The main conclusions and recommendations arising from the research are listed in this chapter. Separately presented are conclusions and recommendations on balancing market design, balancing market harmonization, balancing market integration, balancing market internationalization, and balancing market internationalization in Northern Europe. After that, the research question is answered, a reflection on the research is presented, and suggestions for further research are provided.

Appendices The appendices include the following: a list of acronyms (appendix A), a list of definitions of important balancing market terms (appendix B), an overview of current balancing market design and performance in Northern Europe (appendix C), an overview of the balancing market performance criteria and design variables (appendix D), a description of the expert validation of the performance criteria (appendix E), further descriptions of the agent-based modelling studies on the imbalance pricing mechanism (appendix F) and the cross-border balancing arrangements (appendix G), and the detailed qualitative effect estimations of national variables (appendix H), multinational variables (appendix I), and cross-border balancing arrangements (appendix J).

2 Literature study

The literature study consists of three main parts. First, in section 2.1, balancing market regulations found in sector-specific documents are described in detail for Northern Europe. This provides information for the case study of Northern Europe. In addition, balancing service market design differences in and outside Europe are shortly discussed. Second, in section 2.2, literature on balancing market design is described. Third, section 2.3 includes a study of the literature on balancing market integration. These three parts all form an important input for the formulation of the balancing market design framework presented in chapter 3. The first two sections contribute to the formulation of national balancing market design variables, and the third section to the formulation of multinational variables. Most of the found literature is dedicated to Europe, which fits the research scope of this thesis.

The presentation of the literature study requires the use of some key balancing market terms that are explained and defined in the design framework in chapter 3. These terms are written in italic.

2.1 Literature on national balancing market rules

Rules and regulations of the balancing markets in Northern Europe are described in subsection 2.1.1, based on a literature study of mostly operational documents from the electricity sector. The Nordic region, Germany and the Netherlands are treated separately. In subsection 2.1.2, literature on balancing market regimes in other countries is treated.

2.1.1 Regulations in Northern Europe

The studying of North-European balancing regimes is not only useful for the case study, but also as an input for the balancing market design framework. An overview of the North-European balancing market regulations described below can be found in Table C.1.

The Nordic region The Nordic region consists of Norway, Sweden, Finland and Denmark[1]. Interestingly, Norway, Sweden, Finland and Eastern Denmark form a synchronous zone (the former Nordel zone) that is separate from the former UCTE zone of

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[1] Iceland is not connected to the Nordic synchronous zone.

continental Europe, to which Western Denmark belongs[2]. Since 2002, a common regulating power market exists in the Nordic balancing region (Nordel, 2002). The regulating power reserves are manually activated *balancing services*; the TSOs do not make use (yet) of Load-Frequency Control (see below). Also, the system frequency is the only control criterion for real-time balancing. Each hour the cheapest regulating bids in the regional bid ladder are activated to balance demand and supply in the entire region. The bid price of the last activated bid in price order becomes the *regulation price* with which all selected bids are settled; this is called 'marginal pricing'. In case no congestions arise between different pre-defined zones, one regional regulation price is determined. However, if congestion occurs, the Nordic region is divided into different price zones, with different regulation prices. In principle, the *imbalance prices* are directly based on the regulation prices, which means that imbalance prices will differ similarly in settlement periods with congestion between subsystems.

Nordel distinguishes between Frequency Controlled Normal Operation Reserves (FCNOR), Frequency Controlled Disturbance Reserves (FCDR), and Fast Active Disturbance Reserves (FADR). The first two can be classified as primary control services, the last one as a (fast) tertiary control service, because it is manually activated, or as secondary control service, due to its function (see below). The FADR is the reserve that is offered in the regulating power market; energy delivered by the other two types of reserves is not rewarded, and thus there is no market for these. According to the Nordic System Operation Agreement, there should be at least 600 MW FCNOR (that should be completely activated for a frequency deviation of 0.1 Hertz), there should be FCDR 'of such magnitude and composition that dimensioning faults will not entail a frequency of less than 49.5 Hz', and FADR 'shall exist in order to restore the FDNOR and the FCDR ... and in order to restore transmissions within applicable limits following disturbances'. Also, a secured reserve volume of FADR of over 5000 MW is mentioned (Nordel, 2006a). According to Grande et al. (2011), the Nordic system has a total FCDR of 1160 MW and a FADR of 4680 MW.

With regard to reserve capacity procurement methods, the Norwegian TSO applies a weekly national reserve capacity market, which is used mostly in the winter months. Since 2009, there is also a seasonal product, for the length of the period in which the weekly market is expected to be active. For the winter period of 2010-2011, 500 MW was contracted in the seasonal market, whereas usually 1000 to 1500 MW was contracted on a weekly basis (Statnett, 2011). Next to that, there are also bilateral agreements between TSOs and reserve providers in the Nordic region.

Detailed rules and regulations on balancing service provision differ from country to country, but in 2009 some of these rules were harmonized. These include a maximum activation time of 15 minutes for regulating power bids, a lower bid price limit equal to the day-ahead spot price, a higher bid price limit of ± 5000 €/MWh, a minimum bid size of 10 MW, and the application of pay-as-bid pricing to bids used for congestion management (Nordel, 2008b). An example of a remaining country-specific rule is the maximum bid size of 50 MW which is still applied in Denmark, whereas the other countries do not have such a restriction. Two more relevant regional-wide provisions are that bids must be available during the entire operating hour, and that the final gate closure time for submission of

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[2] On July 1st 2009, UCTE and Nordel were incorporated in ENTSO-E, the European Network of Transmission System Operators for Electricity. This did not change the division of synchronous zones.

regulating energy bids is 45 minutes before delivery (the same as the final gate closure time for energy schedules).

Before 2009, each Nordic country had its own national rules with regard to balance planning and settlement. However, Nordel proposed some harmonization steps in 2007, which became effective on January 1st 2009. These include a final gate closure time of 45 minutes before the hour of delivery, a production balance to which two-price settlement is applied, and a consumption balance (including trade) to which one-price settlement is applied (Nordel, 2007). Two-price settlement implies that *Balance Responsible Parties* do not receive a profit from having an imbalance in the direction opposed to the system imbalance, whereas they would under one-price settlement. The Nordic arrangement implies that producers are more severely penalized for imbalances than consumers. In principle, the imbalance prices for positive and negative BRP imbalances are both equal to the regulation price in the main regulation direction[3], but for production imbalances the imbalance price for the direction opposite to the system imbalance is the day-ahead spot price instead (Grande et al., 2008). Sweden and Finland apply alternative imbalance pricing rules in shortage situations, i.e. in settlement periods in which power shortages occurred and/or last-resort reserves were activated or load-shedding occurred (NordREG, 2006). Furthermore, area imbalances between the subsystems (countries) are settled with the common regulation price, or with the average regulation price of both subsystems in case of congestion (Nordel, 2002).

The used settlement period in the Nordic region is one hour, which means that for each separate hour the planned production and consumption must be indicated. Initial *energy schedules* are submitted on the day before delivery, but the exact submission time differs per country; it is 7:00 p.m. for production schedules in Norway, 4:00 p.m. in Sweden, 4:30 p.m. in Finland, and 3:00 p.m. in Denmark. Furthermore the frequency of settlement of the imbalance costs differs: This is weekly for Norway, bi-monthly for Sweden, and monthly for Finland and Denmark (NordREG, 2006).

Germany In the UCTE Operation Handbook, a basic distinction is made between *primary control*, *secondary control* and *tertiary control* services. Primary control is activated within seconds by means of a local control signal in order to 'contain' the frequency deviation. Secondary control is typically activated within minutes by means of a control signal from the *Transmission System Operator (TSO)* in order to restore the system balance. Tertiary control is usually manually activated in minutes to hours by the TSO in order to restore the balance after large disturbances (UCTE, 2004, 2009a). In continental Europe, secondary control is activated by means of *Load-Frequency Control (LFC)*, an automatic control system used by TSOs. Within 15 minutes, the *Area Control Error (ACE)* of a *control area*, i.e. the deviation from the planned energy interchange with adjacent control areas, should be removed. For this purpose, the TSO of a control area uses the LFC system to automatically activate secondary control services, but manual tertiary control services can also be used for this purpose (UCTE, 2009a).

Load-Frequency Control is also used in Germany. Germany consists of four large German control areas, each managed by a TSO, but due to the full integration of the ba-

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[3] If there is a negative system imbalance direction (system shortage) in a certain settlement period, the main regulation direction is positive, and vice versa.

lancing service markets in 2009 the system balance of Germany as a whole is maintained, instead of four separate control area balances (see subsection 2.3.3).

Germany distinguishes between primary control reserves, secondary control reserves, and tertiary control reserves (minute reserves). Reserve capacity for primary control is tendered monthly, and only a capacity payment is made. *Reserve capacity* and *balancing energy* for secondary control are procured in a single tender, which is also held on a monthly basis[4]. Bids are selected based on the capacity price, but real-time activation is based on the energy price. The selected bids form the energy bid ladder, which is fixed for the entire month. No new bids may enter once the tender is finished. In the tender, a distinction is made between a peak and an off-peak period; off-peak being Monday to Friday from 8:00 p.m. to 8:00 a.m., the weekend, and public holidays. There are also separate tenders for the offering of *upward and downward regulation*, which means that there are actually four secondary control reserve markets. A similar single tender exists for tertiary control reserves, but this takes place on a daily basis. Furthermore, separate tenders are run for up- and down-regulation services, and for the six four-hour time blocks that exist in a day. In all tenders, pay-as-bid pricing is applied, which means that *Balancing Service Providers* receive the energy price they stated in their own bid. The average monthly demanded secondary control capacity in 2010 was 2200 MW upward and 2400 MW downward, and the average daily demanded tertiary control capacity was above 2000 MW. The monthly demanded primary control capacity in 2010 was 623 MW (Amprion et al., 2011), which follows from an ENTSO-E agreement regarding the distribution of the primary control reserves among control areas in ENTSO-E Region Continental Europe (UCTE, 2009a). The German TSOs use a common probabilistic method to dimension the secondary and tertiary control reserves (Consentec and University of Stuttgart, 2010). TSOs are responsible for the deployment of reserves only within the first four quarterly hours after the occurrence of a power imbalance (Bundesnetzagentur, 2006; Grande et al., 2008).

The used settlement period in Germany is 15 minutes, which is thus equal to the time unit used for ACE control. There are no separate balances for production and consumption. Instead, a total (net) balance is applied, which means a Balance Responsible Party (BRP) can net production and consumption imbalances. Furthermore, the TSOs have the balance responsibility for wind power and solar power, following the Renewable Energy Law, which comes down to a socialization of the imbalance costs from renewable electricity production (Bundesregierung Deutschland, 2005; Bundesministerium der Justiz, 2008). The gate closure time for the submission of the initial energy schedule is 2:30 p.m. on the day before delivery. Furthermore, BRPs can transfer the responsibility for imbalance settlement to another BRP (Bundesnetzagentur, 2006). The final gate closure time is 45 minutes before the settlement period of delivery, but if an energy schedule merely contains intra-area exchanges it can be adapted up to 4:00 p.m. on the day after delivery (Bundesnetzagentur, 2006). This enables ex-post trading, i.e. the trading of imbalances between BRPs after real-time in order to reduce their imbalance volumes (and thereby imbalance costs). Energy schedules in Germany are also used for the determination of the Day Ahead Congestion Forecast (DACF), which is used for grid security calculations (Technical University of Dortmund and E-Bridge, 2009).

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[4] Since 27 June 2011 the tender has been taking place weekly (Amprion et al., 2011).

The integration of the secondary and tertiary control tenders of the four German control areas has led to reserve capacity exchange, but still there are specific reserve requirements for the control areas in order to ensure the availability of reserves in case of congestions, as required by §6 of the Electricity Grid Access Regulation ('StromNZV') (Bundesregierung Deutschland, 2005; Amprion et al., 2011). The integration has not changed regulation pricing; pay-as-bid pricing is still used. However, imbalance pricing has become regional, meaning that imbalance prices are determined on the country level, and thus apply to BRPs in all control areas. Single imbalance pricing is applied, i.e. the imbalance prices for BRP surpluses and shortages are identical. The imbalance price for a settlement period is calculated by dividing the net costs of activation of secondary and tertiary control energy by the net activated regulation volume (50Hertz, 2009). Finally, according to Bundesnetzagentur (2006) the TSO may penalize BRPs for 'the violation of several imbalance settlement criteria', by not giving any compensation for positive imbalances and charging twice the power exchange price for negative imbalances. The frequency of settlement is monthly.

With regard to the publishing of tendering information, Germany has made major steps towards more transparency. All (anonymous) bids offered within a tender can be accessed, including the indication which of those were selected by the TSO (Amprion et al., 2011). Regarding real-time activation, only activated up-and down volumes and imbalance prices can be found. No real-time information is provided to the Balance Responsible Parties.

The Netherlands Like Germany, the power system of the Netherlands belongs to the synchronous zone of continental Europe, but it only consists of one control area. The Netherlands also makes use of a settlement period of 15 minutes, and one net balance for Balance Responsible Parties that may include both production and consumption. The gate closure time for the submission of the initial energy schedule is 2:00 p.m. on the day before delivery, and the gate closure time for the final energy schedule is one hour before the period of delivery (Energiekamer, 2010). Energy schedules do not provide the TSO with information on transmission flows; this is indicated by means of so-called transport prognoses.

Primary control capacity is not remunerated, but the introduction of this is investigated. In 2011, 116 MW of primary control reserves were needed in the Netherlands, based on the agreement within the ENTSO-E Region Continental Europe. The TSO yearly contracts 300 MW regulating power (automatic secondary control), and 300 MW emergency power (interruptible load, only upward). The amount of 300 MW regulating power is based on a square-root formula given by the UCTE Operation Handbook, which returns a recommended minimal amount of secondary reserves given a maximum system load[5] (UCTE, 2009a). The main balancing energy market, which operates on a 15-minute basis, may both include regulating power bids and reserve power bids, the last of which are activated manually. A distinction is made between reserve power bids that can be activated within 15 minutes (for ACE control), and reserve power bids with a larger activation

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[5] The formula is just one of several methodologies indicated in the Handbook, which have an advisory nature. National governments and TSOs are free to determine the amounts of secondary and tertiary reserves for their own control areas.

time. Bids are activated in price order to restore the system balance, and the price of the last activated bid becomes the regulation price (marginal pricing).

According to the Grid Code, all connected parties with more than 60 MW generation capacity are obliged to offer all available up- and down-regulation capacity to the TSO in the form of bids for the market for regulating and reserve power (TenneT, 2010b; Energiekamer, 2011). On the day before delivery, the bids must be submitted before 2:45 p.m.. Afterwards, bids can be adapted up to one hour before the period of delivery. Automatic regulating power bids should have a regulating speed of at least 7%/minute. The bid volume should be between 4 and 100 MW, and the bid price should be between -100,000 and 100,000 euro/MWh. On the TSO website, the bid prices at certain spots in the bid ladder (± 100 MW, ± 300 MW, ± 600 MW) are indicated already for bid ladders applicable to the next day. Activated balancing energy is automatically rewarded by the SO, and the energy schedules of the relevant Balance Responsible Parties are adapted accordingly (TenneT, 2010b).

The imbalance pricing mechanism in the Netherlands is quite complicated. In principle, single imbalance pricing is applied (see above), but depending on the 'regulation state', dual pricing may be applied. Dual pricing means that the upward regulation price is applied to negative BRP imbalances and the downward regulation price to positive BRP imbalances. There are four different regulation states that may be attributed to a settlement period. The regulation state depends on the pattern of requested balancing energy during the settlement period. Dual pricing applies when both upward and downward regulation have been activated in an erratic fashion (Energiekamer, 2010; TenneT, 2010a). Finally, a so-called incentive component is added to the imbalance price for negative imbalances and subtracted from the imbalance price for positive imbalances if two conditions with regard to the number and size of *involuntary exchanges* are met. This component is determined weekly, does not change by more than ± 2 euro/MWh, and cannot be lower than zero (Energiekamer, 2010; TenneT, 2010a,b). In practice, this component has been equal to zero most of the time. An interesting recent addition to the published information on the TSO website is the real-time, minute-to-minute indication of the bid price of the last activated bid, next to the minute-to-minute dispatched balancing energy volume (TenneT, 2011). This allows Balance Responsible Parties to better predict the imbalance prices and risks, and attune their real-time strategies to this.

Findings The above description of the North-European balancing market design has led to the identification of the same balancing market design variables that have also been found in literature on balancing market design (see section 2.2). This forms a verification of the obtained list of variables. Also, detailed design variables and possible values have been identified above, which have been incorporated in the balancing market design framework. With regard to the possible internationalization of balancing markets in Northern Europe, the descriptions have made clear that there are a lot of potential institutional barriers to integration, because of the national design differences. This makes the consideration of balancing market harmonization quite important for this region. The identified balancing market designs will be used to assess the impact of balancing market internationalization for the case study of Northern Europe in section 4.7 and section 5.4.

2.1.2 Regulations elsewhere

The studying of balancing regimes in other countries is useful as an input for the balancing market design framework, and in order to find out to what extent balancing market designs are different in and outside Europe.

Comparison by Rebours, Kirschen, Trotignon and Rossignol (2007a,b) In Rebours, Kirschen, Trotignon and Rossignol (2007a), a comparison is made of the technical features of frequency control services in Australia, New Zealand, California, PJM, Belgium, France, Germany, Great Britain, the Netherlands, Spain, and Sweden. It can be observed that each area has its own classification of services, and uses its own definitions. As the same term is sometimes used to indicate totally different services in different countries, this may create a lot of confusion. According to Rebours, Kirschen, Trotignon and Rossignol (2007a), some differences may be explained by e.g. the different size of power systems, the relative amount of interconnection capacity, or the size and technical features of the present generation capacity. The technical parameters for frequency control services are also compared. Important parameters are the deployment time, deployment start, the time to full availability, deployment end, and accuracy of the measurement. For primary control, the parameters are largely the same among European countries, as they are part of the same synchronous zone. Interestingly, the North American Electric Reliability Council (NERC), unlike the UCTE, generally gives no recommendations regarding primary and secondary control parameters. It is concluded by Rebours, Kirschen, Trotignon and Rossignol (2007a) that primary control is a very differentiated product because of its multiple parameters and decentralized nature. On the other hand, secondary control is managed centrally by the TSO, which makes this a less differentiated product.

In Rebours, Kirschen, Trotignon and Rossignol (2007b), the economic features of frequency control services are compared for Australia, New Zealand, PJM, France, Germany, Great Britain, Spain, and Sweden. Regarding the procurement methods used for primary control, Spain and PJM apply compulsory provision, France applies bilateral contracts, Germany, Great Britain and Sweden apply a tendering process, and New Zealand and Australia apply bilateral contracts, a tendering process, and a spot market. For secondary control, France applies bilateral contracts, Germany and New Zealand apply a tendering process, and Australia, Spain and PJM apply a spot market. Sweden and Great Britain do not use secondary control, as Sweden can rely on a lot of fast manual hydropower resources, while Great Britain is a single synchronous zone and control area that thus does not need ACE control (Rebours, Kirschen, Trotignon and Rossignol, 2007a). It is noted, however, that the difference between tendering and a spot market is not always that clear. In Rebours, Kirschen, Trotignon and Rossignol (2007b), a spot market is defined as a market with standardized products and a short duration (a week or less). Regarding the remuneration method, primary control is not remunerated in PJM and Spain, a regulated price is used in New Zealand, a common clearing price in Australia, and a pay-as-bid system is applied in all areas except PJM and Spain. For secondary control, a common clearing price is used in Australia, Spain and PJM, and a pay-as-bid system in all eight areas. The same variation in design variable values among areas can be observed for other market characteristics of primary, secondary and tertiary control.

Comparison by ENTSO-E (2011a) ENTSO-E has collected information on balancing service markets designs throughout Europe, creating an overview of the current balancing market design differences between ENTSO-E member countries (ENTSO-E, 2011a). Included in the overview are twenty-six European countries. The design variables are listed separately for primary control, secondary control and for tertiary control, and also separately for *reserve capacity* and *balancing energy*. Regarding the procurement scheme for reserve capacity, a voluntary market is applied a lot, showing that market-based balancing service provision has been initiated in most European countries. In case of primary control, mandatory provision is also applied in many countries. For balancing energy, a market arrangement is used in more countries than mandatory offering, but for many countries procurement of balancing energy is listed as 'not applicable'. In case of secondary and tertiary control, this may be caused by an arrangement similar to the one applied in Germany, in which only the contracted bids are used in real-time. The pricing mechanism varies a lot between countries. For all types and classes of balancing services, pay-as-bid pricing is used in more countries than marginal pricing, except for primary control energy. Regulated pricing is applied in quite a few countries as well. Two widely applied product resolution values for reserve capacity are a 'year or more' and 'hours(s)', while frequently applied procurement cycle values are 'year or more' and 'day(s)'. For balancing energy, 'hour (or blocks)' is applied a lot, in case of secondary and tertiary control. The gate closure for balancing energy bid submission is often 'day-ahead' in case of secondary control, and varies from 'day-ahead' to 'less than one hour ahead' for tertiary control. In summary, the overview by ENTSO-E (2011a) shows a large variety of adopted design variable values and of overall balancing service market designs, but at the same time some values are applied much more than others.

Implication Viewing the variety in balancing market designs in different European countries, it becomes clear that there are a lot of viable design options, which increases the vastness and complexity of the research. Apparently, there is no clear 'best design' that performs well in all power markets, which suggests that balancing market performance is context dependent. As a consequence, the realization of balancing market internationalization will be challenging, and harmonization of national balancing market designs will constitute an important part of the internationalization process. Moreover, it will be hard to assess the impact of balancing market internationalization on balancing market performance in general, because this impact is likely to depend on the exact balancing market designs and power markets of the considered countries.

The found national balancing market design descriptions are in line with the literature on balancing market design. See the next section.

2.2 Literature on balancing market design

In subsection 2.2.1, balancing market design variables found in literature are presented. The resulting overview of design variables is given in subsection 2.2.2.

As already mentioned in chapter 1, the balancing market includes both the provision of *balancing services*, i.e. ancillary services for frequency regulation, and the planning of production and consumption and settlement of schedule deviations. The *System Operator* is the final responsible party for balancing the system, and for that purpose procures balancing services. A distinction can be made between *balancing energy*, i.e. the real-time energy dispatched to maintain the power balance, and *reserve capacity*, i.e. the option to activate balancing energy. *Balancing Service Providers (BSPs)* are market parties that offer balancing services to the System Operator. Finally, *Balance Responsible Parties (BRPs)* are market parties that are responsible for scheduling energy production and consumption, and are financially accountable for schedule deviations. More information can be found in the design framework in chapter 3.

2.2.1 Design variables in literature

The literature on balancing market design is split into three paragraphs. First, the balancing market design options listed by Vandezande et al. (2008) are discussed. Second, ancillary service market design issues from Rebours, Kirschen and Trotignon (2007) and Rebours (2008) are considered. Third, some European TSO documents on balancing market design and integration are compared with the design options of Vandezande et al. (2008).

Design options by Vandezande et al. (2008) A convenient arrangement of important balancing market design aspects is provided by Vandezande et al. (2008). The author makes a high-level distinction between design aspects related to procurement of balancing services and design aspects related to delivery and settlement. Under the first group fall three categories of design options: balancing service definitions, times and methods of procurement, and methods for remuneration. These options apply to the Balancing Service Providers. The second group consists of four design options: gate closure times, settlement periods, methods of imbalance volume calculation, and methods of imbalance pricing. These options apply to the Balance Responsible Parties. This is orderly presented in Table 2.1. Further descriptions of the seven design options follow below.

First of all, one can distinguish between different balancing service definitions. Such a distinction is often based on possible different functions or technical characteristics of services. Due to the independent development of power systems and balancing markets in different countries, different balancing service classes and definitions have emerged (ETSO, 2003; Rebours, Kirschen, Trotignon and Rossignol, 2007a). Based on function, the former Union for the Coordination of Transmission of Electricity (UCTE), the organization of Transmission System Operators of the synchronous zone of continental Europe, has made a general distinction between primary, secondary and tertiary control (see section 2.1). Regarding technical characteristics, important distinctive criteria are the response speed and the method of activation.

Secondly, two important methods of procurement exist: bilateral contracts and auctions (Vandezande et al., 2008). Balancing services can be contracted bilaterally between the System Operator and Balancing Service Providers, or procured in a one-sided auction, in which BSPs are directly competing against each other, and in which the System Operator is the single buyer. Different methods of procurement may be applied to different balancing service classes (primary/secondary/tertiary control), or to reserve capacity vis-à-vis balancing energy. It is also possible that the provision of balancing services is mandatory. Finally, there may be no procurement at all, if a service is not required. The latter may apply if reserve capacity procurement is not needed to ensure the availability of a certain balancing service class. In case of primary control energy, it is not possible to procure the service, because this service is automatically delivered within seconds after a frequency disturbance based on the system frequency deviation (UCTE, 2009a). Bilateral contracting and auctions may have different time frames with regard to the time of procurement and the procurement period itself. Of course, these time frames can also differ between balancing services.

Thirdly, different methods of remuneration of balancing services exist. Different methods may apply to different balancing service auctions. Common are marginal pricing (uniform pricing), pay-as-bid pricing (discriminatory pricing), and regulated pricing. In case of bilateral contracting, only pay-as-bid pricing or regulated pricing is possible. Balancing services (classes) are paid for either only availability (i.e. capacity), or only utilisation (i.e. energy), or both (Vandezande et al., 2008). It is also possible that neither is paid for, if the provision is mandatory[6].

Fourthly, a first design option related to balance planning and settlement is the final gate closure time, which is the time at which wholesale trade between market participants (Balance Responsible Parties) ceases (Vandezande et al., 2008). At this point, the System Operator becomes responsible for balancing the system. The final gate closure is often just before the time of delivery. Furthermore, an initial gate closure time often exists on the day before delivery, at which BRPs must submit a first energy schedule. BRPs may adapt their schedule until final gate closure (Vandezande et al., 2008).

Fifth, a balancing market has a settlement period, which is the period over which BRP imbalance volumes are calculated (Vandezande et al., 2008). This implies that the energy schedules submitted by Balance Responsible Parties indicate the planned energy exchange during this settlement period. The time unit applied to the balancing energy market is equal to the settlement period, because imbalance pricing is based on the balancing energy procurement costs for the relevant period (see below).

Sixth, there are two main methods of imbalance volume calculation. In the 'one step method', a Balance Responsible Party can be responsible for both generation and consumption, whereas in the 'two step method' he can only be responsible for either of them (Vandezande et al., 2008). The latter will cause larger imbalances, because generation and consumption imbalances cannot cancel out within a BRP portfolio.

Seventh and last, different methods of imbalance pricing may be applied. Imbalance prices are the prices at which energy schedule deviations are settled between the System Operator and the Balance Responsible Parties. The imbalance prices are determined per settlement period, and are usually based on the balancing energy procurement costs per period. This results in a recovery of these costs, and provides an incentive to BRPs to follow up their energy schedules. An important choice within this design option is between a 'single-pricing system', in which one imbalance price applies to both short and long positions (negative and positive imbalances) of BRPs, and a 'dual-pricing system' in which different imbalance prices apply to short and long positions (Vandezande et al., 2008).

Design issues by Rebours, Kirschen and Trotignon (2007) and Rebours (2008) Eight fundamental issues in the design of ancillary service markets are provided by Rebours,

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[6] Note that mandatory provision can still go together with remuneration.

Table 2.1 – Balancing market design options in Vandezande et al. (2008)

Elements	Design options
Balancing service procurement	Balancing service definitions Times and methods of procurement Methods for remuneration
Planning and settlement	Gate closure times Settlement period Method of imbalance volume calculation Method of imbalance pricing

Kirschen and Trotignon (2007) and Rebours (2008)[7]. They are 1) Nominating the responsible entity of procurement, 2) Matching supply and demand, 3) Choosing the relevant procurement methods, 4) Defining the structures of bids and payments, 5) Organizing the market clearing procedure, 6) Avoiding price caps, 7) Providing appropriate incentives, and 8) Assessing the procurement method. These design issues are discussed below. The new balancing market design variables that we have identified from these issues are listed in Table 2.2.

The first design issue of nominating the responsible entity of procurement finds its origin in the existing arrangement in PJM[8], where it is the load-serving entities that must provide frequency control services, instead of the System Operator. This way, procurement costs are implicitly allocated to system users (Rebours, Kirschen and Trotignon, 2007). However, it is still the System Operator who assesses the total need for balancing resources, and who activates these resources and settles the real-time balancing energy. The obligation for market parties to purchase balancing resources can be considered a procurement method, but also a (capacity) cost allocation method. This brings us to the identification of the procurement cost allocation method as a design variable[9].

Secondly, the issue of matching supply and demand is about possible ways to ensure that the system balance is maintained. Mentioned are proper incentives to invest in new ancillary service resources, connecting conditions, different methods of procuring ancillary services, and incentives to provide ancillary services. Because incentives follow from ancillary service pricing, and because connecting conditions (obligations for new generation plants to invest in frequency control equipment) are part of an overall obligation to provide ancillary services (Rebours, Kirschen, Trotignon and Rossignol, 2007b), this issue is already tackled by identified national balancing market design variables.

Next, choosing the relevant procurement methods is a clear balancing market design option. This option has already been identified above in the design options of Vandezande et al. (2008). Different methods to obtain ancillary services listed are compulsory provision, self-procurement, bilateral contracts, tendering, and the spot market (Rebours, Kirschen and Trotignon, 2007; Rebours, 2008). Some of them, however, appear to be

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[7] With ancillary services not only frequency control services are meant, but also voltage control services.

[8] PJM stands for the power system spanning multiple states in the Eastern of the U.S. that is operated by the Regional Transmission Organization named PJM Interconnection LLC.

[9] In European balancing markets, reserve capacity costs are normally recovered through the network tariff, while balancing energy costs are recovered through imbalance settlement. See chapter 3.

only applicable in power markets where market parties are obliged to purchase balancing resources.

Defining the structures of bids and payments also concern a potential design variable: the payment structure(s) used to remunerate ancillary service provision. Different payment structures given by Rebours, Kirschen and Trotignon (2007) are a fixed allowance, an availability price, a utilization payment, payment of an opportunity cost, a utilization frequency payment, and a price for kinetic energy. Also mentioned are the issue of the price sign and the price symmetry, which can be considered sub-variables of the pricing mechanisms, or specific bid requirements, depending on how they are dealt with. The overall design issue will not be considered in our design framework, as the distinction between reserve capacity and balancing energy is adopted as an intrinsic part of the balancing market concept, and pricing of these elements follows from the presence of market mechanisms for these elements (see chapter 3). Hereby, the availability price and the utilization payment are included. The remaining payment structures are considered too detailed and uncommon in Europe. Besides, these structures could be considered to be part of either the availability payment (fixed allowance, opportunity cost) or the utilization payment (opportunity cost, utilization frequency payment, price for kinetic energy).

The fifth design issue of organizing the market clearing procedure also includes multiple features. A first feature given by Rebours, Kirschen and Trotignon (2007) is the structure of the overall power market, which is actually a fundamental wholesale power market design option. It concerns the presence of a centralized power pool. A centralized power pool involves centralized unit commitment and dispatch. Often, the real-time energy market is integrated with the centralized day-ahead power pool[10]. Other mentioned features are the types of auctions, scoring of offers, coordinating the various markets, the settlement rule, and the timing of market events. These are all design variables, but the types of auctions is considered relatively low-level and unimportant, because usually classical sealed-bid auctions are used in ancillary service markets (Rebours, Kirschen and Trotignon, 2007). Furthermore, coordinating the various markets can be considered to be part of the timing of markets. The scoring of offers, which deals with the order of selection of balancing bids by the System Operator, is a new design variable, however. The settlement rule is a variable that has already been identified.

Sixth, avoiding price caps is more a design principle or recommendation than a design variable. The design option of setting price caps can be regarded as a part of the design variable of the pricing mechanisms used in the ancillary service markets, or as part of the bid requirements (when Balancing Service Providers are not allowed to bid higher or lower than a certain price). The aspect of the dependency of bid selection on bid prices is covered by the scoring of offers.

Subsequently, providing appropriate incentives is about incentivizing both market parties and the System Operator to behave properly. Mentioned incentives are incentivizing the System Operator to define the optimal quantity, quality and location of ancillary services, incentivizing the System Operator to minimize the procurement costs, incentivizing Balancing Service Providers to deliver balancing services, and incentivizing market parties (Balance Responsible Parties) to 'improve their behaviour in order to reduce the need for system services' (Rebours, Kirschen and Trotignon, 2007). These are again de-

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[10] The relation of this fundamental power market design issue with balancing market design is further treated in chapter 3.

sign principles that may help to improve balancing market performance. They can be followed up by defining rules and procedures that provide financial stimuli to System Operators and market parties. We observe that already identified design variables may incorporate such rules. For the above incentives, these variables are among others the reserve requirements, the procurement method, the scoring of offers, the procurement pricing mechanism, and the method of imbalance pricing. Two design variables that are mentioned by Rebours, Kirschen and Trotignon (2007) related to this design issue are the method chosen to allocate the costs of system services, and the provision of price information to market parties. This last variable has not been identified yet, and is taken up as 'publication of market data'.

Last, assessing the procurement method is a recommendation to assess a designed procurement method on the basis of effectiveness, minimal running costs and economic efficiency. Thus, this design issue actually concerns the evaluation of a design option, instead of a design option.

Table 2.2 – Balancing market design variables in Rebours, Kirschen and Trotignon (2007) and Rebours (2008)

Elements	Design variables
Balancing service procurement	Scoring of offers
Planning and settlement	Procurement cost allocation method Publication of market data

Design variables by ETSO (2003, 2007) Some reports on balancing markets and balancing market integration by the former market-oriented organization of European Transmission System Operators (ETSO) also describe numerous design variables. New variables are included in Table 2.3.

In ETSO (2003), an extensive comparison of definitions and features of different frequency control reserves in various European countries is provided. Included aspects are among others the procurement mechanism (including time frame) and the remuneration scheme, which covers all the balancing service procurement aspects of Vandezande et al. (2008). Also, ETSO (2003) lists balancing service features like 'notice to deliver' and 'time to 100% delivery'. These could be considered part of the service definitions, but alternatively they could be regarded as a separate design option of 'balancing service requirements', especially when these requirements are very detailed and adapted to a specific market situation. Also, volume requirements in megawatts, i.e. the amounts of reserve capacity demanded and procured by the System Operator, are shortly treated, which is yet another design option. In addition, ETSO (2003) considers the gate closure time, and, as part of 'imbalance settlement', the method of imbalance pricing and the settlement period. The method of imbalance volume calculation is also mentioned as a feature, which means that all seven design options of Vandezande et al. (2008) are discussed. Another imbalance settlement feature mentioned is the obligation of a 'planned balance', which means that schedules for production and consumption must balance. A last indicated feature is how a net income from balance settlement (imbalance costs paid by Balance Responsible Parties minus remuneration paid to Balancing Service Providers) is allocated: It could be a profit to the TSO, or it could be returned to market parties.

The final report from ETSO on balancing market integration describes all the balancing market design options given by Vandezande et al. (2008) in the light of harmonization issues, albeit some more explicitly than others (ETSO, 2007). Reserves requirements are mentioned, which both include balancing service requirements and reserve volume requirements. Furthermore, the publication of balancing market data is discussed, which contributes to market transparency and may enhance competition.

Table 2.3 – Balancing market design variables in ETSO (2003, 2007)

Elements	Design variables
Balancing service procurement	Balancing service requirements Reserve volume requirements
Planning and settlement	Planned balance for energy schedule Allocation of net income of balance settlement

2.2.2 National balancing market design variables

The identified design variables in Vandezande et al. (2008), Rebours, Kirschen and Trotignon (2007), Rebours (2008) and ETSO (2003, 2007) are listed in Table 2.4. We note that from the study of balancing market regulations presented in section 2.1 the same list of design variables can be deduced. This list has been a main input for the created balancing market design space that is part of the balancing market design framework.

Table 2.4 – Overview of balancing market design variables in literature

Balancing service procurement	Planning and settlement
Balancing service definitions	Gate closure times
Times and methods of procurement	Settlement period
Methods for remuneration	Method of imbalance volume calculation
Balancing service requirements	Method of imbalance pricing
Reserve volume requirements	Planned balance for energy schedule
Scoring of offers	Allocation of net income of balance settlement
Procurement cost allocation method	Publication of market data

2.3 Literature on balancing market integration

The literature on balancing market integration is mostly limited to (explorative) documents from TSOs, regulators and governments on possible integration in Europe. Papers on ancillary service market integration have not been found. However, some studies have been carried anticipating on the integration of the four balancing markets in Germany that has been realized by now. An important scientific reference is the PhD thesis of Leen

Vandezande, titled 'Design and integration of balancing markets in Europe' (Vandezande, 2011).

The below literature study covers different integration aspects in six subsections. In subsection 2.3.1, the technical options for balancing service exchange between control areas in Europe are described. Next, subsection 2.3.2 discusses different balancing market integration models presented by the various references, which has been used for the formulation of four main cross-border balancing arrangements in the balancing market design framework in chapter 3. Then, an elaboration on the integration in Germany in 2009 and 2010 is given in subsection 2.3.3, which illustrates the viability of balancing market integration and the usefulness of step-wise integration. After that, the need for harmonization is covered by subsection 2.3.4. In subsection 2.3.5, the balancing market performance criteria mentioned and used in literature are listed, which forms the basis for the performance criteria set in the design framework. At the same time, the analysis and discussion of the impact of integration by literature is presented. Finally, multinational balancing market design variables derived from literature are described in subsection 2.3.6, which supports the multinational part of the design space in the design framework.

2.3.1 Technical possibilities for balancing service exchange in Europe

Balancing market integration is in essence about the exchange of balancing services between control areas. Such *balancing service exchange* always requires the availability of *interconnection capacity*. For the exchange of reserve capacity, this means interconnection capacity must be available for the entire contract period. Also, it should be noted that, with regard to primary control reserves, only reserve capacity can be traded, as balancing energy is delivered automatically and decentrally within seconds[11]. In Policy 1 of the UCTE Operation Handbook, which by the way does not have the status of legislation, some provisions on balancing service exchange can be found (UCTE, 2009a). Different provisions exist for primary, secondary and tertiary control reserves due to their different technical characteristics and functions.

With regard to the exchange of primary control reserves, a control area is allowed to increase its reserves by 30% in order to fulfil the primary control contribution obligation of other control areas, but no more than 90 MW[12]. However, such exchange should be previously confirmed by the TSOs, and the reserve should be exchanged directly between adjacent control areas or remain inside the same control block[13]. Furthermore, a generation unit or load can only have obligations to one reserve receiving TSO at a time. The technical realization of primary control exchange is relatively simple, it only requires the adaptation of the default setting of the frequency gain in the secondary controller (UCTE, 2009a).

The cross-border exchange of secondary control can be technically realized in two different ways: 1) The reserve receiving TSO sends its request for power directly to the generation unit, or 2) The reserve receiving TSO sends its request for power directly to

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[11] Note that reserve capacity exchange implies also balancing energy exchange, i.e. the energy delivered by the exchanged balancing resources.

[12] The shared responsibility for the provision of primary control is distributed between control areas of the synchronous zone proportional to the share of the energy generated within one year (UCTE, 2009a).

[13] A control block consists of of one or more control areas, cooperating in the function of secondary control, with respect to the other control blocks of the synchronous zone it belongs to (UCTE, 2004).

the reserve connecting TSO (UCTE, 2009a). In the first case, the involved generation unit will be coupled by a 'virtual tie line' to the control area of the reserve receiving TSO, which implies that it is coupled to the LFC system of that TSO. In the second case, the reserve connecting TSO will activate the requested power. The exchange of reserve capacity requires a confirmation by the involved TSOs. A limitation is that 66% of the needed reserve capacity must be kept within the control area, and 50% of the secondary and tertiary control capacity needed in total. Also, sufficient interconnection capacity must be allocated for the procurement of foreign reserves. The control areas of the reserve connecting TSO and the reserve receiving TSO do not have be adjacent, but of course interconnection capacity must be available across the borders of any reserve transiting TSO(s) as well. Like with primary control, a generation unit can only be contracted by one TSO at a time.

There are three different recommended scenarios for the technical realization of the exchange of tertiary control reserves across control areas: 1) Direct activation of the generation unit by the reserve receiving TSO and delivery of the activated reserve by measurement value, 2) Direct activation of the generation unit by the reserve receiving TSO and delivery by exchange schedule, and 3) power request by the reserve receiving TSO through the reserve connecting TSO. In the first scenario, the on-line measurement value of the delivered energy is sent to the LFC systems of both TSOs, in order to adapt the Area Control Errors. In the second scenario, the ACEs are adapted by means of an exchange schedule that indicates the tertiary control energy exchange[14]. In the third scenario, there is no activation signal being sent by the reserve receiving TSO directly to a generation unit; instead the reserve connecting TSO activates the generation. Directly activated tertiary control reserves can be exchanged between control areas applying scenario 1 or 3; schedule activated tertiary control reserves can be exchanged using scenario 2 or 3 (UCTE, 2009a).

Options for asynchronous zones Grande et al. (2008) consider technical possibilities for the exchange of reserves between separate synchronous systems. This is a special case of balancing service exchange, with other technical characteristics and implications. Interconnection lines between asynchronous control areas are High Voltage Direct Current (HVDC) lines, instead of the High Voltage Alternating Current (HVAC) lines which lie between control areas that are part of the same synchronous zone. Unlike HVAC interconnectors, HVDC interconnectors need to be actively controlled in order to realize balancing service exchange. It is technically very well possible to control the HVDC terminal quickly enough for this purpose. According to Grande et al. (2008) it is even possible to exchange primary control energy, although technical challenges are fundamental.

Grande et al. (2008) mentions three 'levels of ambition' for the exchange of reserves between separate synchronous systems: 1) The HVDC terminal acts as a source or sink for the provision of manual balancing services, 2) The HVDC terminal acts under Load-Frequency Control, and 3) The HVDC terminal contributes to primary control. These clearly deal with the exchange of tertiary, secondary and primary reserves, respectively. With regard to the second option, three potential models are mentioned: a) The LFC

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[14] The main input for the ACE is the difference between scheduled and actual interchange of energy with other control areas, see section 3.1.

controls the HVDC terminal only, b) the LFC controls both the HVDC terminal and the exchanging generator, and c) an integrated balancing market. In the first model, the HVDC terminal will be just another resource in the LFC system of one of both control areas[15]. In the second model, exchanging generators will become part of the LFC system of the importing area, in which case activation of the corresponding energy bids will require a control signal for both the HVDC terminal and the generator at the same time. In the third model, the balancing energy markets of both control areas are merged, which means a technical coupling of both LFC systems in order to economically optimize real-time balancing in the overall region considering physical constraints (congestions and HVDC ramping restrictions). All three models create their own market-related and technical challenges (Grande et al., 2008).

Conclusion It can be deduced from the above that multiple technical arrangements for the exchange of balancing services exist, which relate to the division of power systems into synchronous zones and control areas, and the existence of different balancing service classes that are controlled differently. This research will not go into further detail on these technical arrangements. However, two important observations are made. First, balancing service exchange is technically feasible, even between control areas belonging to different synchronous zones. Second, procurement of a minimum share of the required reserve capacity within the own control area remains necessary to safeguard operational security of supply, which limits the potential for reserve capacity exchange[16].

2.3.2 Alternative integration models for Europe

As stated before, balancing market integration is in essence about the integration of balancing service markets, notably the balancing energy markets for secondary and tertiary control. This is because it is harder to integrate reserve capacity markets, due to the importance of national reserves to safeguard operational security of supply in the own control area, and due to the need to reserve interconnection capacity. Moreover, primary control energy cannot really be marketed and involves much smaller energy volumes[17]. Different European electricity organizations have made a distinction between alternative models for the cross-border exchange of balancing services, or ‘cross-border balancing models’, starting with ETSO (ETSO, 2003, 2005, 2006, 2007), and followed by electricity industry organization Eurelectric (Eurelectric, 2008), and regulator organization ERGEG (ERGEG, 2009). Furthermore, Frontier Economics and Consentec (2005) and Vandezande (2011) have assessed alternative models. Below, the cross-border balancing models found in literature are described. An overview is given in Table 2.5.

Alternative models In ETSO (2005), two alternative cross-border trading models for tertiary reserves are outlined: the BSP-TSO trading model and the TSO-TSO trading model. In the first model, Balancing Service Providers can directly offer their reserves to

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[15] Following UCTE (2009a), the HVDC terminal cannot be part of both LFC systems at the same time.

[16] In addition, an economic obstacle to reserve capacity exchange is the possibly substantial reduction in economic revenues from conventional cross-border trade. This issue is incorporated in the design framework.

[17] Primary control energy is provided automatically and locally within seconds, and should be replaced by secondary control energy.

neighbouring Transmission System Operators, whereas in the last model TSOs trade with each other. Hereby, the first model gives the choice of cross-border balancing trade to the BSP, and in the second model this choice lies with the TSO. The focus on tertiary reserves has been chosen, because automatic frequency control services have a 'much more complex nature', and because it is believed that there is in potential more economic value in tertiary reserve trading (ETSO, 2005).

Next, in ETSO (2006), ETSO has presented four 'basic technical models, representing different levels of technical cooperation/integration'. These models also concern the trade of tertiary control reserves, for the same reasons as indicated by ETSO (2005). The first model is the case of no trading, in which only the exchange of emergency reserves takes place[18]. The second is called 'cross-border reserve pooling' which creates a common balancing energy market in which the TSOs can voluntarily share 0-100% of their balancing energy bids with other TSOs, and where activation occurs on a first-come-first-served basis. The third model of 'cross-border reserve trading' allows for the procurement of a part of the reserve capacity from another control area, where the possibility of balancing energy exchange can either be ensured by reservation of interconnection capacity or be subject to its availability in real-time. The fourth and last model is 'sharing of reserve capacity' and involves the agreement of TSOs on the sharing of a common reserve and on an individual share each TSO has to contribute.

In ETSO (2007), ETSO mentions three different integration models: 'pooling of reserves', 'sharing of reserves' and 'from area control to regional control'. The first two models are basically the same as the models of 'reserve pooling' and 'sharing of reserve capacity' in ETSO (2006). The third model is described as the next integration step that will include both reserve pooling and reserve capacity sharing, and the levelling of surpluses and shortages in different areas. Looking back at the model descriptions in ETSO (2006), this third model thus includes *system imbalance netting*, reserve capacity exchange and balancing energy exchange. System imbalance netting is the netting of opposing system imbalances of two or more control areas, which reduces balancing energy demand in both control areas. It is also interesting to note that, where ETSO (2005) and ETSO (2006) specifically considered the exchange of tertiary control reserves, ETSO (2007) mentions that the models apply to secondary and tertiary control reserve markets, and that primary reserves can be pooled as well[19] (although other terms are used for these service classes; see section 3.1).

In addition, three generic models for the linking of balancing arrangements of neighbouring control areas are described and discussed in Frontier Economics and Consentec (2005): 'System Operator to System Operator trading', 'integrated balancing arrangements', and 'participant offers to multiple mechanisms', all of which treat the exchange of balancing energy. These models are similar to reserve pooling of ETSO (2005), regional control of ETSO (2007), and BSP-TSO trading of ETSO (2005), respectively. It is interesting that these models are formulated based on three European cases where these models have been introduced; these are England-France, the Nordic area, and Germany,

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[18] Emergency reserves are tertiary reserves that are only activated when the other (secondary and tertiary) reserves are insufficient to restore the system balance. This does not happen a lot; it typically occurs after the failure of a major generation unit or transmission line.

[19] ETSO (2007) does remark that primary control reserve volumes cannot be reduced due to the shared use of this service within the synchronous zone.

Table 2.5 – Cross-border balancing models in literature

Source	Model
ETSO (2005)	BSP-TSO trading TSO-TSO trading
ETSO (2006)	No trading Reserve pooling Reserve trading Sharing of reserve capacity
ETSO (2007)	Pooling of reserves Sharing of reserves From area to regional control
Frontier Economics and Consentec (2005)	TSO-TSO trading Integrated balancing arrangements Participant offers to multiple mechanisms
Eurelectric (2008)	Reserve capacity market coupling Balancing market coupling
Univ. of Leuven and Tractebel (2009)	TSO-BSP trading TSO-TSO real-time energy trading TSO-TSO reserve trading One regional control area
ERGEG (2009)	TSO-BSP system TSO-TSO model without common merit order TSO-TSO model with common merit order
Vandezande (2011)	System imbalance netting TSO-BSP trading TSO-TSO real-time energy trading TSO-TSO reserve contracting Cross-border imbalance settlement One regional control area

respectively.

Then, Eurelectric has described principles and preferred design choices for balancing market integration. The models of 'reserve capacity market coupling' and 'balancing market coupling' are discussed, which cover the cross-border trade of reserve capacity and balancing energy, respectively. For both, the creation of a merit order is advocated, along with the use of marginal pricing of bids. A first step towards 'balancing market coupling' is stated to be the ruling out of balancing in different directions, i.e. system imbalance netting (Eurelectric, 2008).

Furthermore, the European Commission has commissioned a report dedicated to balancing market integration, which gives an overview of the proposals on cross-border balancing models (Catholic University of Leuven and Tractebel Engineering, 2009). Four models are shortly described: 'TSO-BSP trading', 'TSO-TSO real-time energy trading', 'TSO-TSO reserve trading', and 'one regional control area'. The second model involves the possibility for TSOs to share a part or all of their balancing energy services, and the third model involves the exchange of reserve capacity between TSOs. In the fourth model, one regional control area is created, which goes beyond the regional control model from ETSO (2007).

Subsequently, a report on guidelines for balancing market integration by ERGEG (2009) mentions three cross-border balancing models for the exchange of balancing energy, namely a TSO-BSP system, a TSO-TSO model without common merit order, and a TSO-TSO model with common merit order. The names of these models are quite clear on their content: In the first model BSPs have the choice to directly bid into another balancing energy market, in the second model TSOs may exchange energy bids on a voluntary basis, and in the third model balancing energy exchange is optimized by the creation of a regional merit order for energy bids. The reason for the focus on balancing energy in ERGEG (2009) is that the cross-border trade of reserve capacity is considered not economically viable. Furthermore, the report deals with manually activated reserves, although it foresees future opportunities for the cross-border exchange of automatically activated reserves.

Finally, Vandezande (2011) describes and evaluates five cross-border balancing proposals. 'System imbalance netting' concerns the netting of opposed control area imbalances, resulting in reduced activation of real-time energy. 'TSO-BSP trading' enables Balancing Service Providers to offer services directly to the TSO of a neighbouring control area. 'TSO-TSO real-time energy trading' concerns the cross-border exchange of real-time energy services, either limited to surplus services not needed by the connecting TSOs, or including all services in the form of a common merit order. 'TSO-TSO reserve contracting' enables the exchange of reserve capacity between TSOs. 'Cross-border imbalance settlement' concerns the cross-border trade of imbalances of Balance Responsible Parties. 'One regional control area' concerns the merging of control areas.

Cross-border balancing arrangements It can be seen that the different references generally mention the same possible cross-border balancing models, but that there are differences regarding the included balancing service classes (primary/secondary/tertiary), the type of balancing service included (reserve capacity and/or balancing energy), and the consideration of technical arrangements (control area merging, system imbalance netting). Furthermore, an interesting observation is that system imbalance netting is only considered explicitly by Vandezande (2011). The fact that Germany has implemented system imbalance netting as a separate first step in its balancing market integration process indicates its value as an independent model (see subsection 2.3.3).

The aforementioned models have been the basis for the formulation of four fundamental *cross-border balancing arrangements* in the balancing market design framework in chapter 3. These four arrangements are called 'system imbalance netting', 'BSP-SO trading', an 'additional voluntary pool', and a 'common merit order list'. Of these, the first has been considered by Vandezande (2011). The second arrangement comes directly from ETSO (2005). The third arrangement is what ETSO (2006) calls reserve pooling, and what ERGEG (2009) calls a TSO-TSO model without common merit order. The fourth arrangement is what ETSO (2007) calls regional control, and what ERGEG (2009) calls a TSO-TSO model with common merit order. A further explanation of the four cross-border balancing arrangements is provided in the design framework.

With this set of arrangements, the focus lies on different market arrangements for the cross-border exchange of balancing services, rather than different technical options related to such exchange. This focus fits with the emphasis on design and decision making in this research, but is also justified by the observation that balancing market performance is principally determined by the behaviour of market parties, and that this behaviour is shaped by the market design (see chapter 4).

Evaluation Important technical options concern the issue of the reservation of interconnection capacity for balancing purposes, the different realization options mentioned by UCTE (2009a) (see subsection 2.3.1), the technical models described by Grande et al. (2008) (see subsection 2.3.1), and the merging of control areas. The reservation of interconnection capacity is considered to be a separate market design issue, and comes back as a design variable in the balancing market design space (see also subsection 2.3.6). Next, the realization options from UCTE (2009a) and the technical models from Grande et al. (2008) concern different technical characteristics of cross-border balancing exchange related to the specific controls systems and balancing services. When implemented effectively, however, the impact of different technical options can be expected to be similar (for the same market arrangement). Finally, the merging of control areas, which is mentioned by Catholic University of Leuven and Tractebel Engineering (2009) and Vandezande (2011), is expected to roughly have the same impact on balance management as a fully integrated balancing market in a region with multiple control areas (see below). This last option has been included in the research as a design variable. Summarizing, the choice for market-oriented cross-border balancing models appears acceptable.

As follows from the literature study, the alternative market arrangements are concerned with the relationships between System Operators and Balancing Service Providers in the different control areas with regard to cross-border balancing. The nature of these relationships is determined by the overall market mechanisms that exist in and between the different control areas. The arrangements of BSP-TSO trading, the additional voluntary pool and the common merit order list represent the main alternative market configurations. It should be noted that these three market arrangements could apply to both reserve capacity markets and balancing energy markets, and thus transcend this distinction[20]. In addition, system imbalance netting is included in the set of four main cross-border balancing arrangements even though it is a technical option. This is because it significantly reduces the demand for balancing energy by enabling *surplus energy exchange* between control areas. Therefore, system imbalance netting can be considered to introduce *cross-border balancing* just like the other arrangements.

The model of cross-border imbalance settlement introduced by Vandezande (2011) is an interesting proposal, because it may indirectly lead to a more efficient balancing service procurement, if Balance Responsible Parties move their imbalance to the country with the lower imbalance price. We have chosen to not include this proposal in our set of cross-border balancing arrangements, because it does not entail an implementation effort that will increase the level of cross-border balancing, in contrast to the four arrangements mentioned above.

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[20] The impact of the arrangements will be different for these two types of markets, however, due to the different nature of reserve capacity and balancing energy.

2.3.3 Integration in Germany

Until recently, Germany had four separate balancing markets for the four existent control areas. Integration of the balancing markets started in December 2006, when a common Internet market platform for balancing services was introduced by the German TSOs (Riedel and Weigt, 2007), and minute reserves started to be procured jointly. As of December 2007, a common tender for primary and secondary control reserves was held on a monthly basis, instead of bi-annually, like before (Amprion et al., 2011). Much more rigorous, however, was the sequence of integration steps that took place in 2009, which came in the form of four 'Modules' (Grande et al., 2011).

After the introduction of the first Module, on December 1st 2008, control area imbalances could cancel each other out, preventing counter-acting balance regulation (system imbalance netting). The net imbalance of the region was distributed pro rata between the control areas, leading to reduced Area Control Errors. The second Module, from May 1st 2009 on, concerned a common dimensioning of secondary reserves, reducing the procured reserve capacity. However, TSOs retained 'national shares' and prioritized the utilization of reserves in the own control area. In addition, a common imbalance price was introduced (see section 2.1). With the third Module, commencing on July 1st 2009, a common market for secondary reserves was introduced, in which communication was simplified: BSPs now only needed an IT-connection to the TSO of their own control area. Finally, in the fourth Module, which was initiated on October 1st 2009, a common merit order list, i.e. a fully integrated balancing service market for secondary reserves, completed the integration process (Technical University of Dortmund and E-Bridge, 2009; Grande et al., 2011). The provision of tertiary reserves was also subject to further integration, but the form and time schedule of this integration was different from the above-mentioned integration for secondary control[21]. Still, tertiary reserves were also included in the common dimensioning of reserves, although it should be noted that tertiary reserves are only used to free up secondary reserves, and are therefore hardly activated (LichtBlick, 2008; Grande et al., 2011).

It can be seen that the integration steps in Germany show a resemblance with the four cross-border balancing arrangements adopted in our design framework (see the last subsection). System imbalance netting and the common merit order list, i.e. the first and the last German Module, are part of these four. With Module 2, Germany introduced some form of a voluntary pool. Module 3 only differed from Module 2 in terms of the different communication links between TSOs and BSPs, and thus can be considered a voluntary pool version as well.

The newly integrated secondary and tertiary control market is also called the 'Optimierten Netzregelverbund (ONRV)', which translates into Grid Control Cooperation. It is interesting to note that Amprion (formerly RWE Transportnetz Strom), one of the four TSOs, originally favoured the merging of the four control areas into one, which would involve the installing of a central control system and System Operator (Grande et al., 2011). This concept has been called the 'Zentrale Leistungs-Frequenz-Regelung (ZNR)', which translates into Central Load-Frequency Control (Technical University of Dortmund and E-Bridge, 2009). In 2010, however, the German regulatory authority forced Amprion to join the ONRV (Bundesnetzagentur, 2011).

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[21] K. Eggenberger (E-Bridge), personal communication, March 2010.

Impact assessments Preceding the balancing market integration in Germany, some impact assessment studies have been carried out. First, in LichtBlick (2008), the potential cost reductions of the creation of one control area were calculated. The calculations were based on historical data, and considered system imbalance netting and the reduction of reserve capacity due to a lower total reserve requirement[22]. Reductions of 314 million euro and 341 million euro were found for 2006 and 2007, respectively, if one merged control area had been present in those years. This would have caused a balancing costs reduction of 37.9% in 2006 and of 47.6% in 2007. About 45% of the costs reductions were due to the reduction of balancing energy dispatch, and the rest due to reserve capacity procurement reduction.

More elaborate has been the study of Technical University of Dortmund and E-Bridge (2009), which has assessed and compared the financial impact of the ONRV and the ZNR for Germany. Most importantly, it is argued that the impact of the two 'conflation concepts' is comparable, as they realize the same kind of costs reductions (Technical University of Dortmund and E-Bridge, 2009; Grande et al., 2011). For both concepts, system imbalance netting is estimated to reduce balancing costs by 56 M€, and the decrease of procured reserve capacity to reduce costs by 140 M€. Thus, the total costs reduction lies for both concepts around 200 M€. Still, a slightly larger balance management costs decrease has been found for the ZNR concept compared to the ONRV concept, due to the lower balance planning costs. However, a limitation of this finding is that the congestion management costs were not quantified and thus not included in the calculation. For a more detailed description of this study, see the subsection 5.1.1, in which the impact of the design variable 'control area boundaries' is elaborated on.

Conclusion In conclusion, the completed balancing market integration for the four German control areas proofs that balancing market integration is, as Catholic University of Leuven and Tractebel Engineering (2009) argue, profitable and achievable: The integration has taken place within a year time, and is estimated to have brought large balancing costs reductions. Furthermore, this case shows that a step-by-step internationalization process is both sensible and possible (see also the next subsection), and that alternative cross-border balancing arrangements can be implemented as consecutive steps in this process. It is important to note, however, that the balancing market designs of the different German control areas were already harmonized, as they were grounded in the same national legislation. An internationalization process that requires both harmonization and integration is likely to be more difficult, more time-consuming and less fruitful.

2.3.4 Need for harmonization

The literature generally acknowledges the need for a step-by-step approach of balancing market integration. The need for a step-by-step development is a quite straightforward recommendation, in view of the uncertainties surrounding the possibilities and effects of integration. Indeed, ERGEG (2009) states that "integration is a process of evolution of

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[22] In the study by LichtBlick (2008), the reduction of the reserve requirement is based on the maximum system load. The maximum system load for the whole of Germany is lower than the sum of the maximum system loads of the four control areas.

connecting balancing markets in order to achieve their functioning as a common balancing market", and Eurelectric (2008) argues that "indeed given the need to ensure that balancing market design does not adversely impact on system security we recognise that the move to this model should be done in a step-by-step manner".

An important reason for a step-wise integration approach is the need for harmonization. In Catholic University of Leuven and Tractebel Engineering (2009) and ERGEG (2009), balancing market harmonization is seen as a prerequisite for integration. The need for harmonization provides a good reason to integrate gradually, as a sequence of integration steps fits with the difficulty to harmonize balancing market designs and the uncertainties about the effects of balancing market harmonization. As a matter of fact, the same can be said about integration. This is recognized by Frontier Economics and Consentec (2005), who note that a phased approach to integration can be beneficial because a number of differences in the balancing regimes can initially be retained.

Views in literature Regarding the need for harmonization as a precondition for integration, Eurelectric (2006) states that "it is necessary that TSOs agree to harmonised key parameters for the balancing market, e.g. operation windows, gate closure times, technical requirements, pricing and settlement, etc. in order to facilitate the participation of as many bidders from the demand and supply side as possible[23]". With this, balancing market integration is implicitly considered as a way to improve liquidity in balancing service markets in order to reduce balancing costs.

Next, ETSO (2007) argues that in order to achieve full benefits of balancing market internationalization, all important balancing market design aspects need to be harmonized. Mentioned goals are increased competition, transparency and equal market conditions. Regarding the priority of harmonization, it is stated that "depending on the regional situation harmonization steps could drive integration steps and vice versa, therefore no priority has been given to either process".

In addition, European Commission (2007) states that "harmonizing balancing market rules would not only be a first step prior to integration, it would also simplify trade and transparency for market participants that are active in more than one Member State". Thus, apart from the facilitation of integration, harmonization is considered to be beneficial for the overall wholesale market too.

Catholic University of Leuven and Tractebel Engineering (2009) present a practical roadmap consisting of three consecutive phases: 1) the implementation cross-border balancing with minimum harmonization prerequisites, 2) harmonization of the remuneration for balancing services, and 3) harmonization of imbalance settlement. As can be seen, the emphasis in this roadmap is on harmonization. In support of this, it is noted that the harmonization of some balancing market design variables is required to enable cross-border balancing, whereas further harmonization may be needed to realize 'full and well-functioning' balancing markets. Moreover, one recommendation on balancing market harmonization is the following: "As market-based solutions are not always feasible on a national scale, cross-border balancing implementation should precede market design harmonization[24].". By this, Catholic University of Leuven and Tractebel Engineering (2009)

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[23] With 'bidders' is meant Balancing Service Providers.

[24] In order to increase the level of competition in the national balancing markets.

sketch a balancing market internationalization process that starts with basic harmonization, is followed up by integration (possibly accompanied by more harmonization for better results), and ends with further harmonization. Furthermore, the report also argues that cross-border balancing without the harmonization of national balancing market designs 'may involve several distorting effects' on day-ahead and intra-day trade. Ergo, two reasons for balancing market harmonization are put forward by Catholic University of Leuven and Tractebel Engineering (2009), i.e. the facilitation of balancing market integration and the reduction of market inefficiencies, but it is pointed out that harmonization is also facilitated by balancing market integration.

Furthermore, ERGEG (2009) states: "Full harmonization of balancing markets is not a prerequisite for cross-border balancing. Thus, in a step-wise process, cross-border balancing implementation should precede definition and implementation of a standard market design. But increased compatibility would be highly valuable and allow enhanced cross-border balancing exchanges.". Hereby, ERGEG (2009) expresses the same views and recommendations as Catholic University of Leuven and Tractebel Engineering (2009).

Finally, Vandezande (2011) also argues that minimum harmonization suffices for initial balancing market integration. Also, she suggests that, since integration and the resulting enhanced market liquidity can make the proposed market-based balancing market design options more feasible, integration 'may have to precede' harmonization. Hereby, integration is presented as a means to harmonization, rather than the other way around (Vandezande, 2011). Again, this puts forward a transition process that starts with initial harmonization, follows up with integration, and ends with full harmonization.

Conclusion We conclude from the above that the distinction between balancing market harmonization and balancing market integration is indeed meaningful (as argued in section 1.2), that (partial) harmonization is a prerequisite for integration, and that a step-by-step approach to balancing market internationalization is highly recommendable. Moreover, it is concluded that merely some initial harmonization is required to start up integration, and that full integration may precede full harmonization. However, considering the multitude of balancing market design variables and possible harmonization and integration steps, as well as the mutual interaction between harmonization and integration, the balancing market harmonization process is likely to be intricately intertwined with the balancing market integration process.

As day-ahead and intra-day markets are outside our research scope, we will not further discuss the interactions between these markets and the balancing market. However, we will take into account that these interactions exist, as Balance Responsible Parties will trade in these markets to balance their energy portfolio, while Balancing Service Providers may alternatively sell their energy in these markets.

As mentioned in chapter 1, harmonization and integration strive for different primary goals and are realized in a different way. Harmonization is realized by the streamlining of national balancing market designs and aims at transparency and non-discrimination, whereas integration is realized by the implementation of prerequisite harmonization and a cross-border balancing arrangement and aims at the increase of economic efficiency of balancing service markets and a higher availability of balancing resources.

2.3.5 Performance criteria and impact

Literature In the research documents that have been written about the possibility of balancing market integration in Europe (see above), not many statements can be found on the desired and expected impact of integration. Still, some performance criteria are mentioned in the literature, which forms a starting point for the definition of a set of balancing market performance criteria set as part of the design framework in chapter 3. Also, some quantitative analyses of the impact of integration have already been carried out.

First of all, a short assessment of three main integration models has been executed by Frontier Economics and Consentec (2005), using three high-level performance criteria: economic efficiency, security of supply, and implementation costs. Some differences in the implementation costs between these models are given. It is stated that none of the models reduce the security of supply. The economic efficiency is not explicitly discussed, however. Detailed effects, or effects of integration on other criteria or indicators, are not included.

Secondly, Eurelectric (2008) states that the cross-border trade of balancing services should improve the economic efficiency of balancing service provision while maintaining system security levels, and argues that the exchange and sharing of reserves will realize this. Principles for balancing markets are given, but the impact of integration is not discussed.

In addition, the final report of the European Energy Sector Enquiry from January 2007 states that balancing markets for electricity are “highly concentrated, which gives generators scope for exercising market power” (European Commission, 2007). The report recognizes that the integration of balancing market may not only lower the concentration of balancing service markets, but also enable a better utilisation of low-cost resources. Moreover, it states: “Clearly, if two balancing markets were linked (assuming sufficient transmission capacity between the two systems) it would reduce the overall costs for maintaining the balance across the two systems.” (European Commission, 2007).

Following up on European Commission (2007), ERGEG (2009) concludes that “a lack of integration of balancing markets is a key impediment to the development of a single European electricity market”. Potential benefits of balancing market integration mentioned are the increase in transparency of market rules, a lower total amount of needed reserves, more efficient procurement of balancing services by the TSOs, the minimization of overall system costs, the increase of competitive pressures, and the increase of security of supply due to the possibility to procure balancing services from neighbouring TSOs.

Also, Vandezande et al. (2008) call balancing market integration a logical next step in the process towards a single Central Western European electricity market. As main potential benefits of integration they mention the reduction of overall balancing costs and the restriction of market power in the balancing service markets.

Furthermore, in article 15 of the European electricity directive 2009/72/EC concerning common rules for the internal market in electricity that the European Commission pursues, it is stated that “rules adopted by transmission system operators for balancing the electricity system shall be objective, transparent and non-discriminatory, including rules for charging system users of their networks for energy imbalance” (European Commission, 2009a). The stipulation of objective, transparent and non-discriminatory balancing markets is clearly conceived from the higher-level goal of overall (balancing) market efficiency, the same reason why an internal electricity market is aimed at. In addition, article 12 stipulates that the TSO is responsible for ensuring the availability of all necessary ancillary services. Interestingly, it is stated in article 37 that "in fixing or approving the tariffs or methodologies and the balancing services, the regulatory authorities shall ensure that transmission and distribution system operators are granted appropriate incentive, over both the short and long term, to increase efficiencies, foster market integration and security of supply and support the related research activities". This suggests that the European Commission considers balancing market integration to be an effective way to realize the above objectives.

Next, Catholic University of Leuven and Tractebel Engineering (2009) argue that balancing market design differences between European countries cause market distortions in today's increasingly integrated electricity markets. Also, the report gives a short analysis of the impact of a common merit order list for balancing energy (including system imbalance netting) for Belgium and France, based on data from a specific day in 2008. The results show a balancing costs reduction of about 6% making use of remaining interconnection capacity at the intra-day stage, which "illustrates that the implementation of a cross-border balancing market is a lucrative and achievable goal that does not entail unrealistic or overly expensive preconditions" (Catholic University of Leuven and Tractebel Engineering, 2009). Thus, balancing energy cost reduction (as a result of system imbalance netting and improved utilisation of balancing resources within the region) is the main positive effect indicated in the report. Other statements in the report are design recommendations rather than desired or expected effects. A lot of detailed recommendations flow from the general principle that real-time markets (balancing markets) should be market-based.

Subsequently, Jaehnert and Doorman (2010b) have analysed the impact of the integration of the balancing markets of Germany, the Netherlands and the Nordic region based on a common day-ahead market, using an optimisation model. Perfect markets were assumed, and data from 2008 was used on installed power plants, transmission systems, production, consumption and cross-border exchange in this region. The integration of balancing energy markets (assuming an integrated German market) was found to reduce the real-time system balancing costs from 96 to 60.22 million euro for a wet year and from 113.5 to 73.69 million euro for a dry year[25], which is a 37.5% and a 35%reduction, respectively. Used output parameters are reserve procurement costs and volumes, real-time system balancing costs and volumes, and volumes exchanged between areas.

Finally, Vandezande (2011) makes use of four 'levers for cost reductions' in balancing service procurement to assess the benefits of integration qualitatively: the capacity price, the amount of reserves needed, the real-time energy price, and the amount of real-time energy activated. Furthermore, three types of costs are identified: enabling costs, incentivation costs, and opportunity costs. Enabling costs are the unavoidable costs to realize integration. Incentivation costs result from 'efforts undertaken to convince all TSOs involved to proceed with implementation'. Opportunity costs are the 'lost benefits' resulting from integration. The six cross-border balancing models distinguished by Vandezande (2011) (see subsection 2.3.2) are qualitatively analysed using these indicators.

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[25] The Nordic region has a lot of hydropower resources, which are very suitable for balancing. The level of rainfall and temperature have a large impact on the production capacity of hydropower plants.

Apart from that, Vandezande (2011) carries out a quantitative assessment of the impact of TSO-TSO real-time energy trading with a common merit order list (including system imbalance netting) for the Netherlands and Belgium using 2008 data. Indicators used here are the total balancing energy volume and the total balancing energy costs. A global cost saving of 37% (more than 17.3 M€) has been found. Next, used indicators for the quantitative assessment of cross-border imbalance settlement for the Netherlands and Belgium in 2008 are the imbalance price levels and the total and average profits and losses associated with different BRP strategies. Last but not least, the cost-reflectivity of imbalance prices is considered an important objective, as imbalance prices are reflected in wholesale prices. Because the TSO-TSO common merit order leads to the most efficient real-time energy procurement, this model is considered as most beneficial, although it is emphasized that the magnitude of costs and benefits are 'fully border-dependent'.

A last interesting observation from the literature on the impact of balancing market integration is that integration is considered to be beneficial for the overall wholesale electricity markets: It contributes to the goal of an internal European electricity market. In addition, it is put forward by Vandezande (2011) that balancing market integration is a means to increase balancing service market liquidity, which facilitates the harmonization towards a more market-based balancing market design in Europe. Similar to this is the view of European Commission (2007), which argues that integration will reduce imbalance costs for market parties, reducing wholesale market entry barriers for small participants, and thereby enhancing wholesale competition.

Discussion Viewing all the above, the literature does not include many specific statements on the desired impact of integration, or give detailed indications of the likely effects on balancing market performance. Instead, prerequisites and principles for the design of integrated balancing markets are given (Eurelectric, 2008; ERGEG, 2009), or balancing market design recommendations (Eurelectric, 2008; Catholic University of Leuven and Tractebel Engineering, 2009). The documents from ETSO do not go further than the identification of relevant design variables and alternative cross-border balancing models (ETSO, 2005, 2006, 2007). There are three exceptions. The first is ERGEG (2009), which gives several potential benefits of integration on balancing market performance. The other two are Jaehnert and Doorman (2010b), who analyse the impact of balancing market integration for Northern Europe, and Vandezande (2011), who systematically assesses the effects of several cross-border balancing models on the basis of a set of indicators, and the impact of a common merit order list for Belgium and the Netherlands. These two references both find a balancing energy costs reduction of about 35% despite the different regions considered, which is a strong first indication that the overall economic benefits of balancing market integration are substantial.

In this thesis, we aim to contribute to the systematic analysis of the impact of balancing market harmonization and integration, considering all important design variables and performance criteria, and distinguishing between four main cross-border balancing arrangements. This will provide a completer picture of the value of balancing market internationalization in European power markets.

Performance criteria With regard to performance criteria and indicators, the ones explicitly mentioned and/or used in literature are economic efficiency, overall costs of balancing service procurement, security of supply, implementation costs, balancing service market liquidity/concentration, efficiency of utilisation of balancing resources, market transparency, non-discriminatory rules, availability of balancing services, the reserve capacity price, the amount of reserve capacity needed, the balancing energy price, the activated balancing energy volume, enabling costs, incentivation costs, opportunity costs, and cost-reflective imbalance prices (see above). We consider economic efficiency and security of supply to be the two fundamental (most high-level) balancing market performance criteria. Implementation costs, utilization efficiency, market transparency, non-discrimination and availability of balancing resources are relevant high-level performance criteria that are included in the performance criteria set (see section 3.2). The other variables mentioned above are performance indicators, i.e. low-level variables with which the scoring on performance criteria can be measured.

The other performance criteria included in the design framework can be linked quite easily to the literature. Balancing service price efficiency is the criterion that deals with cost-reflective balancing service prices. The criterion of social welfare of cross-border exchanges actually concerns the most important opportunity cost of integration, i.e. the reduction in cross-border trade value due to reservation of cross-border capacity for balancing purposes (cf. Vandezande (2011)). The relevance of the criterion of operational efficiency, i.e. the level of transaction costs, can be derived from the example of the reduced administrative costs of scheduling in case of a merged control area (Technical University of Dortmund and E-Bridge, 2009; Vandezande, 2011). The criterion of balance quality follows from the use of the Area Control Error as a control criterion in synchronous zones. The criterion of cost allocation efficiency concerns the efficiency of allocation of balancing service costs, and corresponds to the objective of cost-reflective imbalance prices from Vandezande (2011). This criterion is influenced by the design variables of the procurement costs allocation method, the method of imbalance pricing, and the allocation of the net income of balance settlement identified in section 2.2. The criterion of balance planning accuracy is important because it concerns the demand for balancing services, which is reflected by the principle of Rebours, Kirschen and Trotignon (2007) to incentivize market parties to improve their behaviour in order to reduce the need for system services (see section 2.2).

2.3.6 Multinational balancing market design variables

Next to the national design variables identified in section 2.2, there are design variables that specifically relate to multinational balancing markets. Most variables are not explicitly mentioned by literature, but can be deduced from it. The identified variables are described below, and listed in Table 2.6. This list has been a main input for the multinational part of the design space in the balancing market design framework.

In the literature discussed above, some multinational variables have been brought up already. Three technical ones are the control area boundaries, the geographical distribution of reserves, and the control systems. As described by UCTE (2009a), a synchronous zone consists of multiple control areas, which sets the targets of secondary control: Secondary control is used to return the actual energy exchange between control areas to the scheduled values. The boundaries of control areas could be adapted within a synchronous zone, which would change the scope of balance management. A practical example is the

Table 2.6 – Multinational balancing market design variables in literature

Design variables
Control area boundaries
Geographical distribution of reserves
Control systems
Balancing region boundaries
Reservation of interconnection capacity
Control area imbalance pricing
Cross-border balancing arrangement
Regional balancing service provision rules
Regional imbalance pricing mechanism
Publication of regional market data
Organization of System Operators
National vs. international regulations

Nordic region, where control areas have been integrated and a regional balancing market has been created in 2002 (Frontier Economics and Consentec, 2005). A geographical distribution of reserves, which is required to maintain the system balance throughout the synchronous zone irrespective of cross-border congestions, is also stipulated by UCTE (2009a). This sets some constraints on the potential of the cross-border trade of balancing services (UCTE, 2009a) (see subsection 2.3.1). Here, the relevance of control systems also becomes clear: Different control areas have their own Load-Frequency Control system, or may not even have an automatic control system at all (e.g. the Nordic region[26]). Therefore, the coordination between control systems is an important aspect of cross-border balancing (see subsection 2.3.1). The IT systems and communication structures used for real-time system balancing are regarded as an element of this (Grande et al., 2008, 2011).

Two more technical variables have been found in literature. One that is very central to the topic of balancing market integration is the 'balancing region' boundaries that are adopted. According to ETSO (2007), a balancing region is a group of control areas that coordinates some balancing activities. We will define a *balancing region* as a group of adjacent control areas that has established some form of balancing market internationalization. A regional approach to balancing market integration is clearly the right approach according to literature, and practical experience tells us the same[27] (Frontier Economics and Consentec, 2005; ETSO, 2007; Consentec and University of Stuttgart, 2010). The second variable is the possibility of reservation of interconnection capacity for balancing purposes, i.e. the cross-border trade of balancing services. One of the balancing market integration guidelines of ERGEG (2009) is that no interconnection capacity shall be reserved for cross-border balancing. ENTSO-E advocates that the reservation of interconnection capacity should be based on a social welfare calculation (ENTSO-E, 2011d). Because such reservation will greatly increase the potential for cross-border balancing, this is an important variable.

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[26] The introduction of Load-Frequency Control in the Nordic region is however under preparation.

[27] With too many countries involved, institutional and technical barriers are likely to become too high. Only when regional balancing markets would have been introduced, the harmonization and coupling of these markets could perhaps be considered.

Another multinational variable mentioned by ETSO is control area imbalance pricing, which is about the settlement of imbalances of control areas between System Operators (ETSO, 2007). In continental Europe, such settlement takes place 'in natura': If a control area has on a net basis imported too much energy in the form of inadvertent exchanges, this energy is scheduled to be exported in the next week in a so-called compensation program (UCTE, 2009b). Imbalances between subsystems in the Nordic region are also settled (Nordel, 2002).

Furthermore, the cross-border balancing arrangements discussed in subsection 2.3.2 can be considered a key multinational balancing market design variable. The cross-border balancing arrangement represents the multinational dimension of the balancing service market design in the balancing region. The arrangements represent different degrees of integration (see chapter 3). As the list of national design variables suggests, there are a lot of sub-variables underneath the cross-border balancing arrangement. Notably, the case of Germany in subsection 2.3.3 has shown that a fully integrated balancing market implies integrated procurement, timing and pricing rules. We can translate this into a broad multinational variable called 'regional balancing service provision rules'. Furthermore, a regional imbalance pricing mechanism was introduced in Germany, which is considered another multinational variable. Also, similar to the design variable of the publication of national balancing market data, on the regional level the publication of regional market data becomes an issue. For Germany, this data is published on a regional website (Amprion et al., 2011).

Finally, two high-level institutional multinational design variables can be identified. First, the organization of System Operators is important, because it deals with the level of coordination between System Operators, i.e. the distribution of balance management responsibilities and tasks. In Frontier Economics and Consentec (2005) it is argued that in a common merit order list a lot of coordination problems may arise. A solution to this possible problem could be a regional System Operator, to which some balancing tasks are delegated, as occurs in the Nordic region (Nordel, 2002; Frontier Economics and Consentec, 2005). Second, the internationalization of balancing markets puts forward the question whether international rules and regulations need to be formulated, or whether the national regulations suffice. In this context, ERGEG (2009) emphasizes the need for national regulators to coordinate with regard to cross-border balancing, and to remove the 'regulatory gap' that would cause obscurity on the legal aspects of regional balancing market design and functioning.

3 Balancing market design framework

In this chapter we present our balancing market design framework, which is one of the main outputs of this thesis, and a useful instrument in the decision-making process about national and multinational balancing market design. The framework consists of a reference model, an evaluation set, and a design space. All of these have been formulated on the basis of the gathered literature on balancing market design and integration (see chapter 2), in which a structured overview of balancing market design options, requirements and definitions was missing.

The reference model (section 3.1) introduces the concepts of the national balancing market and the multinational balancing market and provides standard terminology. The evaluation set (section 3.2) discusses requirements, offers a set of performance criteria that can be used to assess the performance of (multi)national balancing market designs, and links the better measurable performance indicators to these. The design space (section 3.3) lists the relevant design variables.

We emphasize that the design framework is dedicated to electricity markets with a voluntary power exchange, which are common in Europe. Nevertheless, parts of the framework may also be applicable to pool-based markets. At least, some balancing market design features of pool-based markets are considered in the framework.

3.1 Reference model

The reference model consists of the concept of the national balancing market (subsection 3.1.1), the concept of the multinational balancing market (subsection 3.1.2), and of standard balancing market terminology (subsection 3.1.3). The balancing market concepts provide a clear delineation of the topic (design object), and the standard terminology offers a clear set of definitions. These are important prerequisites for decision-making on balancing market design and internationalization, especially since each country (control area) currently has a different balancing market design and therefore a different understanding of balancing market boundaries, elements and terms. In short, the reference model will introduce a shared understanding of the decision-making case, and provide a shared language, which enhances the speed and effectiveness of the decision-making.

3.1.1 National balancing market concept

In the description of the national balancing market concept, balancing market terms will be used that are included in the list of standard terminology in subsection 3.1.3, which provides standard definitions. The first time a standard term is used here, it is written in italic.

Balance management is the power system operation service that concerns the continuous, real-time maintenance of the balance between electricity generation and consumption in a power system. We define the *(national) balancing market* as the institutional arrangement that establishes market-based balance management in a liberalized electricity market (see subsection 1.1.2). A balancing market consists of three design 'pillars': balance planning, balancing service provision, and balance settlement. Balancing service provision is connected to the market role of the Balancing Service Provider (BSP). Balance planning and settlement are closely related pillars that are connected to the market role of the Balance Responsible Party (BRP).

Actor network In a balancing market, there are three important actors (stakeholders): the Balancing Service Providers (BSPs), the Balance Responsible Parties (BRPs), and the System Operator (SO). The *System Operator* is the operator of a power system, and is responsible for maintaining system security, and therefore for balance management. *Balance Responsible Parties* are responsible for balancing a generation and/or consumption portfolio. *Balancing Service Providers* provide the resources that are used for balancing the system. BRPs and BSPs are both market parties. A market party can be either BRP or BSP, or both. BRPs are typically large market parties (generators, traders, energy delivery companies); BSPs are typically large generation companies.

Design pillars There are three main institutional pillars in the balancing market: balance planning, balancing service provision, and balance settlement.

Balance planning requires Balance Responsible Parties (BRPs) to schedule generation, consumption and trade, and makes them accountable for schedule deviations. This financial accountability is also called *balance responsibility*. BRPs submit *energy schedules* to the System Operator indicating their scheduled position, which usually state for each *Schedule Time Unit (STU)* in the day of delivery what the net energy injection into, or withdrawal from, the grid is planned to be. Deviations from these scheduled positions are settled in the imbalance settlement process, which gives BRPs an incentive to submit accurate energy schedules, and to balance their portfolio. Typically, initial schedules should be submitted on the day before delivery, but adapted schedules can be submitted up to some time close to the STU of delivery. This is the *final gate closure time*, the time at which the system operator is given the 'sole responsibility for controlling individual levels of production and consumption' (Shuttleworth, 2002), and the energy schedules become definitive[1]. In European markets without a centralized power pool, this time is typically one hour before the STU of delivery. In contrast, markets with a pool have a final gate closure on the day before delivery. For each generation and consumption connection, a

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[1] In case ex-post trading is applied in a balancing market, BRPs may be allowed to trade imbalance with each other up to a specific time after delivery. This is only possible in markets that apply 'zonal balancing'. See section 3.3.

Balance Responsible Party should be responsible. In principle, the related generator or consumer is balance responsible, but the responsibility can be transferred to another market party with the role of BRP. Usually, a BRP is responsible for a portfolio of generation and connections. Only BRPs can execute trade transactions, which must be indicated in the energy schedules.

Balancing service provision is about the provision of balancing services by Balancing Service Providers (BSPs), and the procurement and dispatch of these services by the System Operator in the scope of balance management. We define *balancing services* as ancillary services for frequency regulation. A fundamental distinction in balancing services can be made between reserve capacity and balancing energy, following Eurelectric (2008) and ERGEG (2009). *Balancing energy* (in MWh) is dispatched by means of the real-time upward or downward adjustment of *balancing resources* (generation or load), in order to resolve the real-time *system imbalance*, whereas *reserve capacity* (in MW) is procured by contracting the optional right to dispatch balancing energy in order to ensure the availability of the balancing resource during the contract period (ERGEG, 2009). Balancing services are often offered to the System Operator in balancing service markets, by means of the submission of balancing service bids. In line with the above, we can distinguish between reserve capacity markets and balancing energy markets. Clearing of a reserve capacity market results in (a) reserve capacity price(s) (availability payment), which is/are paid to successful bidders (in m.u./MW/time unit). The balancing energy market is cleared each Schedule Time Unit, which leads to (a) balancing energy price(s) (utilization payment) that is/are paid to successful bidders (in m.u./MWh). A single clearing price for balancing energy is alternatively called the *regulation price*. Separate markets may exist for upward and downward regulation services, and for different balancing service classes (see below). The paid balancing service prices form the incentive for BSPs to offer resources in the balancing service markets. Alternatively, an obligation for the market to procure balancing services could exist, with or without remuneration. If reserve capacity and balancing energy are rewarded both, a separate reserve capacity market and a balancing energy market may exist, or a single market. In case of separate markets, BSPs with selected reserve capacity bids should offer the same capacity in the balancing energy market (cf. Eurelectric (2008)). In case of a single market, balancing service bids contain both a reserve capacity price and a balancing energy price (cf. Riedel and Weigt (2007)).

Balance settlement comprises of the settlement of procured balancing services, and the allocation of the resulting balancing costs to the market. Reserve capacity costs and balancing energy costs are normally recovered in a different way. Reserve capacity costs are usually recovered from all system users through a system service tariff, since the availability of balancing resources benefits all. Balancing energy costs are recovered through imbalance settlement. *Imbalance settlement* is the financial settlement of energy schedule deviations with an *imbalance price*. Such deviations can also be called 'BRP imbalances', or 'individual imbalances' (as opposed to the overall system imbalance). The imbalance of a Balance Responsible Party (BRP) is equal to the scheduled net energy exchange minus the measured dispatch (compensated for any activated balancing energy). For each Schedule Time Unit (STU), two imbalance prices are determined, one for BRPs with a shortage (negative imbalance) and one for BRPs with a surplus (positive imbalance). These two prices can be the same. BRPs with a shortage pay the *short imbalance price* to the System Operator, whereas BRPs with a surplus receive the *long imbalance price* from the System

Operator[2]. Imbalance settlement serves two functions. Firstly, the balancing energy costs are allocated to the market (namely to the BRPs). Secondly, the imbalance prices provide an incentive for BRPs to limit individual imbalances. As all final mismatches between planned and actual energy exchange are settled with the imbalance prices, market participants try to balance their energy portfolio to prevent imbalance costs if they expect those to be higher than the costs of their balancing efforts. As a results, the imbalance prices are reflected in wholesale short-term energy market prices[3] (Vandezande, 2011). After imbalance settlement between BRPs and the SO and balancing energy settlement between BSPs and the SO, some net (positive or negative) cash value may remain, which is usually allocated to the market. This value will be called the *net settlement sum*.

The above description of the balancing market architecture, elements and interrelations is visualized in Figure 3.1.

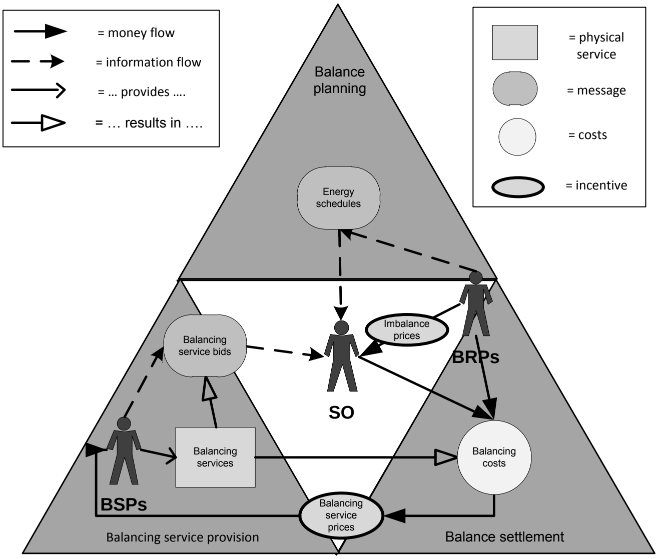

Figure 3.1 – Basic structure of the balancing market. BRPs = Balance Responsible Parties; BSPs = Balancing Service Providers; SO = System Operator.

Bases for distinction of balancing services There are three approaches to distinguishing between balancing services: according to types, directions, or classes. See Figure 3.2 (upper box). As mentioned above, the two fundamentally different types of balancing services are reserve capacity and balancing energy, the first being the contracted option to utilize the second for real-time system balancing. There are also two directions in which

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[2] Imbalance settlement can thus be regarded as the purchase/sale of 'imbalance energy'. However, because this is a compulsory payment that typically imposes additional costs to the market parties, we consider this settlement to be a penalty rather than a trade.

[3] As Vandezande et al. (2009) puts is, the imbalance prices determine to what extent the balancing market is an alternative for the wholesale market.

balancing resources can be adjusted in real-time: upward and downward. *Upward regulation* refers to the positive adjustment (increase) of generation resources or the negative adjustment (decrease) of demand resources, which helps to resolve a negative system imbalance. Conversely, *downward regulation* refers to the negative adjustment of generation or the positive adjustment of demand. In the balancing energy market, upward and downward regulation energy bids are placed and ranked separately, together forming the *bid ladder* (or merit order list). Activated upward bids are remunerated to the Balancing Service Providers (BSPs) by the System Operator (SO). However, balancing energy prices for downward regulation are typically paid by the BSPs to the SO. This is because downward regulation of power plants means less fuel costs. For upward regulation, bids are selected in increasing price order, and for downward regulation, bids are selected in decreasing price order. Figure 3.2 (lower right box) illustrates this. Furthermore, there are different balancing service classes. A basic distinction that is used by the UCTE is between *primary control (reserves)*, *secondary control (reserves)*, and *tertiary control (reserves)* (UCTE, 2009a), but ETSO-E is considering to adopt the terms *Frequency Containment Reserves (FCR)*, *Frequency Restoration Reserves (FRR)* and *Replacement Reserves (RR)* instead, following ETSO (2007). The classes differ in terms of function, activation time, activation method, activation scope, and activation duration. FCR (primary control) is a decentralized automatic service that is activated in a matter of seconds, FRR (secondary control) is a centralized and often automatic service that is activated in a matter of minutes, and RR (tertiary control) is a centralized and manual service that is activated within minutes up to hours. The function of FCR is to contain the frequency deviation after a disturbance, that of FRR is to restore the system frequency (and to remove unintentional deviations as well, see below), and that of RR is to return operation back to schedule. In addition, FRR replaces FCR, so that it becomes available again for containment of new frequency disturbances, and RR replaces FRR (cf. ETSO (2007) and UCTE (2009a)). See the lower left box in Figure 3.2, which has been adapted from UCTE (2009a). Different power systems often have a different set of service classes, with different names and characteristics (cf. Rebours, Kirschen, Trotignon and Rossignol (2007a)), even within the synchronous zone of continental Europe (the former UCTE zone) (cf. ETSO (2003)). Therefore, more specific definitions of FCR, FRR and RR cannot be given. Typically, different balancing service markets exist for different service classes (such as in Germany), but different service classes could also be offered into the same market (such as in the Netherlands). See e.g. subsection 2.1.1.

In general, a balancing market may include all kinds of combinations of reserve capacity markets and/or balancing energy markets for balancing service types, directions and classes. Different service types, directions and/or classes may be offered into the same market. Moreover, the provision of some balancing services may be compulsory and not remunerated, and some balancing services may not be provided at all, e.g. reserve capacity in a balancing market that has a large excess of balancing energy bids without any contracting. Examples regarding service classes are the absence of a balancing energy market for FCR[4], the 'regulating and reserve power market' in the Netherlands that incorporates both FRR and RR, and the absence of automatic FRR in the Nordic region (see subsection 2.1.1). Another one is the possibility to have a single market that deals with both

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[4] FCR energy concerns small quantities that are delivered automatically and decentrally.

reserve capacity and balancing energy (see above). An example regarding service directions is the possibility of separate markets for upward and downward reserves, such as in Germany (Amprion et al., 2011).

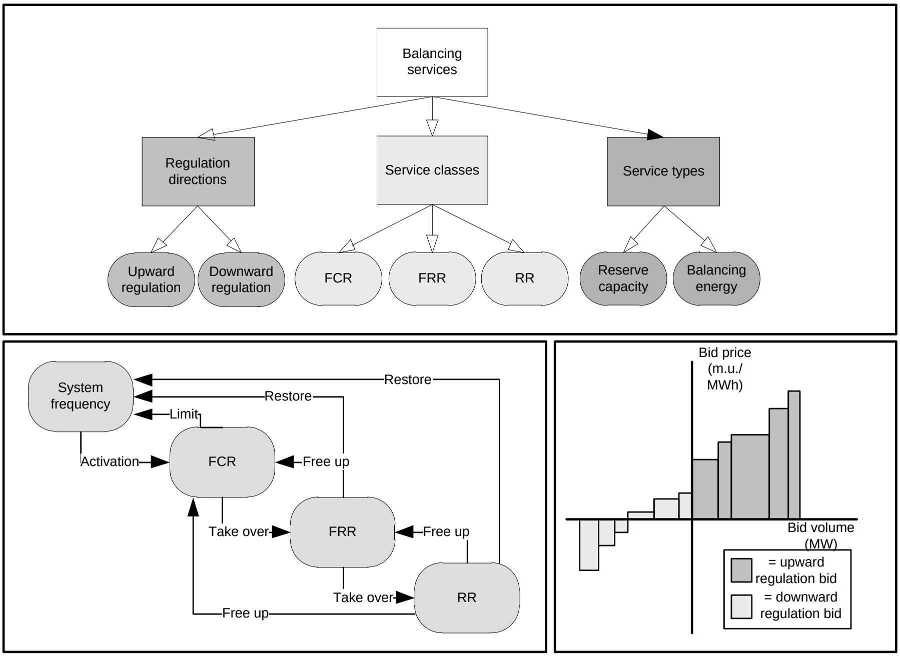

Figure 3.2 – Overview of different kinds of balancing services (upper box), indication of the function of different service classes (lower left box), and illustration of a balancing energy bid ladder (lower right box). FCR = Frequency Containment Reserves; FRR = Frequency Regulation Reserves; RR = Replacement Reserves.

3.1.2 Multinational balancing market concept

In the description of the multinational balancing concept, balancing market terms will be used that are included in the list of standard terminology in subsection 3.1.3. The first time a standard term is used here, it is written in italic.

We define the *multinational balancing market* as the total set of balancing market rules within the boundaries of a *balancing region*, i.e. a group of multiple adjacent control areas that have implemented some form of *balancing market internationalization* (see below). Some different aspects of balance management in a multinational context are treated below.

Geographical boundaries A *synchronous zone* is an interconnected power system consisting of one or more control areas, in which a single system frequency is maintained. We define a *control area* as a power system area for which a separate system balance is maintained. In a synchronous zone with multiple control areas, another control signal is applied next to the system frequency, i.e. the *Area Control Error (ACE)*. The ACE is defined as the instantaneous difference between the actual and the scheduled value for the power interchange of a control area, taking into account the effect of primary control. The ACE (in MW) is calculated as in Equation 3.1 (UCTE, 2009a).

$$ACE = \Delta P + k\Delta f \tag{3.1}$$

In this equation, ΔP (in MW) is the difference between the actual and scheduled value of power interchange (the *unintentional deviation*), k (in MW/Hz) is the control area contribution factor for primary control, and Δf (in Hz) is the frequency deviation. In other words, the ACE is "the control areas' unbalance minus its contribution to the primary control" (UCTE, 2004).

In a control area, the ACE is continuously reduced to zero, by means of the activation of balancing energy. The reduction of the ACE is usually executed by automatic activation of secondary control by a *Load-Frequency Control (LFC)* system, which takes the ACE as an input. In case a control area covers an entire synchronous zone the system frequency is the only control signal.

Between countries, interconnectors connect the different power systems. The *interconnection capacity*, or cross-border capacity, of these interconnectors is limited, which means there is a limited potential for cross-border energy exchange. Separate synchronous zones are linked by direct current (DC) interconnectors; control areas within a zone are usually linked by alternating current (AC) interconnectors. See Figure 3.3. Through both types of links, balancing services can be exchanged. The main differences between both are that the failure of a DC interconnector between two zones causes large frequency disturbances (in both zones), and that DC interconnectors need to be actively operated to realize balancing service exchange.

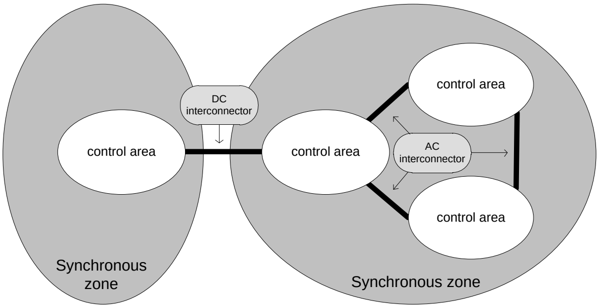

Figure 3.3 – Synchronous zones and control areas. DC = Direct Current; AC = Alternating Current.

In principle, a control area has a single set of balancing market rules, and one System Operator. However, sometimes two or more System Operators operate in a control area, e.g. when multiple countries are part of the same control area (as is the case in the Nordic region). Conversely, one System Operator can operate more than one control area, and the same set of rules may hold for multiple control areas. Also, a country (national balancing market) may exist of multiple control areas with different SOs and balancing market rules, although at least common national electricity laws and codes will be present.

Cross-border balancing We define *cross-border balancing* as the exchange of capacity and energy between control areas for the purpose of balance management. A first form of cross-border balancing is the prevention of opposing real-time balance regulation in neighbouring control areas by adaptation of the Area Control Errors (ACEs), something we introduced in subsection 2.3.2 as system imbalance netting (see below). Such netting leads to *surplus energy exchange*: The surplus energy of the area with a positive system imbalance flows to the area with a negative system imbalance. A second form of cross-border balancing is the exchange of balancing services between control areas, which we will call *balancing service exchange*, or cross-border balancing trade.

Technically, both forms of cross-border balancing are realized by altering the set-points in the Load-Frequency Control systems of the concerned control areas. This can be done by adapting the ACEs, or, more indirectly, by adapting the *exchange programs* of the involved control areas. The exchange program "represents the total scheduled interchange between two control areas" (UCTE, 2009a). But before the set-points are altered, the System Operators should first check whether interconnection capacity is available, and if no congestion problems or security threats arise as a result of the cross-border balancing. Because the options for cross-border balancing are considered in real-time, such security checks should be executed quickly and immediately, which could provide a barrier for cross-border balancing.

For the exchange of reserve capacity, interconnection capacity must be reserved for the length of the contract period to ensure its availability for the utilization of the optional right to activate balancing energy during that period. For the exchange of balancing energy, interconnection capacity should only be available during the period of actual energy exchange. To realize the latter multiple possibilities exist: a) utilization of the remaining interconnection capacity after final gate closure, b) exchange in the direction opposite to the cross-border trade, c) reservation of interconnection capacity for balancing purposes d) utilization of a part of the Transmission Reliability Margin that is not allocated to the market for security reasons, and e) temporary overloading of the interconnection line. Of these, a) and b) are the most practical options, whereas d) may jeopardize the frequency stability by prohibiting primary control energy exchange, and e) reduces the lifetime of the interconnection lines. The potential of possibility c) depends on the degree to which the reservation of interconnection capacity for balancing does not decrease social welfare. Furthermore, to realize balancing energy exchange, the ACEs of the involved control areas need to be adapted. This is done by means of the adaptation of the exchange programs of the involved control areas, and prevents the control systems from counteracting the cross-border balancing energy exchange.

It should be noted that the above considerations regarding balancing service exchange does not hold for primary control, the provision of which is coordinated and shared within the synchronous zone. All control areas contribute proportionally to the primary control service, which is activated automatically in a matter of seconds after a disturbance in the interconnected zone. The involved cross-border energy exchanges are possible thanks to the Transmission Reliability Margins on the interconnectors. The primary control contribution immediately changes the actual power interchanges and should be replaced by secondary control, which is why it must be taken into account in the calculation of the ACE (UCTE, 2004, 2009a).

Balancing market internationalization The possible internationalization of balancing markets, i.e. the development of multinational balancing markets, has two dimensions: harmonization and integration. *Balancing market harmonization* involves the equalization of balancing market rules in different countries / control areas, whereas *balancing market integration* is focused on the integration of balancing service markets, realizing balancing service exchange between the involved control areas. The differences and interrelations between harmonization and integration have been discussed in subsection 2.3.4, where it was concluded from literature that (partial) harmonization is a prerequisite for integration, but that full integration may precede full harmonization. Both harmonization and integration will change the national balancing market designs and thereby balancing performance. Although harmonization has a wider scope than integration, integration is technically more complex, because it introduces an additional market arrangement that establishes interaction between the national balancing markets in the region: the cross-border balancing arrangement.

Cross-border balancing arrangements In subsection 2.3.2, we have formulated, on the basis of literature on alternative cross-border balancing models, four fundamental *cross-border balancing arrangements*: 'system imbalance netting', 'BSP-SO trading', an 'additional voluntary pool', and a 'common merit order list'. These arrangements are described below, and illustrated in Figure 3.4.

System imbalance netting is defined as the 'netting' of positive and negative system imbalances in adjacent control areas, resulting in a surplus energy flow from the surplus area to the deficit area, which prevents opposing balancing energy dispatch in those control areas. Within synchronous zones, system imbalance netting involves the combination and redistribution of Area Control Errors of adjacent control areas. This arrangement does not require any change in balancing market design, which makes it different from the other three.

BSP-SO trading is defined as the facilitation of cross-border trade of balancing services between Balancing Service Providers (BSPs) and the System Operators (SOs) of other control areas in the balancing region by means of harmonization of basic balancing market rules such as the Schedule Time Unit, gate closure times, and balancing service bid requirements. BSPs can place balancing bids in the balancing service markets of other control areas, which could then be activated by the SOs of those areas. This arrangement is the only one in which the Balancing Service Providers are actively involved.

An *additional voluntary pool* is defined as an additional multinational balancing service market in which SOs of adjacent control areas can share balancing services on a voluntary basis. In the most simple form, this will be a bilateral exchange of balancing service bids between two SOs, where SOs offer bids they will not use themselves to each other. In the most advanced form, SOs place bids they want to share in a 'regional pool' (hence

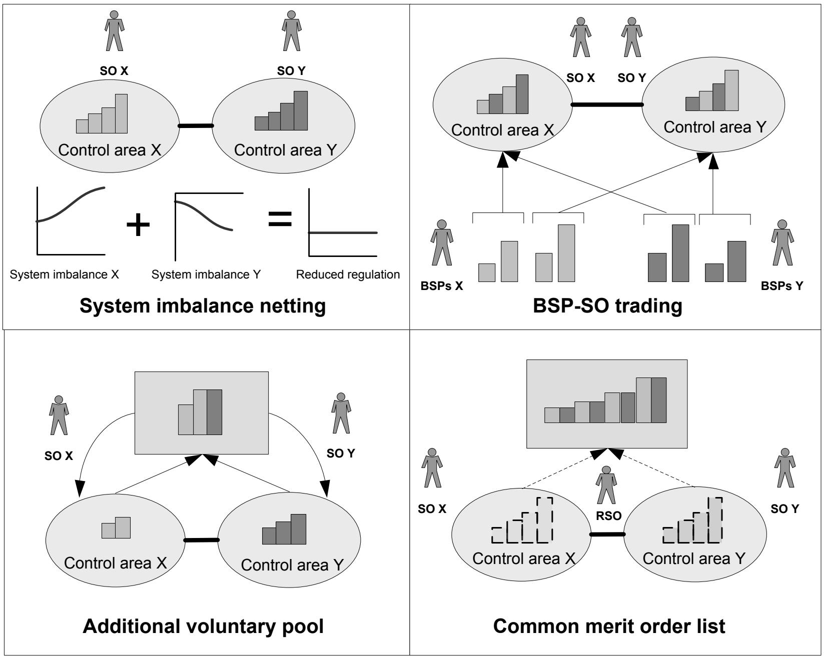

Figure 3.4 – The four main cross-border balancing arrangements. The arrows indicate the submission, exchange or transposition of balancing service bids.

the name of this arrangement[5]). SOs can then take bids from the regional pool, and place it in the bid ladder of their own market. This may take place on a first-come-first-served basis. This arrangement is a form of SO-SO trading (trading between System Operators).

A *common merit order list* is defined as a regional (multinational) balancing service market that is created by the integration of national balancing service markets. The national bid ladders are combined to form a common merit order list. All bids in the balancing region are included. SOs pass on the bids of their area to a *'regional System Operator'*, who will be responsible for the maintenance of the regional system balance. This arrangement is also a form of SO-SO trading.

The last three arrangements are relevant for Frequency Restoration Reserves and Replacement Reserves, and can be applied to either reserve capacity exchange or balancing energy exchange, or both. Also, it can be remarked that a common merit order list for reserve capacity implies the presence of a common merit list for balancing energy as well. Furthermore, we notice that it is possible to introduce a different cross-border balancing arrangement for reserve capacity than for balancing energy regarding the same balancing service class. The implementation of system imbalance netting is independent from the

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[5] We find that the difference between bilateral exchange and a regional pool is not so large as to justify making an explicit distinction, which is in line with the cross-border models found in literature. The used name is that of the most far-reaching form, which will be considered in the analysis.

implementation of BSP-SO trading and the additional voluntary pool, but is actually an inherent part of the common merit order. This is because in the latter arrangement the regional system balance is maintained, rather than the control area imbalances. For regional system balancing, it is economically optimal to apply system imbalance netting, reducing the activation of balancing energy.

As a final remark, we emphasize that we deliberately exclude the option of the merging of control areas from the considered set of main cross-border balancing arrangements. This is because the impact on balance management is not expected to be significantly different from a fully integrated balancing market in a region with multiple control areas, as found in a quantitative study by Technical University of Dortmund and E-Bridge (2009). To our knowledge, there are no large technical and operational barriers to adapt Area Control Errors for cross-border balancing in a common merit order list. This is supported by the realized balancing market integration in Germany, where a common merit order list has been successfully implemented while retaining the four control areas. We note that a merged control area may bring about lower transaction costs of balance planning and settlement if the number of energy schedules is reduced, but if congestion areas (price areas) are defined for the purpose of efficient congestion management[6], the number of energy schedules will remain the same.

3.1.3 Standard terminology

In the above descriptions of the concept of the national and multinational balancing market, a lot of specific terms on balancing markets have been introduced. These terms need to be clearly defined, forming a list of standard terminology on balancing markets. Standard terminology is a prerequisite for decision-making on balancing market design and internationalization, because decision-makers need a shared 'language' to gain a shared understanding of the decision-making case. A shared understanding is essential to working together towards a common multinational balancing market design and implementation.

The standard terms are listed in Table 3.1, and the standard definitions can be found in appendix B. In the remainder of this thesis, the standard terminology will be used consistently.

3.2 Evaluation set

In this section, requirements (subsection 3.2.1), performance criteria (subsection 3.2.2) and indicators (subsection 3.2.3) for (multi)national balancing markets are presented. Requirements are the objectives and constraints that a designer wants to meet. Performance criteria are the high-level factors that can be found within these requirements. Indicators are lower-level factors with which the value of the performance criteria can be measured to some degree (cf. Dym and Little (2004)). In chapter 4 and chapter 5, the performance criteria are used to evaluate the effects of balancing market design and internationalization.

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[6] This option corresponds with the balancing market design variable 'zonal vs. nodal responsibility' (see section 3.3.

Table 3.1 – Proposed standard terminology on national and multinational balancing markets

Balance management	Balance Responsible Party (BRP)	Schedule Time Unit (STU)
Balancing market	Balancing Service Provider (BSP)	Energy schedule
Balance planning	System Operator (SO)	System imbalance
Balance responsibility	Regional System Operator	Final gate closure time
Balancing service provision		Imbalance price
Balance settlement		Long imbalance price
Imbalance settlement		Short imbalance price
		Net settlement sum
Balancing resources	Reserve capacity	Frequency Containment Reserves (FCR)
Balancing services	Balancing energy	Frequency Restoration Reserves (FRR)
Bid ladder	Upward regulation	Replacement Reserves (RR)
Regulation price	Downward regulation	Primary control reserves
		Secondary control reserves
		Tertiary control reserves
National balancing market	Cross-border balancing arrangement	Balancing region
Multinational balancing market	System imbalance netting	Area Control Error (ACE)
Balancing market harmonization	BSP-SO trading	Unintentional deviation
Balancing market integration	Additional voluntary pool	Exchange program
Balancing market internationalization	Common merit order list	Control area
Balancing service exchange		Synchronous zone
Surplus energy exchange		Interconnection capacity
Cross-border balancing		Load-Frequency Control (LFC)

3.2.1 Requirements

Any design process starts with the formulation of the requirements. In this case, the requirements that national and multinational balancing markets should meet must be specified. This is fairly easy at the highest level: The balancing market design should make sure that the operational security of supply of the control area or balancing region remains above an acceptable level at minimum costs for society. Thus, operational security of supply is a fundamental constraint, and economic efficiency is a fundamental objective.

It is a lot harder to break down these fundamental requirements into lower-level ones. Thinking about functional requirements does not bring us much further. Functions that balancing markets perform are scheduling of generation and consumption, acquiring of balancing services, real-time system balancing, and allocation of balancing costs (settlement). However, these are inherent parts of a balancing market design (see subsection 3.1.1). Furthermore, balancing markets should provide appropriate incentives to Balance Responsible Parties and Balancing Service Providers. 'Incentive compatibility' could therefore be regarded another functional requirement, but this requirement is a means rather than an end. Appropriate incentives should lead by definition to efficient and effective balancing markets (otherwise the incentives would be inappropriate[7]).

Other requirements for national and multinational balancing markets are directly related to the identified performance criteria. For example, the requirement of a maximum availability of balancing resources includes the performance criterion 'availability of balancing resources.' The desired direction for all included criteria (see subsection 3.2.2) is a maximization. The exception is 'internationalization costs', where minimization is the

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[7] As market parties have the freedom to behave irrationally and respond illogically on the given incentives, the most appropriate incentives may not lead to the expected outcome, however.

desired direction[8]. Thus, we now turn to the performance criteria.

3.2.2 Performance criteria set

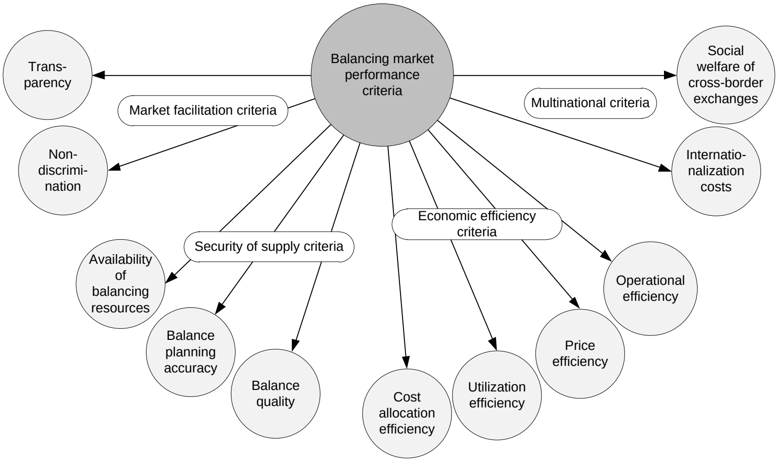

Figure 3.5 – Balancing market performance criteria set

The balancing market performance criteria included in the performance criteria set are relevant to both national and multinational balancing markets. However, two of the criteria are only relevant to multinational balancing markets, namely the internationalization costs and the social welfare of cross-border exchanges. The performance criteria have been identified in subsection 2.3.5. They are depicted in Figure 3.5 and shortly explained below, along with the corresponding performance indicators. An overview of criterion definitions and indicators can be found in Table D.1. The relative importance of the performance criteria is treated in section 4.3.

Transparency can be considered a market facilitation criterion. It consists of information availability, information symmetry (equal access to information) and clarity for market parties[9], and concerns both balancing market design and balancing market performance. Transparency of the balancing market design concerns the spreading of information about all the balancing market laws, rules and procedures. Transparency of balancing market performance concerns the spreading of balancing service and imbalance prices, balancing service bids, and system balance information. Transparency influences the ability of market parties to make informed decisions, and the barriers to entry. It is indicated by the number of rules, the consistency of rules across control areas, the accessibility of

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[8] Maximization means here that a higher value reflects a higher balancing market performance. It should not be the goal to make the value as high as possible. This will not lead to the highest overall performance, as trade-offs exist between the criteria.

[9] Market parties in the context of balancing markets are Balance Responsible Parties and Balancing Service Providers.

information, and the completeness of data (the extent to which market parties receive detailed balancing market data).

Non-discrimination can be considered a market facilitation criterion. It involves the equality of balancing market parties in terms of market rules and resulting conditions (opportunities, risks, revenues and costs), i.e. the existence of a level-playing field for market parties. Any differentiation in balancing market variable values for different market parties or different control areas may be considered discriminatory, although different power system/market characteristics may justify differentiation in balancing market rules[10]. Also, barriers to enter the balancing market as a new Balance Responsible Party (BRP) or Balancing Service Provider (BSP) can be considered a form of discrimination. The same holds for market design aspects that favour large market parties. Relevant indicators are the number of discriminating rules and the strictness of market requirements.

The *availability of balancing resources* is a performance criterion related to the fundamental requirement of operational security and supply. It concerns the availability of reserve capacity (given the reserve requirements) and the availability of balancing energy (given the system imbalances), which is influenced by the level of offering of balancing services by Balancing Service Providers. Naturally, more procurement of reserve capacity will increase the availability of balancing energy. Indicators are the ratio between procured reserve capacity and maximum system load, the ratio between procured and offered reserve capacity, and the ratio between dispatched and offered balancing energy.

Balance planning accuracy is related to the fundamental requirement of operational security and supply. It is defined as the accuracy with which energy schedules of Balance Responsible Parties reflect actual energy injections and withdrawals. Smaller schedule deviations mean a higher balance planning accuracy. These deviations involve energy imbalances over the Schedule Time Units (STUs). In addition, smaller power imbalances within the STUs are considered to improve balance planning accuracy. Therefore, the balance planning accuracy reflects the need for balancing energy: The higher the accuracy, the lower the need. Because BRP imbalances can even out on the system level, the accuracy of the net sum of all energy schedules gives the most information on the need for balancing energy. Indicators are the ratio between market imbalance (the net energy imbalance of BRPs combined) and system load, and the size and volatility of power imbalances within the STU.

Balance quality is related to the fundamental requirement of operational security and supply. It is defined as the effectiveness with which the system balance is maintained. This is about the degree to which the system frequency is maintained at nominal frequency, but also about the effectiveness of maintaining the control area balance. Maintaining the control area balance, i.e. following up scheduled cross-border exchanges, is substantially contributes to the overall goal of effectively balancing power supply and demand in interconnected power networks. A high balance quality contributes to the operational security of supply, as System Operators are better able to plan and execute their balancing tasks. Indicators are the number and size of frequency deviations, the Area Control Error (ACE), and the system imbalance direction. The latter is about whether the system imbalance of a control area is positive (a surplus) or negative (a shortage). Because system surpluses are

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[10] For example, different capabilities of generation units may call for different bid requirements.

generally easier to resolve and thus pose lower security risks, we consider them to result in a higher balance quality than system shortages.

Cost allocation efficiency is related to the fundamental requirement of economic efficiency. It is the efficiency with which the balancing service costs, i.e. the payments made to Balancing Service Providers, are allocated to the market. More concrete, it deals with the issue whether the right parties (the parties that have incurred the costs or benefit from the provided services) pay for the balancing service costs. If the imbalance costs that Balance Responsible Parties pay reflect the balancing service costs well, the cost allocation efficiency is high. However, if the imbalance costs are disproportionally high, BRPs will be too strongly incentivized to balance their portfolio, which will lead to higher 'portfolio balancing costs' than necessary. Furthermore, too high imbalance costs result in a large net settlement sum. This sum should be redistributed to the market, which may lead to a further decline of cost allocation efficiency. Thus, indicators are the ratio between imbalance prices and balancing energy prices, and the net settlement sum.

Utilization efficiency is related to the fundamental requirement of economic efficiency. It is the economic efficiency with which the available balancing resources are utilized. This may concern both reserve capacity and balancing energy. In a multinational context, the presence of balancing services in the entire balancing region is taken into account. This means that the selection/activation of the cheapest services in the region, given a certain demand for these services, will lead to a high utilization efficiency. A second aspect of utilization efficiency is the degree of utilization of procured reserve capacity, because a low degree could signify an inefficient procurement. A third aspect of utilization efficiency is the efficiency of the more general use of balancing resources by either the System Operator or the Balance Responsible Parties. After all, BRPs may use balancing resources for portfolio balancing, which can generally be assumed to entail a less efficient utilization of resources than in case of centralized balancing by the SO. Thus, indicators are the ratio between actual and possible minimum balancing service costs, the opportunity costs of unutilized reserve capacity (i.e. the difference between the capacity payments and the day-ahead value of corresponding energy), and the degree of 'BRP portfolio balancing'.

Price efficiency is related to the fundamental requirement of economic efficiency. It concerns the cost-reflectivity of the balancing service bid prices submitted by Balancing Service Providers, which increases with higher competition within the balancing service markets. Indicators are the difference between balancing energy prices and day-ahead prices, the opportunity costs of the reserve capacity procurement (i.e. the difference between the capacity payments and the day-ahead value of corresponding energy), the ratio between procured and offered balancing services, and market concentration indices.

Operational efficiency is related to the fundamental requirement of economic efficiency. It concerns the economic efficiency of handling the transactions related to the administrative process of balance planning, balancing service provision and balance settlement. This includes the submission of energy schedules by the Balance Responsible Parties, the submission of balancing service bids by the Balancing Service Providers, the sending of control signals and measurement values, and the settlement of selected bids and individual imbalances by the System Operator. If cross-border balancing is involved, it also includes the adaptation of ACEs, exchange programs and energy schedules, and the notification of other SOs. Each information or money exchange in the balancing market, which is either between the SO and a balancing market party (BRP or BSP) or between SOs of different control areas, is a balancing market 'transaction'. For the estimation of this criterion, the transaction costs of a reference balancing market design with minimal transaction costs should be considered. The higher the transaction costs compared to this reference case, the lower the operational efficiency. This represents the main performance indicator. Because the amount, frequency and complexity of transactions determine the height of the transaction costs, these can be considered more elementary indicators.

Internationalization costs is one of the two performance criteria that are only relevant for multinational balancing markets. The internationalization costs are the switching costs from the current design with separate balancing markets to the new multinational design. In other words, they are the harmonization and/or integration costs. These costs are only incurred once, and depend both on the initial design and the final design of the balancing markets. It should be noted that the internationalization costs are principally related to institutional change, as balancing market internationalization is principally an institutional process. Therefore, these costs are not very tangible. Indicators are the number of changed design variables in the different control areas, changes in the number and scope of balancing service markets, changes in ICT systems, and changes in the amount, content and format of messages[11].

Social welfare of cross-border exchanges is one of the two performance criteria that are only relevant for multinational balancing markets. Moreover, this particular criterion is only relevant for balancing market integration. Integration has an impact on the social welfare of cross-border exchanges when cross-border balancing takes place. The social welfare of cross-border exchanges is the total economic value generated by both conventional cross-border trade and by cross-border balancing. This is calculated by multiplying the price difference of a product with the exchanged volume of that product, and adding up for all exchanged products. Thus, indicators are the amount of cross-border trade and balancing service exchange, and the day-ahead price difference and balancing service price difference. Cross-border balancing will in principle improve social welfare, but the reservation of interconnection capacity for this purpose could lead to a decline.

3.2.3 Performance indicators

Performance indicators are the operational factors in a system that indicate the value of performance criteria. Because the balancing market performance criteria are quite abstract, indicators need to be defined. These indicators can be used to evaluate the effects of balancing market design and internationalization on the performance criteria. The identified indicators, mentioned above, are listed in Table D.1. They follow directly from the given definitions of the balancing market performance criteria.

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[11] Messages are the units of information that are exchanged between actors. Each message represents an information transaction (see 'operational efficiency'). Energy schedules and balancing service bids are the most important messages in the balancing market.

3.3 Design space

The design space consists of all the relevant design variables (Dym and Little, 2004). The design variables incorporated in the balancing market design space have been derived from the literature study presented in chapter 2. They are illustrated in Figure 3.6, and shortly explained below. The variables are ordered by national/multinational level and by design pillar (planning, service provision, and settlement). 'National' is here synonym to 'control area level', and 'multinational' to 'balancing region level'. In appendix D, the variables are listed along with short definitions and possible values. For more information about balancing service market design, we refer to Abbasy (2012).

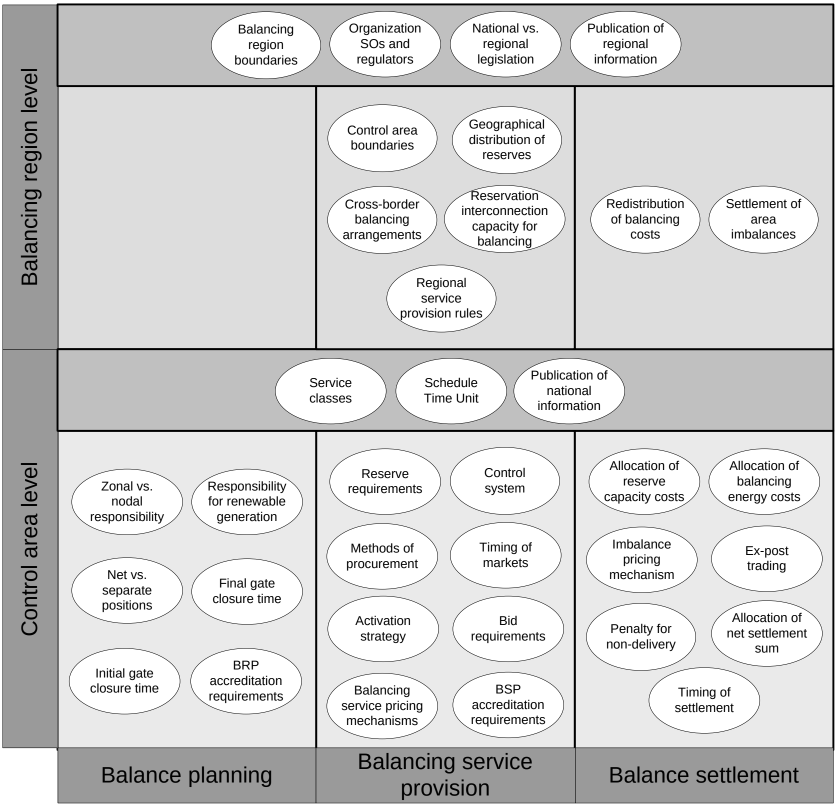

Figure 3.6 – Balancing market design space

Control area level variables

General variables (national)

Service classes: ENTSO-E, the organization of European TSOs, distinguishes between three main classes of balancing services: Frequency Containment Reserves (FCR), Frequency Restoration Reserves (FRR) and Replacement Reserves (RR), but in a balancing market different service classes could be defined. In the U.S., widely-used service classes are regulation, synchronized (spinning) reserves, and non-synchronized reserves (Isemonger, 2009).

Schedule Time Unit (STU): An alternative term is 'settlement period'. This is the main time unit used within the balancing market. It is the time unit for which energy schedules are specified by Balance Responsible Parties (BRPs), and for which balancing energy bids are specified by Balancing Service Providers (BSPs). The size of the STU determines the division of balance responsibility between the System Operator (SO) on the one hand, and the BRPs on the other hand. Throughout Europe, STUs of 15 minutes, 30 minutes and 60 minutes are in use (ETSO, 2003).

Publication of national information: This concerns the accessibility, format, symmetry, and frequency of balancing market information spread to BRPs and BSPs. Balancing market information can be either on the balancing market design itself (rules, procedures, etc.), or on balancing market results (bid data, balancing service prices, imbalance prices, imbalance volumes, etc.).

Balance planning variables (national)

Zonal vs. nodal responsibility: If BRPs must submit energy schedules for each network node, and are penalized for deviation per node, 'nodal balancing' is applied. If energy schedules are submitted, and schedule deviations are settled, for geographically defined subsystems of the control area, 'zonal balancing' is applied. If energy schedule submission and settlement is carried out on a control area basis 'control area balancing' is applied. The latter two are used throughout Europe. The Nordic region applies zonal balancing, as follows from the use of price areas and market splitting, which leads to different regulation and imbalance prices in cases of congestion (Nordel, 2008a). In the PJM system in the U.S., the use of Locational Marginal Pricing (LMP) results in the determination of real-time LMPs with which deviations from day-ahead schedules are settled (PJM, 2008). This shows that nodal balancing is applied there.

Responsibility for renewable generation: Balance responsibility for renewable generation can reside with the market (the BRPs), just like for all other generation technologies. However, it is possible that balance responsibility for renewable generation lies completely with the System Operator, which means that he is the Balance Responsible Party for renewable generation connections. This can be regarded as a renewable energy stimulation measure, and implies that imbalance costs of renewable energy are socialized. Finally, it is possible that a separate imbalance pricing mechanism is applied to renewable generation (as a less rigorous stimulation measure). Germany is an example of a country where the TSO has full responsibility for renewable generation, whereas in Belgium the TSO is partially responsible for off-shore wind power generation, as it only takes care of BRP imbalances that remain within a certain tolerance margin (de Vos and Driesen, 2009). This variable is most relevant for intermittent power generation technologies, i.e. wind power and solar power, because these are much less predictable and controllable, and therefore cause relatively high imbalances and balancing costs.

Net vs. separate positions: There are two basic options with regard to the definition of scheduled positions. If separate production and consumption positions exist, BRPs have to submit separate energy schedules for production and consumption that are settled separately, which means that production and consumption imbalances cannot cancel each other out. If a 'net position' applies, there is only one type of scheduled position that includes both generation and consumption. The Nordic region has adopted separate positions for production and consumption, for which different imbalance pricing mechanisms are applied (Nordel, 2007).

Final gate closure time: This is the time at which the energy schedules become final. Between the initial and final gate closure time, BRPs can submit adapted energy schedules to the SO, which replace the last submitted version. In European countries, the final gate closure time ranges from less than one hour before the STU of delivery up to one whole day before delivery (CEER, 2010b).

Initial gate closure time: The time at which BRPs should submit an initial energy schedule to the SO. Often, this is done on the day before the day of delivery, for all the STUs on the day of delivery. The initial gate closure time is then normally after the day-ahead market clearing time. It is also possible that there is no distinction between first and final gate closure, especially in countries where the final gate closure time is already on the day before delivery.

BRP accreditation requirements: In order to be authorized as a Balance Responsible Party by the SO, a market party must meet the BRP accreditation requirements. 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.

Balancing service provision variables (national)

Reserve requirements: The reserve requirements are the volume requirements for FCR, FRR and RR in the control area, which have been set for the reason of safeguarding security of supply. The national reserve requirements state the amount of reserve capacity that the System Operator should procure. SOs make use of different ways to determine the reserve requirements, ranging from simplified methods and guidelines (cf. Rebours, Kirschen and Trotignon (2007) and UCTE (2009a)) to complex calculations based on e.g. loss of load probabilities.

Control system: The control system that is used by the System Operator to activate balancing energy bids of FRR and RR. In case automatic FRR is used, a Load-Frequency Control (LFC) system is operated, the use of which has to be coordinated with the manual activation of RR. The use of either manual activation or automatic activation of FRR has not only important implications for the effectiveness of balance management of the national power system, but also for cross-border balancing. It could be that a SO applying manual activation does not accept automatic balancing energy bids, or vice versa, prohibiting the cross-border trade of balancing energy. Another issue relates to the control hierarchy of LFC. It makes a difference for the technical realization and costs of balancing service exchange whether or not different control areas have a separate LFC system or whether one regional LFC system is introduced.

Methods of procurement: 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, types, and directions (see subsection 3.1.1). Alternatively, balancing services could be acquired by the SO through bilateral contracting. It is also possible that balancing services are owned by the SO himself, as occurs e.g. in Sweden and Finland (Nordel, 2008b). Furthermore, there may exist different kinds of obligations for the market regarding balancing service provision, including the obligation to install technical equipment enabling automatic response on control signals, and the obligation to submit bids. In PJM, so-called Load-Serving Entities are assigned reserve obligations based on load share, which they can fulfil by means of self-procurement of reserves, by entering into bilateral arrangements with other market participants, or by purchasing reserves on the market[12] (PJM, 2008; Rebours, Kirschen and Trotignon, 2007). Another example is Belgium, where generators are obliged to offer regulation capacity to the SO as tertiary reserves (Elia, 2009).

Timing of markets: This relates to the time aspects of balancing service markets, i.e. the timing of bid procedures and the timing of market clearance. The timing of bid procedures is about the opening and closure times for the submission of balancing service bids by BSPs to the SO, relative to the market clearance times. The timing of market clearance consists of the frequency of balancing service market clearance and coordination with the clearance of day-ahead and intra-day markets. The frequency of market clearance determines the number of bid procedures: If a reserve capacity market is cleared monthly, there are twelve bid procedures per year. The balancing energy market is cleared for each Schedule Time Unit. In case of a single market for reserve capacity and balancing energy, the frequency of bidding may be much smaller than the frequency of clearance of the balancing energy market. For example, in Germany the secondary reserves market is cleared monthly, resulting in a balancing energy bid ladder that is fixed for the entire month and used for each STU in that month (see chapter 2).

Activation strategy: The activation strategy is about the strategy applied by the System Operator regarding the activation of balancing bids. Two aspects of this are the order of activation and the time of activation. The order of activation is about the strategy or procedure the SO applies to determine the order of activation of bids. This is normally in order of increasing bid price (merit order), but other bid specifications like grid location and regulating speed also play a role. Moreover, the activation order of energy bids from different markets or the partial activation of bids are also relevant issues here. The time of activation is about the question whether the SO activates all energy bids at real-time as a reaction to the momentary system imbalance (reactive strategy), or whether he also activates bids before real-time to anticipate on expected system imbalances (proactive strategy)[13].

Bid requirements: The requirements that balancing service bids must meet. These may contain requirements about bid price, volume, grid location, regulating speed, response speed, activation time, activation duration, method of activation (automatic or manual), divisibility of the bids, relevant BRP, and possibly other bid requirements. In the Netherlands, for example, balancing energy bids must have a volume between 4 and 100 MW, and the regulation speed of Load-Frequency Control-based ‘regulating power’ must be at least 7% per minute (TenneT, 2003).

Balancing service pricing mechanisms: The pricing mechanisms used for various balancing service markets. The pricing mechanism in a balancing service market determines what the balancing service price is that Balancing Service Providers receive for their se-

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[12] This is at the same time the way reserve capacity costs are allocated to the market.

[13] If the SO is responsible for renewable generation, the balancing task of the SO is more difficult and important, and requires a proactive activation strategy. This likely leads to more balancing energy dispatch, but also to more stable activation patterns and a larger use of replacement reserves.

lected bid. There are two market-based pricing mechanisms, based on the bid prices of the activated bids: 'pay-as-bid pricing' and 'marginal pricing'. An alternative is 'regulated pricing', where the balancing service price is not (solely) based on the bid prices, e.g. it can be the day-ahead price plus/minus a fixed sum. For example, balancing energy bids are settled with pay-as-bid pricing in England & Wales, and with marginal pricing in Spain (ETSO, 2003).

BSP accreditation requirements: In order to be authorized as a Balancing Service Provider by the SO, a market party must meet the BSP accreditation requirements. These may concern the capability to exchange information with the SO, but more importantly the technical pre-qualification of the balancing resources, i.e. the checking of the technical capabilities of the balancing resources asked from the relevant balancing service class.

Balance settlement variables (national)

Allocation of reserve capacity costs: Reserve capacity costs are usually allocated to all system users, because this balancing service benefits all. This is done through adaptation of the system services tariff. An alternative allocation method is by means of the assignment of reserve obligations to load-serving entities such as in PJM (Rebours, Kirschen and Trotignon, 2007). Also, reserve capacity costs could be (partially) recovered through imbalance settlement, an option that is proposed by Catholic University of Leuven and Tractebel Engineering (2009). Finally, a separate fee structure for BRPs can be adopted, such as in the Nordic region (Nordel, 2006b; NordREG, 2008).

Allocation of balancing energy costs: Usually, imbalance settlement serves to allocate balancing energy costs to the Balance Responsible Parties. Alternatively, balancing energy costs could be (partly) recovered through a system services tariff, which means that real-time balancing costs are socialized.

Imbalance pricing mechanism: The pricing mechanism that is used to determine imbalance prices. The simplest mechanism is that of 'single pricing'. In this design, the short imbalance price and the long imbalance price are identical, and are usually based on the balancing energy price in the main regulation direction. With 'dual pricing', the long and short imbalance price differ. Two important options exist here: 1) the two imbalance prices are based on the balancing energy prices in the two different regulation directions, and 2) the relevant balancing energy price is applied to the 'main imbalance direction' while the day-ahead spot price is applied to the other direction[14]. Single pricing is used in Germany, whereas option 1 of dual pricing is applied in the Netherlands (Grande et al., 2008), and option 2 of dual pricing is applied in the Nordic region (Nordel, 2007). In addition, different imbalance pricing rules can apply to different types of scheduled positions (production vs. consumption), different regulation states (predefined states that can be assigned to a STU based on volumes and/or patterns of upward and downward regulation during that STU), or different security conditions (e.g. for STUs in which emergency power had to be deployed). Furthermore, additive components could be added to the imbalance prices, or price caps could be imposed. Last but not least, imbalance prices could be calculated from the total balancing energy costs. This makes most sense in a balancing

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[14] If the system imbalance is negative (system shortage), the 'main imbalance direction' regarding BRP imbalances is also negative (BRP shortage), while the 'main regulation direction' is positive (mainly upward regulation has been activated).

market where pay-as-bid pricing is used for the remuneration of balancing energy, such as in Germany (50Hertz, 2009).

Ex-post trading: Ex-post trading enables Balance Responsible Parties to trade 'imbalance energy' with each other after real-time in order to mutually reduce their imbalance volumes. This implies that energy schedules are not yet definitive at final gate closure in case ex-post trading is applied. An example is Germany, where energy schedules can be adapted up to 4:00 p.m. on the day after delivery when concerning intra-energy exchanges (Bundesnetzagentur, 2006).

Penalty for non-delivery: Involves the charging of a penalty to Balancing Service Providers for the failure to deliver balancing energy called by the System Operator. This requires the measurement of the second-to-second power output of the corresponding balancing resources. The penalty will be in addition to the imbalance costs resulting from non-delivery, which may provide an extra incentive to deliver. Alternatively, it could remove adverse incentives to not deliver created by imbalance prices that are below operating costs (such incentives could result from cross-border balancing).

Allocation of net settlement sum: Allocation of the net income or expenditure from balance settlement at the system level. Often, the total imbalance costs paid by Balance Responsible Parties to the System Operator will exceed the balancing energy payments paid by the System Operator to the Balancing Service Providers. The difference of the two is the net settlement sum. This sum could be given back to system users through the system services tariff, as occurs in the Netherlands (Energiekamer, 2010), or to Balance Responsible Parties through adaptation of imbalance prices, such as in Germany (50Hertz, 2009). Alternatively, the net settlement sum could be redistributed to BRPs by means of separate fees, or it could be an income for the System Operator.

Timing of settlement: Balance settlement includes imbalance settlement and balancing services settlement, which both have a certain procedure. Relevant sub-variables are the frequency of settlement (periods over which the balancing service costs or imbalance costs are aggregated and settled in one transaction), and the time of settlement (the time lapse between the end of the aggregation period and financial settlement).

Balancing region level variables

General variables (multinational)

Balancing region boundaries: This design variable defines the boundaries of the balancing region, that is, which control areas are included in the group of control areas that has implemented (or is considering) some form of balancing market internationalization.

Organization SOs and regulators: The division of roles and responsibilities between different System Operators and regulators in the balancing region. A distinction can be made between roles and responsibilities regarding adaptation of the balancing market design (regulators and SOs), and regarding the operation of balancing market tasks (SOs). Increasing balancing market integration requires an increasing multilateral coordination between System Operators. Alternatively, regional balance management tasks can be performed by a Regional System Operator. This entity could be the central balancing service market operator. However, balance planning and settlement will continue to be control area-level processes administered by the respective SOs.

National vs. regional legislation: The division of legislation on balance management between the control area level and the balancing region level. With an increasing degree of balancing market integration, more balancing market elements will be shifted to the regional level, making a similar shift to regional legislation a logical option. Some issues regarding this variable are the embedding of balancing market rules in directives, laws and codes, the level of detail in these legal documents, the consistency of national vs. regional legislation, and the hierarchy in legislation (whether regional legislation prevails or not).

Publication of regional information: Concerns the accessibility, format, symmetry, and frequency of regional balancing market information that is distributed to BRPs, BSPs and SOs. Balancing market information can be either about the regional balancing market design itself, or about the regional balancing market results. This design variable also concerns the compatibility of national information with regional information.

Balance planning variables (multinational)

No multinational balance responsibility variables exist. After all, balance planning is carried out on a control area basis. Balance Responsible Parties must indicate cross-border trade transactions to the System Operator. The planning of all the cross-border exchanges is reflected in the exchange program of the control area.

Balancing service provision variables (multinational)

Control area boundaries: This design variable is about the geographical scope of system balancing. The definition of control areas sets the geographical boundaries relevant for the technical objectives of balance management. Separate balances are maintained for separate control areas, from which follows separate scheduling, service provision and activation, and settlement. Balancing market integration will reduce or remove these separate designs and activities. However, the existence of control area boundaries always requires separate energy schedules for separate areas, which are essential for control area balancing.

Geographical distribution of reserves: The geographical distribution of reserves is the regional equivalent of the control area design variable of 'reserve requirements', but shifts the focus to the relative and total size of reserved volumes in the balancing region, and to the safeguarding of security of supply in the entire balancing region.

Cross-border balancing arrangements: This variable concerns the choice for a specific cross-border balancing arrangement (system imbalance netting, BSP-SO trading, an additional voluntary pool, or a common merit order list), as has been defined and explained in subsection 3.1.2. In a balancing market integration process, a step-wise integration in which different arrangements are consecutively adopted is a logical development, because these arrangements represent different degrees of integration, and partially overlap. Such a development has taken place for the four German control areas in the period 2008-2010 (see subsection 2.3.3).

Reservation of interconnection capacity for balancing: This variable concerns the choice whether or not to reserve interconnection capacity to ensure its availability for the purpose of cross-border balancing.

Regional service provision rules: Depending on the implemented cross-border balancing arrangement, a certain amount of rules for balancing service provision have to be defined for the overall balancing region, in addition to, or replacing the national rules. For BSP-SO trading, no regional rules are needed. For an additional voluntary pool, such rules involve several to all balancing service provision variables, but the regional values would only apply to the additional pool. For a common merit order list, all variables are involved (except 'reserve requirements', which is already covered on the balancing region level by 'geographical distribution of reserves'). After all, the integration into one multinational balancing service market requires a single pricing mechanism, opening and closure time, bid procedure and bid requirements as well. However, it is possible that different bid requirements are used in different areas, as the case of the Nordic region shows (Nordel, 2008b).

Balance settlement variables (multinational)

Redistribution of balancing costs: This variable concerns the possibility of additional settlement of balancing costs between System Operators. In case of the cross-border arrangement of system imbalance netting, such redistribution may involve the pricing of exchanged surplus energy between control areas. In case of the cross-border arrangement of the additional voluntary pool, the exported balancing service bids are paid for by the reserve connecting SO, which necessitates that the reserve receiving SO pays the reserve connecting SO for exchanged balancing services. This can be considered a redistribution, considering that the price paid to the connecting SO may deviate from the price paid to the BSP. In case of a common merit order list, balancing energy bids that have been implicitly exchanged between control areas in the regional real-time balancing process must be settled between SOs. Here, not only pricing but also allocation of balancing energy exchange to different areas is an issue. Finally, the cross-border exchange of balancing energy bids may also call for some compensation of the reserve connecting SO for incurred reserve capacity costs associated with exported bids[15].

Settlement of area imbalances: This design variable concerns the entire synchronous zone, not so much the balancing region. It concerns the settlement of imbalances of control areas, i.e. unintentional deviations, between System Operators. The main options here are not to settle unintentional deviations, to compensate them physically (as occurs in ENTSO-E, see UCTE (2009b)), or to settle them financially.

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[15] The redistribution may lead to a net set settlement sum, which is covered by the variable 'allocation of net settlement sum'.

4 Analysis of national balancing market design and harmonization

In fact, balancing market harmonization comes down to the equalization of the design variable values of national balancing markets. This will not introduce any interaction between national balancing markets, because it does not establish cross-border balancing[1]. Therefore, the analysis of the impact of national balancing market design variables in this chapter will at the same time be an analysis of the possible impacts of balancing market harmonization.

In section 4.1, the most important system factors and interrelations within the national balancing market are analysed, including the links between the balancing market design variables, performance criteria and the performance indicators (all of which were introduced in chapter 3). Using the insights of this system analysis, the importance of the design variables is estimated in section 4.2, followed by an evaluation of the importance of the performance criteria in section 4.3. Based on this, a few design variables are selected that will be studied in more detail in section 4.4. As our focus is on the role of Balance Responsible Party, an agent-based analysis has been executed to analyse the impact of the imbalance pricing mechanism, being the main design variable that incentivizes BRPs to balance their energy portfolio. Next, in section 4.5, we discuss the possible 'context dependence' of the performance of balancing markets, i.e. dependency on contextual power system and market factors, which is taken into account in the further analysis. Then, in section 4.6, the design variables are analysed qualitatively by means of a multi-criteria analysis. The impact level of each design variable is studied, and the context dependence of effects as well. Furthermore, section 4.7 presents a case study, in which the impact of possible harmonization on balancing market performance in Northern Europe is evaluated. Here, the case-specific design, performance and context can be taken into account, allowing for a concrete impact assessment. Findings from this case study are reflected upon in the light of the generic multi-criteria analysis. Finally, all the above allows us to draw some conclusions in section 4.8 on the value (possible impact) of balancing market harmonization.

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[1] Harmonization could make it easier for BRPs to become active in other control areas, but balancing market operation remains distinct for separate control areas.

4.1 Factors and interactions within the balancing market

In this first section, the 'system' of the (national) balancing market is dissected, which forms the basis for the multi-criteria analysis in section 4.6. The system analysis starts in subsection 4.1.1 with the discussion of the system factors (or output variables) of the balancing markets, and the causal links between them. Then, in subsection 4.1.2, the main processes of the balancing market are described. This enables the linking of the balancing market design variables to these processes in subsection 4.1.3, which reveals the interaction between variables and system factors. After that, we study the relation between the balancing market performance indicators and the system factors in subsection 4.1.4. All of this finally enables the exploration of the influence of the design variables on the performance criteria in subsection 4.1.5.

4.1.1 System factors and causal links

The system analysis of factors and interrelations within electricity balancing markets is started up by drawing and exploring a causal loop diagram of the (national) balancing market (Kirkwood, 1998). See Figure 4.1. Depicted are the main system factors and causal relations between those factors, which is based on the description of the concept of the national balancing market (see subsection 3.1.1). The system factors can also be regarded as the main output variables of the balancing market. As such, the causal loop diagram describes the functioning, or mechanisms, of the balancing market.

Standing out in the causal loop diagram are three main feedback loops: the 'reserve capacity loop', the 'balancing energy loop', and the 'imbalance loop'. The first two correspond with the role of the Balancing Service Provider (BSP); the last corresponds with the role of the Balance Responsible Party (BRP).

In the **'reserve capacity loop'**, the *offered reserve capacity* obviously influences the *procured reserve capacity*: What is not offered, cannot be procured. However, there is no causal relationship, i.e. we cannot say that more offered reserve capacity leads to more procured reserve capacity[2]. However, more procured capacity does clearly lead to higher *reserve capacity costs*. In turn, higher costs incentivize BSPs to offer more reserve capacity. As this enhances competition in the reserve capacity market, bid prices may reduce, driving reserve capacity costs down again[3]. Due to reduced profits for BSPs, this may lead to lower amounts of offered reserve capacity, and so on and so forth. It can be seen that the reserve capacity loop is a negative feedback loop, which is fittingly also called a balancing loop (Kirkwood, 1998).

The second feedback loop is the **'balancing energy loop'**. The amount of *offered balancing energy*, which is of course positively affected by the amount of procured reserve capacity, determines how much balancing energy could be dispatched, but besides that does not have a causal link with the amount of dispatched balancing energy. Also, it negatively affects the height of the *balancing energy bid prices* as a result of a change in the level of competition in the balancing energy market (assuming that BSPs use market power to drive prices up). Higher bid prices obviously lead to a higher *regulation price*,

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[2] This however the case when not enough reserve capacity is offered to meet the reserve requirements.

[3] The depicted feedback loop is simplified, and does not include this. However, this loop is basically the same as the balancing energy loop, so the reader can compare with that one.

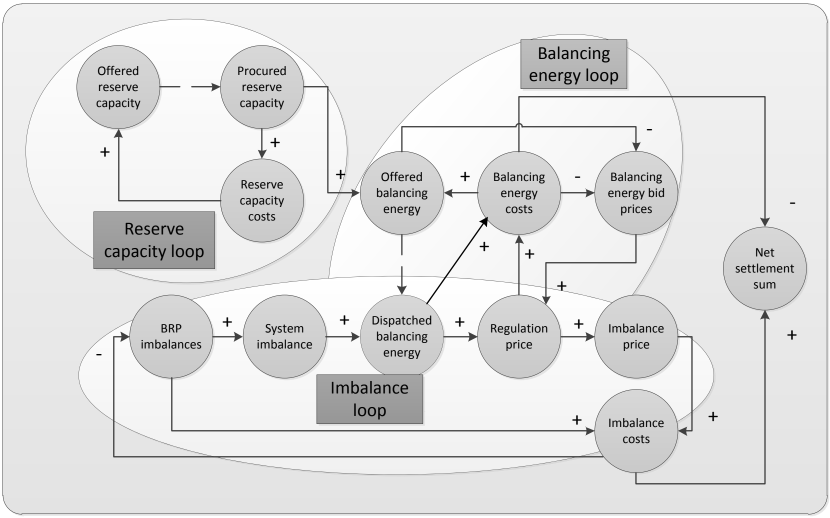

Figure 4.1 – Causal loop diagram of the balancing market. A circle represents a system factor; an arrow with a '+' represents a positive causal relationship; an arrow with a '-' represents a negative causal relationship; an interrupted arrow represents an influence relationship.

which in turn causes higher *balancing energy costs*. Higher costs mean higher profits for the BSPs, who are thereby incentivized to offer more balancing energy, and decrease bid prices to increase the likelihood of activation by the System Operator. Finally, there is a positive causal link between the *dispatched balancing energy* and both the regulation price and the balancing energy costs, because more activation means a larger volume to remunerate, but also a higher bid price of the marginally activated bid. We note that the balancing energy loop is also a negative feedback loop (a balancing loop).

In the third feedback loop, which is the **'imbalance loop'**, the combined result of the *BRP imbalances* is the system imbalance. Although a part of the BRP imbalances evens out on a system level, and BRP imbalances are energy imbalances (imbalances over the Schedule Time Unit) whereas the system imbalance is principally about the momentary power imbalance, it is generally true that higher BRP imbalances will cause a higher *system imbalance*. A higher system imbalance necessitates a larger amount of dispatched balancing energy, which (as mentioned above) pushes up the regulation price. And because the imbalance prices are directly based on the regulation prices (or the bid prices of activated bids in case of pay-as-bid pricing), a higher regulation price causes a higher *imbalance price*. The *imbalance costs* that BRPs are faced with are positively influenced by both the imbalance price and the BRP imbalances. Finally, higher imbalance costs incentivize BRPs to put more effort into balancing their energy portfolio, and thereby reduce their BRP imbalances, which will diminish imbalance costs. Ergo, the imbalance loop is also a negative feedback loop (a balancing loop).

A last system factor that is shown in the causal loop diagram in Figure 4.1 is the *net* *settlement sum*. As this sum is defined as the net cash value that remains after balancing energy settlement and imbalance settlement, lower balancing energy costs and higher imbalance costs lead to a higher net settlement sum.

Summary In summary, there are three 'balancing loops' in the balancing market, which form the core of the functioning of the balancing market. These loops constitute the incentive mechanisms that aim to provide appropriate incentives to market parties from a system perspective. As the incentives given to Balancing Service Providers to offer balancing services and to Balance Responsible Parties to balance their energy portfolio are 'self-balancing' due to the 'balancing loops', these mechanisms appear indeed to provide appropriate incentives.

4.1.2 Balancing market processes

A next step in the balancing market system analysis is the exploration of the effects of design variables on the system factors. In order to do this properly, and also to make this step more easy, an in-between step is the specification and positioning of balancing market processes. These processes are illustrated in Figure 4.2.

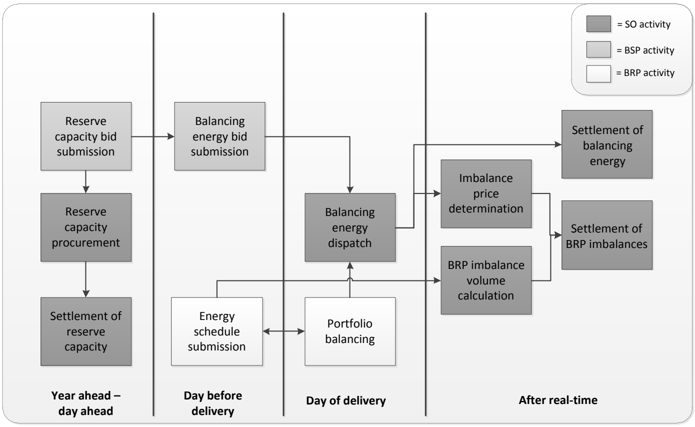

Figure 4.2 – Balancing market processes

The balancing market processes follow directly from the formulation of the concept of the national balancing market in subsection 3.1.1. There is however one process that requires some additional explanation. *Portfolio balancing* is the BRP activity of balancing the energy portfolio in order to minimize imbalance costs. It includes three main subactivities: forecasting generation and load, trading in short-term markets, and so-called '*internal balancing*', i.e. the real-time adjustment of generation and consumption within the BRP portfolio. A special instance of internal balancing is '*passive balancing*', which is the intentional creation of schedule deviations by BRPs by means of internal balancing, in order to make money from imbalance settlement (this is possible if single pricing is applied). The definitions of portfolio balancing, internal balancing and passive balancing are quite relevant for the multi-criteria analysis. Therefore, they have been added to the standard terminology list in appendix B, and will be used in the remainder of the thesis.

Balancing Service Providers submit reserve capacity bids to the System Operator, who procures and settles bids to meet the reserve requirements. The frequency of procurement can range from yearly to daily; different countries apply different frequencies. The submission of balancing energy bids by BSPs and of energy schedules by Balance Responsible Parties usually takes place on the day before delivery. On the day of delivery, BRPs can balance their energy portfolio by forecasting and trading on the intra-day market. In real-time, they can to this end also 'balance internally'. This reduces the amount of real-time 'active balancing' by the SO, i.e. the dispatch of balancing energy in order to restore the system balance[4]. After real-time, the System Operator determines the long and short imbalance prices per Schedule Time Unit (STU), calculates BRP imbalance volumes per STU on the basis of collected measurement values and scheduled positions of BRPs, settles imbalance volumes with BRPs, and settles balancing energy with BSPs.

Subsequently, these processes can be easily linked to the system factors in the causal loop diagram. See Figure 4.3. Self-explanatory are the links between the process of reserve capacity bid submission and the system factor of offered reserve capacity, between reserve capacity procurement and procured reserve capacity, between balancing energy bid submission and offered balancing energy, and between balancing energy dispatch and dispatched balancing energy. Furthermore, settlement of reserve capacity, balancing energy and BRP imbalances can be linked to resp. reserve capacity costs, balancing energy costs, and imbalance costs. Then, the process of imbalance pricing determination clearly corresponds with the imbalance price. And last, the processes of energy schedule submission, portfolio balancing and BRP imbalance volume calculation have a link with the system factor of BRP imbalances.

The nature of these links between processes and system factors differ a bit. There is no doubt that reserve capacity bid submission, reserve capacity procurement, bid energy bid submission and balancing energy dispatch completely determine offered reserve capacity, procured reserve capacity, offered balancing energy and dispatched balancing energy, respectively. However, the three settlement processes do not determine the level of the balancing service and imbalance costs; they just effectuate the payments made between the SO and the BRPs and BSPs. Furthermore, the imbalance price determination is just a process of deriving the imbalance prices from the regulation prices or costs, given the imbalance pricing mechanism used. Similarly, the BRP imbalance volume calculation is just the process of deriving the BRP imbalances from scheduled positions of BRPs and the measurement values. Finally, energy schedule submission and portfolio balancing are processes executed by the BRPs that have a large influence on the BRP imbalances, but do not completely determine this factor: There are always some forecast errors of consumption and generation that affect the BRP imbalance as well.

Wrapping up, a close linkage exists between the balancing market processes and the system factors (output variables), which will make the interlinking of design variables and processes a useful exercise to explore the influence of the variables on the system factors.

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[4] It should be noted, however, that BRPs use flexible resources for internal balancing that could have been offered to the SO. Also, internal balancing will often increase the system imbalance, which is far from efficient (Energinet.dk, 2009).

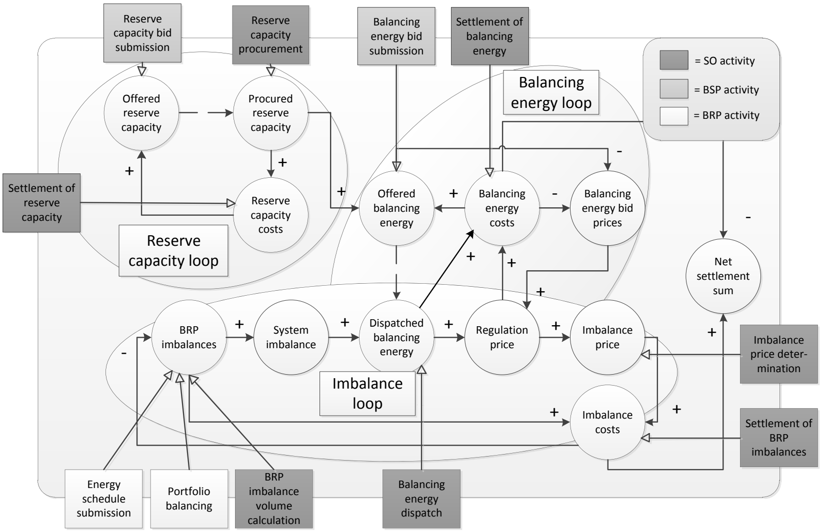

Figure 4.3 – The links between balancing market processes (rectangles) and system factors (circles) in the balancing market

4.1.3 Links between design variables and processes

The next step in the system analysis of the balancing market is the exploration of the links between the balancing market design variables and the balancing market processes, which reveals where and how the design variables interact with the general output variables (the system factors) of the balancing market. In Figure 4.4, the identified links are visualized. They will be shortly discussed below, grouped by process.

The processes of *reserve capacity bid submission* and *balancing energy bid submission* are affected by five national balancing service provision variables: methods of procurement, bid requirements, BSP accreditation requirements, timing of markets and service classes. It is easy to see that these variables set the most important market structures and rules for balancing service provision, and therewith the market opportunities for Balancing Service Providers. These thus have a major influence on the bidding behaviour of BSPs. The same holds for the multinational variable of regional service provision rules, as this variable deals with the same market rules regarding regional balancing service markets. The cross-border balancing arrangement also affects these rules, and thus BSP market opportunities and bidding behaviour. Moreover, balancing energy bid submission is influenced by the Schedule Time Unit, as this variable influences the strength of the incentive to Balance Responsible Parties, and thereby their inclination to keep balancing resources for portfolio balancing.

The process of *reserve capacity procurement* is influenced by two national variables and three multinational ones. The first national variable is the reserve requirements, which set the demand for the reserve capacity to be procured. The second is the control system, which requires the procurement of reserve capacity that can be handled by this system. The multinational variables are the geographical distribution of reserves, the control area

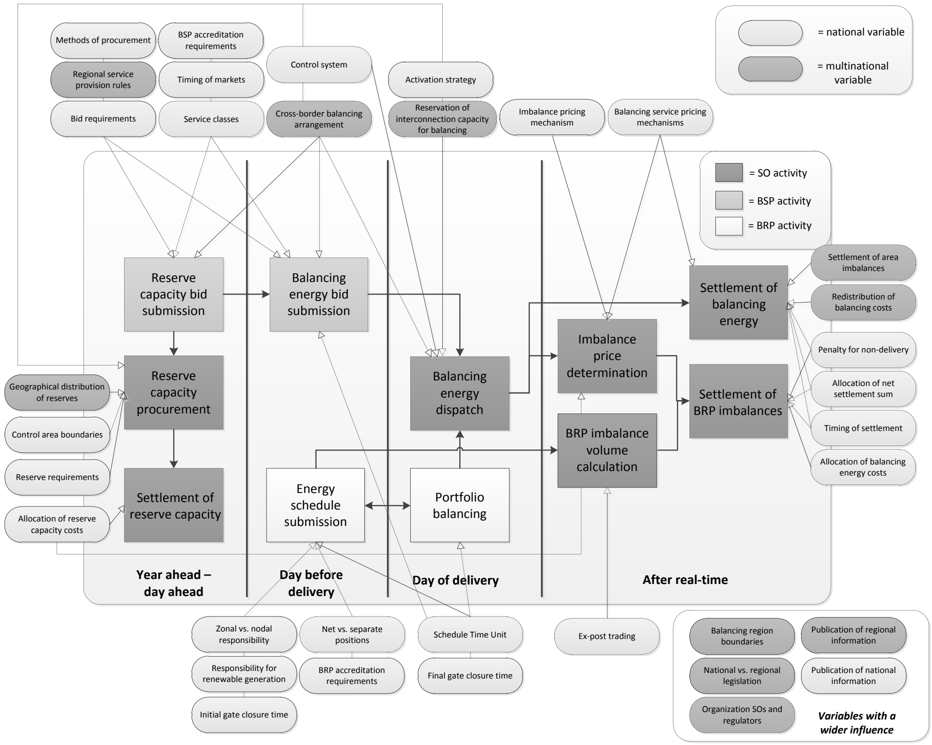

Figure 4.4 – Influence of balancing market design variables (rounded rectangles) on balancing market processes (rectangles)

boundaries, and the cross-border balancing arrangement. The geographical distribution of reserves deals with the coordination of the national reserve requirements. The control area boundaries is a fundamental design variable that delineates the power systems within the synchronous zone for which a separate system balance must be maintained, which has a major impact on the reserve requirements. The cross-border balancing arrangement may influence the options for System Operators to procure reserve capacity from abroad, or perhaps even reduce the procured volume as a result of lower balancing energy demand (due to system imbalance netting) and a higher availability of foreign balancing resources.

The process of *settlement of reserve capacity* is principally affected by the fundamental balancing market design variable of the allocation of reserve capacity costs. Naturally, whether this allocation occurs through the system services tariff or through imbalance settlement determines how this settlement is set up.

The process of *balancing energy dispatch* is affected by two national balancing service provision variables, and two multinational variables. The first national variable is the activation strategy of the System Operator, which affects the amount of activated balancing energy, as well as which bids are activated. The second is the control system, which affects what balancing energy bids can (best) be activated technically. The two multinational variables are the reservation of interconnection capacity for balancing and the cross-border balancing arrangement. The first influences the options for balancing service exchange, and the last impacts substantially on the need for balancing energy and the availability of balancing energy bids. Thereby, both have an effect on the amount and selection of balancing energy bids called by the System Operator.

The process of *settlement of balancing energy* is influenced by three national balance settlement variables and two multinational variables. The first national variable is the timing of settlement, which in this case concerns the time and frequency of the settlement of activated balancing energy bids. The second national variable is the allocation of the net settlement sum, which deals only with the remaining net sum after balancing energy and imbalance settlement. Third, the penalty for non-delivery is an additional imbalance penalty based on the failure to deliver balancing energy, and therefore links to both balancing energy settlement and imbalance settlement. The first multinational variable is the settlement of area imbalances, which can be considered a settlement of balancing energy between control areas. The second multinational variable is the redistribution of balancing costs, which is an additional settlement between System Operators to compensate for cross-border balancing.

The process of *energy schedule submission* is influenced by six national balance planning variables and a general national variable. Zonal vs. nodal responsibility is a fundamental design variable that determines whether one energy schedule must be submitted for the entire control area, or for different zones or nodes within that area. The responsibility for renewable generation determines who is balance responsible for renewable generation. If the market is fully responsible this generation must be scheduled by BRPs, and if the market is partially responsible separate energy schedules should probably be submitted. The initial gate closure time determines when BRPs must submit an initial schedule. Net vs. separate positions determines whether or not separate energy schedules should be submitted for energy production and consumption. BRP accreditation requirements determine the entry barriers of becoming a BRP, which affects the number and size of BRPs, and thereby the process of energy schedule submission (i.e. the number of submitted schedules, and the accuracy of the scheduled positions). The final gate closure time determines the time at which the energy schedules become final. The general variable affecting energy schedule submission is the Schedule Time Unit, which sets the time unit over which energy production and/or consumption should be scheduled.

The process of *portfolio balancing* is influenced by the final gate closure time and the Schedule Time Unit (STU). The final gate closure time determines until which time the Balance Responsible Parties can balance their energy portfolio by means of intra-day trade. The STU, vis-*à*-vis the time unit used in the intra-day market, determines the precision with which BRPs can balance their portfolio by means of intra-day trade. The STU length determines how accurate energy schedules should be, and thus also affects the degree of ‘internal balancing’ by BRPs.

The process of *BRP imbalance volume calculation* is affected by the national balance settlement variable of ex-post trading. Ex-post trading influences the BRP imbalance volumes by trading of opposite imbalances between BRPs after real-time, and thereby influences the BRP imbalance volume calculation.

The process of *imbalance price determination* is influenced by the balancing service pricing mechanism, the imbalance pricing mechanism, and the multinational variables of regional imbalance pricing and the allocation of reserve capacity costs. The balancing service pricing mechanism affects the imbalance pricing mechanism: When pay-as-bid pricing is used the imbalance pricing mechanism should be based on average prices, whereas the use of marginal pricing calls for marginal imbalance prices. Obviously, the imbalance pricing mechanism is the core design variable related to this process. Finally, the allocation of reserve capacity costs will significantly influence the imbalance prices if these costs are allocated to Balance Responsible Parties through imbalance settlement.

The process of *settlement of BRP imbalances* is influenced by four national balance settlement variables. The allocation of balancing energy costs is a fundamental design variable that is considered an intrinsic part of the balancing market. In that respect, this variable determines whether the balance planning and imbalance settlement processes exist in the first place[5]. The allocation of the net settlement sum determines how the remaining sum after balance settlement is redistributed, and will influence the imbalance price determination if the net settlement sum is allocated to BRPs through adaptation of imbalance prices. Third, the timing of settlement includes the time and frequency of settlement of BRP imbalances, and thus clearly affects this process. Last, the penalty for non-delivery is an additional imbalance penalty that links to both types of settlement, as mentioned above.

As a final remark, we just discussed the direct links between design variables and balancing market processes. Indirectly, every design variable influences all processes and system factors. After all, all variables and factors are interlinked, as follows from the causal loop diagram in Figure 4.1.

4.1.4 Links between system factors and performance indicators

The next step in the system analysis is to study the links between the system factors and the performance indicators, so that the interrelations between the design variables and the performance indicators are made completely visible. These links are visualized in Figure 4.5, and are shortly discussed below on the basis of the balancing market performance criteria.

The performance criterion *transparency* has performance indicators that cannot be specifically linked to any of the system factors (balancing market output variables), because these indicators are of a more general nature. The same holds for the performance indicators of the criteria of *non-discrimination*, *operational efficiency*, and *internationalization costs*.

The indicators of the performance criterion *availability of balancing resources* are however clearly connected to the balancing service volume factors, i.e. offered reserve capacity, procured reserve capacity, offered balancing energy, and dispatched balancing energy. The same can be said for *utilization efficiency* and *price efficiency*. This makes sense, because these three performance criteria deal directly with the provision and use of balancing services. The indicators of these last two criteria also relate to the balancing service costs factors. It is striking that the indicators of the ratio between procured and offered reserve capacity and the ratio between dispatched and offered balancing energy are indicators of both the availability of balancing resources and of price efficiency. Indeed, low ratios will

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[5] Therefore, this variable could have been linked to the processes of energy schedule submission, portfolio balancing, BRP imbalance volume calculation and imbalance price determination as well.

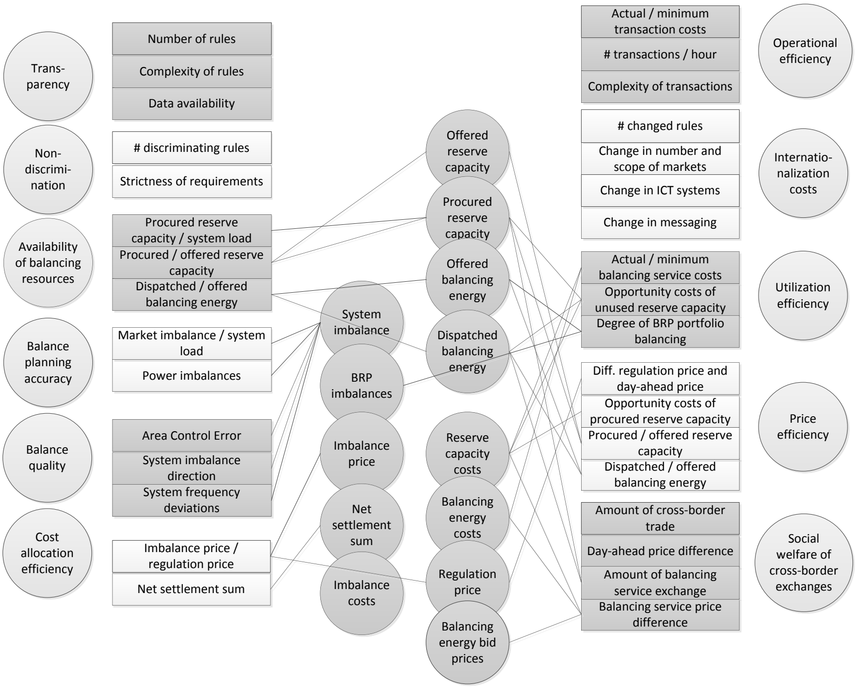

Figure 4.5 – Influence of system factors on balancing market indicators. A dark circle represents a system factor; a rectangle represents a performance indicator; a light circle represents a performance criterion.

indicate a high availability of balancing services and cost-reflective prices, thanks to a high level of competition in the balancing service markets.

Two performance indicators of *balance planning accuracy* have been identified before. These are the ratio between the market imbalance and the system load and the power imbalance, which both can be linked to the system factor ‘system imbalance’. *Balance quality* also has two indicators that can be connected to the system imbalance: the Area Control Error and the system imbalance direction.

The criterion *cost allocation efficiency* has two indicators: the ratio between imbalance price and regulation price, and the net settlement sum. The first obviously links to the system factors of the regulation price and the imbalance price, and the second is actually a system factor itself. Finally, some performance indicators of the *social welfare of cross-border exchanges* can be linked to the balancing service volume and costs factors.

4.1.5 Influence of design variables on performance criteria

Based on the above, the final step of the balancing market system analysis is the exploration of the influence of the balancing market design variables on the balancing market performance criteria. This exploration is summarized in Figure 4.6. Depicted are only the most important influences, which have been derived from the balancing market interrelations identified in the above system analysis. This exploration forms a first indication of the impact of balancing market design.

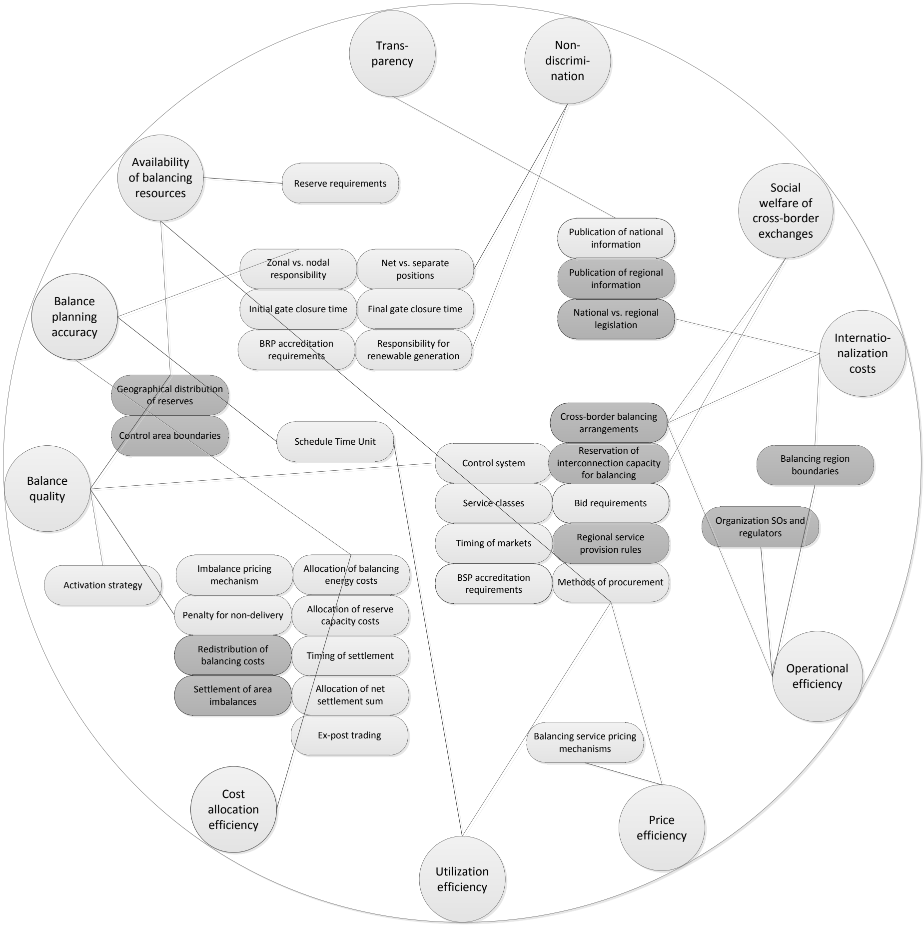

Figure 4.6 – Influence of balancing market design variables (rounded rectangles) on balancing market performance criteria (circles)

Three main groups of design variables can be discerned. The grouped balance planning variables mainly affect balance planning accuracy. The grouped balancing service provision variables mainly have an effect on utilization efficiency, price efficiency, and the availability of balancing resources. The grouped balance settlement variables mainly have an impact on balance planning accuracy and cost allocation efficiency.

There are some loose variables as well. The activation strategy affects balance quality. The balancing service pricing mechanisms principally affect the price efficiency. The organization of SOs and regulators has a main impact on operational efficiency. Balancing region boundaries have a large influence on internationalization costs and operational efficiency. The geographical distribution of reserves and control area boundaries impact on the availability of balancing resources and balance quality. The reserve requirements mainly influence the availability of balancing resources. The publication of national information, the publication of regional information and national vs. regional legislation have a predominant impact on transparency. Net vs. separate positions and responsibility for renewable generation are two variables that deal with non-discrimination. The general national variable of the Schedule Time Unit has an important influence on both balance planning accuracy and utilization efficiency.

The multinational design variable that is central to the establishment of balancing market integration, the cross-border balancing arrangement, is found to have an important influence on almost all performance criteria. Thus, this design variable appears to be not only central to multinational balancing market design itself, but also to its impact on balancing market performance.

Interrelations between design variables In order to carry out the multi-criteria analysis of design variables in section 4.6 and section 5.2, we should be aware of the interrelations between design variables. First of all, important interrelations exist between control area boundaries, the geographical distribution of reserves, national reserve requirements, the control system, service classes and bid requirements. Second, there is a direct relation between the regulation pricing mechanism (part of the balancing service pricing mechanisms) and the imbalance pricing mechanism. Third, there is a relation between the timing of markets and methods of procurement one the one side and regional service provision rules on the other side. Finally, there is a fundamental relation between the allocation of balancing energy costs and most other balance planning variables and imbalance settlement variables: If balancing energy costs are not allocated to BRPs through imbalance settlement, the purpose of balance planning shrinks to informing the System Operator of power transmission flows, and the imbalance settlement process disappears.

Interrelations between performance criteria In order to carry out the multi-criteria analyses, we should also be aware of the interrelations between performance criteria. If criterion A has a interrelation with criterion B, a design variable affecting criterion A would also affect criterion B. These interrelations should be taken into account. An important interrelation exists between the availability of resources and price efficiency. If the availability of resources increases due to an increase in the supply of balancing services and/or a decrease in demand for balancing services, competition in the balancing service markets will increase. In case there is imperfect competition (which is usually the case due to a low number of BSPs), price efficiency will be improved as a result. A second important interrelation chain exists between the three criteria related to security of supply. A high balance planning accuracy leads to lower imbalances and frequency deviations and thus higher balance quality. As a result, the sufficiency of the supply of balancing resources, i.e. the availability of balancing resources, will increase, further increasing balance quality.

4.2 Importance of design variables

Although interrelations and effects of design variables have been explored above, the order of magnitude of these effects have not yet been evaluated, whereas this evaluation is useful for the structuring of the general multi-criteria analysis of design variables below. A simple initial evaluation has been carried out based on the insights from the above system analysis, the results of which are listed in Table 4.1. In general, the higher the magnitude of the effects of a balancing market design variable on performance, the more important the design variable is. A differentiation is made between the balancing market design variables on the basis of a brief estimation whether their impact on performance is high, medium, or low.

Table 4.1 – Magnitude of impact of balancing market design variables

	General variables	Balance planning variables	Balancing service provision variables	Balance settlement variables
High impact	– Schedule Time Unit – Service classes – Balancing region boundaries	– Zonal vs. nodal responsibility	– Control area boundaries – Geographical distribution of reserves – Reserve requirements – Methods of procurement – Timing of markets – Cross-border balancing arrangements – Reservation of interconnection capacity for balancing – Regional service provision rules	– Allocation of reserve capacity costs – Allocation of balancing energy costs
Medium impact	– Publication of national information – Publication of regional information	– Responsibility for renewable generation – Final gate closure time – Net vs. separate positions	– Activation strategy – Balancing service pricing mechanisms – Control system – Bid requirements	– Imbalance pricing mechanism – Ex-post trading – Redistribution of balancing costs – Penalty for non-delivery
Low impact	– National vs. regional legislation – Organization SOs and regulators	– BRP accreditation requirements – Initial gate closure time	– BSP accreditation requirements	– Allocation of net settlement sum – Settlement of area imbalances – Timing of settlement

The uncovered hierarchy of design variables based on the level of impact on performance, along with the earlier system analysis, has brought us to select three national design variables for detailed study in section 4.4, and three multinational design variables for detailed study in chapter 5.

The selected national variables are the Schedule Time Unit, timing of markets, and the imbalance pricing mechanism. The Schedule Time Unit has a high impact on performance, and affects the portfolio balancing behaviour of Balance Responsible Parties in an uncertain way. The timing of markets is a more multi-faceted variable that has a high and ambiguous impact on the bidding behaviour of Balancing Service Providers. The imbalance pricing mechanism has been estimated to merely have a medium impact on performance, but it is the most important balance settlement variable, and its influence on BRP behaviour is rather obscure. From these three, the imbalance pricing mechanism is analysed quantitatively, whereas for the other two variables we present the analysis results of other researchers.

The selected multinational variables are control area boundaries, reservation of interconnection capacity for balancing, and cross-border balancing arrangements. These three all have a high impact on balancing market performance, and play a major role in balancing market integration. In addition, they do not have a straightforward influence on performance. The key variable of cross-border balancing arrangements is the main object of analysis in chapter 5, and will be analysed both qualitatively and quantitatively. Also, findings of other researchers are presented.

As can be seen, the detailed study of balancing market design variables is far from exhaustive. We concentrate on important design variables that have a complicated and intriguing impact on market behaviour and performance.

4.3 Importance of performance criteria

The final evaluation of the impact of harmonization and integration requires an appropriate weighing of performance criteria. After all, some performance criteria could be considered more important than others, necessitating the use of different weights for different performance criteria. To formulate and use a plausible set of weights, we have conducted a small survey under balancing market experts, which constitutes a simple form of expert validation of the balancing market criteria. The details of the expert validation can be found in appendix E. Based on this expert validation, we have decided to apply equal weights, and thus value all performance criteria equally high in the multi-criteria analyses (see appendix E).

4.4 Detailed study of national design variables

As described above, this section covers a detailed study of three core national design variables that have a large but obscure influence on the behaviour of market parties, namely the Schedule Time Unit (affecting BRPs), the timing of markets (affecting BSPs), and the imbalance pricing mechanism (affecting BRPs). The first two design variables have been studied by other researchers, and their results are summarized in subsection 4.4.1 and subsection 4.4.2. The variable of the imbalance pricing mechanism has been analysed by means of an agent-based simulation; the analysis and results are presented in subsection 4.4.3.

4.4.1 Schedule Time Unit

In his PhD thesis titled ‘Analysis of Balancing Requirements in Future Sustainable and Reliable Power Systems’, Jasper Frunt has included an analysis of the impact of the Program Time Unit (PTU)[6] on imbalances in a power system, and on the balancing efforts of the Transmission System Operator (TSO) and the Balance Responsible Parties (Frunt, 2011). Using load and imbalance data from the Netherlands in 2010, three types of imbalances have been modelled: ‘intra PTU imbalance’, ‘over PTU imbalance’, and ‘inter

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[6] This is the same as the Schedule Time Unit (STU) in this thesis.

PTU imbalance'. The intra PTU imbalance corresponds with the momentary power imbalance within the PTUs, as reflected by the Area Control Error (ACE), and forms the main balancing effort of the TSO. The over PTU imbalance corresponds with the energy imbalances of BRPs for entire PTUs, and forms the balancing effort of the BRPs. The inter PTU imbalance is the imbalance caused by the changes in (flat) dispatch schedules of generators from one PTU to the next, and the TSO is responsible for smoothing out this imbalance. In the modelling study, the prediction of load and the drawing up of generation schedules by BRPs have been simulated using the load data, and the three types of imbalances have been modelled for different PTUs, ranging from 8 seconds to 2 years.

The results of the modelling study show that shorter PTUs lead to smaller intra PTU imbalances, and at the same time to larger over PTU imbalances. Inter PTU imbalances are marginal for all PTU lengths. Therefore, the balancing effort for BRPs increases as PTUs get shorter, and decreases as PTUs get longer. For the TSO this is the other way around. Next to that, however, the total balancing effort increases with an increasing PTU. This is especially the case for the range from 1 hour to 1 day: "For PTU lengths longer than one day the combined effort remains almost equal due to the repetitiveness of load profiles in subsequent days." (Frunt, 2011). For PTUs of 1 hour and smaller, the combined effort stabilizes to about 2% of the yearly energy consumption. In this range, the effort of the TSO (intra PTU imbalance) decreases down to zero as PTUs become smaller.

In the light of currently applied Schedule Time Units, the results for the PTUs of 15 minutes, 30 minutes and 60 minutes are most interesting. The main results figure in (Frunt, 2011) shows that the total balancing effort is not much larger for 60 minutes than for 15 minutes (ca. 20%). More striking is the distribution between intra PTU imbalance and over PTU imbalance; this is about 60%-40% for a PTU of 60 minutes, about 35%-65% for 30 minutes, and about 30%-70% for 15 minutes. Furthermore, the change from a PTU of 60 minutes to a PTU of 15 minutes appears to increase the over PTU imbalance by less than half. Furthermore, the change from a PTU of 15 minutes to a PTU of 5 minutes appears to further increase the over PTU imbalance by something in the order of 10%.

Frunt (2011) does not draw a conclusion on the merits and demerits of different STUs. It is not easy to conclude which STU is better. Compared to a STU of 60 minutes, a STU of 15 minutes reduces the total balancing effort in the power system, but increases that of the BRPs. The latter does not only lead to higher imbalance volumes, the utilization of available balancing resources is likely to become less efficient, as BRPs keep more resources for internal balancing. As a result, less balancing resources are offered to the SO in the balancing energy market and price efficiency in this market could drop, which may increase the imbalance price level in spite of lower system imbalance volumes. Thus, it is unclear whether imbalance prices will increase or decrease; this depends on the level of competition in the balancing energy market, and the degree of balancing resource withholding for internal balancing. This also makes it unclear what will happen exactly with the imbalance costs of BRPs, if the STU reduces from 60 minutes to 15 minutes. However, considering the set of balancing market performance criteria, such a change does appear to reduce utilization efficiency. The effect on the availability of balancing resources and price efficiency is uncertain, because it depends on the degree of resource withholding. Of course, balance planning accuracy will increase, which likely contributes to an improvement of security of supply. The above considerations have been incorporated in the multi-criteria analysis of national design variables (see section 4.6).

4.4.2 Timing of markets

Alireza Abbasy, colleague in the project 'Balance Management in Multinational Power Markets', has written two papers dedicated to the design variable 'timing of markets'. See also Abbasy (2012).

In Abbasy et al. (2010b), the Dutch and German balancing service market designs and price levels of 2009 have been compared, and the observations have been used to draw conclusions and recommendations on the timing of balancing service markets.

The main differences between the Dutch and German balancing energy market for secondary control (SC) are that Germany applies a single SC tender in Germany that is cleared monthly[7], whereas the Netherlands has a separate balancing energy market (see subsection 2.1.1). As a result, the secondary control energy bid ladder in Germany is fixed for the whole month.

The comparison shows that German SC prices are much higher than the Dutch SC prices. The monthly average bid prices of activated German secondary control energy bids were 2-7 times higher than the monthly average German intra-day prices in 2009. If comparing the balancing energy bid ladders, the maximum SC bid price in the Netherlands of contracted bids (extracted by taking the 300 MW price indications on the TenneT website) does not go higher than three times the average intra-day price.

The two main reasons given by the authors for the higher prices in Germany are the higher uncertainties (lower forecast accuracy) and lost opportunity costs, both caused by the monthly procurement and corresponding fixation of the balancing energy bid ladder. As the balancing energy bid ladder is determined a month in advance, Balancing Service Providers are more uncertain about day-ahead and intra-day prices during the period to which the SC energy bids apply. Therefore, it is hard to predict what are the opportunity costs of not being able to sell energy in those markets, in case their bids in the SC tender are selected. These uncertainties convert into high bid prices. Another reason of the high prices in Germany may be the identified high level of market power of BSPs. However, the authors suggest that this market power may also be the result of the long time horizon and lower frequency of bidding in German balancing service markets, due to the higher entry barriers that result from the higher uncertainties and requirements in the SC market.

Concluding from the comparison, Abbasy et al. (2010b) make two general recommendations to improve economic efficiency in balancing service markets: 1) reducing the time horizon of the balancing service market, and 2) using the same frequency for the bidding procedure and the market clearance. Both are stated to improve market liquidity, and thereby allocative efficiency (utilization efficiency). Reduced entry barriers for offering bids will improve liquidity, and lower opportunity costs of bidding will reduce balancing service prices.

Finally, it is concluded that the frequency of bidding should be as close as possible to the frequency of market clearance, and it is recommended that the time horizon of the balancing energy market should equal the length of the Program Time Unit, and that a daily reserve capacity market should be introduced.

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[7] Since 27 June 2011 the tender has been taking place weekly (Amprion et al., 2011).

In Abbasy et al. (2010a), the effects of three different ways of coordinating a daily reserve capacity market with the day-ahead market on market volumes and prices are studied by means of an agent-based simulation. The three coordination options are simultaneous market clearing (case A), reserve capacity market clearing before day-ahead market clearing (case B), and day-ahead market clearing before reserve capacity market clearing (case C). The simulation model is dimensioned to the German market, in order to make the simulate case more realistic.

In the model, fixed values are assumed for the day-ahead market demand, the reserve capacity market demand, and total generation capacity. In total, 262 individual agents (BSPs; each owning one unit with a specific volume and marginal cost value) submit in each round one bid into each of the two markets. They decide each round on the distribution of their capacity between day-ahead market and reserve capacity market, and on bid prices. Price step sizes and volume step sizes are used, which leads to a gradual development of offered volumes and clearing prices in both markets over time. The agents take individual profits of previous rounds into account in the decision-making for the new round. Furthermore, a critical cost level is set. Agents with marginal costs above this level will be risk-prone, and try to influence the market price.

In the main analysis, a critical cost level is set at at 41.07 €/MWh, such that 50% of the agents (with the highest marginal costs) are risk-prone. The results are that prices in both markets become highest for case A, and lowest for case C. Case A is worst, because non-selected bids cannot be resubmitted into the other market. In case C, the reserve capacity price drops to zero, compared to a price around 15 euro/MW/hour for both other cases. This is because there are no operating costs involved in the provision of reserve capacity. Case B leads to a higher reserve capacity price, because of opportunity costs of not being able to trade in the day-ahead market that are incorporated in the bid. Moreover, the reduced competition in the day-ahead market in case B leads to a higher day-ahead price than in case C. Regarding offered volumes, case C leads to a two times higher offered volume into the reserve capacity market compared to case B and A, because all non-selected bids from the DA market are offered.

If the critical cost level is set at 44 €/MWh (resulting in less than 50% risk-prone agents), all market prices decrease compared to critical cost level of 41.07 €/MWh. This is because less agents try to influence the price. Also, the sequence of price levels have remained the same, with case A resulting in the highest prices and case C in the lowest, but the differences are more distinct. An additional simulation has been carried out to test the sufficiency of secondary control bids in the reserve capacity market. The results are that enough secondary control is offered. However, the authors emphasize that the sufficiency of generation capacity for balancing highly depends on the generation portfolio (costs and volumes), which means that the decision to clear the reserve capacity market after the day-ahead market, as the analysis results suggest, should be made on a case-specific basis. Nevertheless, the tertiary control market is generally recommended to be cleared after the day-ahead market, because of the lower requirements and higher supply of this balancing service class.

The authors conclude that “the coordination of timing of the reserve capacity and day-ahead markets plays a decisive role in the offered capacities and the market clearing prices, by changing the behaviour of generators who bid in the two markets” (Abbasy et al., 2010a). Thus, it is concluded that this aspect of the design variable of the timing of markets has a large impact on balancing service market performance. Also, this conclusion suggests that, in order to properly study the impact of balancing service market design, the influence of this design on BSP behaviour should be taken into account. Finally, the analysis shows that different balancing market design variable values can have counter-intuitive effects, emphasizing the complexity of balancing market design and the importance of careful design and analysis of balancing market design options.

4.4.3 Imbalance pricing mechanism

This subsection is based on our work presented in van der Veen et al. (2012), and is an extension of earlier work presented in van der Veen, Abbasy and Hakvoort (2010c).

Use of Agent-Based Modelling for balancing market analysis Agent-Based Modelling (ABM) is a relatively new modelling paradigm that focuses on the modelling of individuals who can make decisions. In an agent-based model, these individuals are represented as agents, and individual behaviour is formalised using algorithms (van Dam, 2009). Agent-based models have been applied in social sciences, but also in the evolution of industrial clusters and in energy markets (Chappin, 2011). In Weidlich and Veit (2008), a survey of agent-based modelling studies within the field of electricity markets is presented, with researched sub-topics including strategic bidding, market power, and uniform vs. pay-as-bid pricing.

The main perspective of ABM is that of bottom-up and autonomous decision making, which is of particular use in case individual decision-making results in interactions between agents and with the system, and in emergent system-level behaviour. Weidlich and Veit (2008) state that "Agent-based Computational Economics researches the two-way feedback between regularities on the macro level and interaction of actors on the micro level". A balancing market has an agent (BRP/BSP) level and a system (SO) level, and includes a feedback between individual decisions and system-level observables, which puts forward the suitability of ABM (of which Agent-based Computational Economics is a subset) for the analysis of balancing markets. Most importantly, it is the large dependency of balancing market performance on the behaviour of Balance Responsible Parties (BRPs) and Balancing Services Providers (BSPs) that makes ABM a suitable methodology (see section 4.1). The generic balancing market output variables of system imbalance volumes, procured balancing service volumes, balancing service prices and costs, and imbalance prices and costs, are the result of the combined behaviour of bidding strategies of BSPs and portfolio balancing strategies of BRPs.

In the national balancing market, it is first and foremost the interaction between individual agents on the one hand, i.e. BRPs and BSPs, and system output on the other hand, i.e. balancing market prices, costs and profits, that plays a role. On a STU-to-STU basis, the balancing energy feedback loop and the imbalance feedback loop from Figure 4.1 represent this interaction. In this research, we are especially interested in the influence of BRP behaviour, which has to our knowledge not been modelled before. BRPs' portfolio balancing strategies clearly affect balancing market performance. The agent-based simulation of balancing markets, incorporating BRP strategies, will create insights into the influence of BRP behaviour, and into the impact of design variables. Here, we analyse the impact of the imbalance pricing mechanism. In section 5.4, the impact of cross-border balancing arrangements for the case study of Northern Europe will be analysed with ABM.

Agent-based analysis of impact of imbalance pricing mechanism In order to analyse the impact of the imbalance pricing mechanism, an agent-based model has been built in MATLAB that forms a simplified representation of the balancing market, with the focus on imbalance settlement. This means that the impact of this design variable on the behaviour of Balance Responsible Parties is taken into account, but that the balancing energy bids from Balancing Service Providers are assumed to be fixed. In order to make the model as realistic as possible, the input of the model has been dimensioned to the Dutch balancing market design, characteristics and results.

Model structure The structure of the agent-based model is shown in Figure 4.7. Basically, the imbalance feedback loop from Figure 4.1 is incorporated in the model, with the BRPs as agents, the imbalance pricing mechanism as an input parameter, the intentional imbalance volume of the BRP (level of over/under-contracting) as the decision variable, the individual Actual Imbalance Costs as the decision criterion, and the upward and downward regulation bid ladders as fixed input. A general distinction is made between 'unintentional imbalances' of BRPs and 'intentional imbalances' of BRPs. The first is based on a generation and consumption forecast error, and the BRPs have no influence on this. The second is a deliberate over/under-contracting of energy, which can be useful as a hedging strategy against financial imbalance risks.

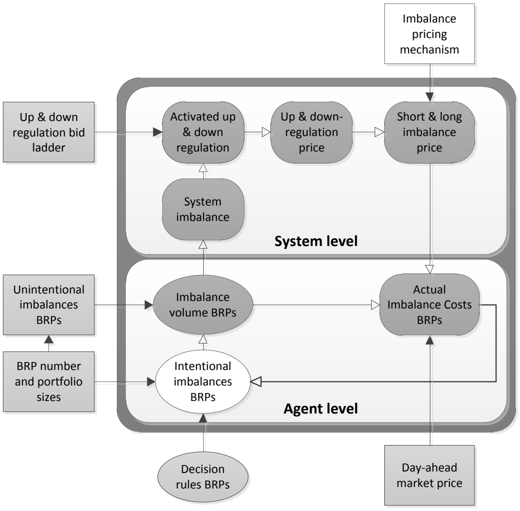

Figure 4.7 – Structure of the agent-based balancing market model, which is used to analyse the impact of the imbalance pricing mechanism, taking into account the behaviour of Balance Responsible Parties.

Model assumptions In the model, Balance Responsible Parties (BRPs) make a choice out of a fixed set of intentional imbalance options (which includes zero) in each round. A round is equal to a Schedule Time Unit. This is the only decision variable[8]. The intentional imbalance options represent different levels of over/under-contracting. Over/under-contracting is a means for BRPs to influence their imbalance volume, in order to hedge against the financial risks of imbalance settlement. The resulting 'Actual Imbalance Costs (AIC)' are calculated by taking the difference between imbalance price and day-ahead price (see below). Furthermore, BRPs will make a new decision only after processing the information that the execution of the last round provided. It is assumed that the creation of an intentional imbalance by means of over/under-contracting will be achieved by trading in the day-ahead market. A further explanation of the use of the AIC is given below. Another assumption is that marginal pricing is applied in the balancing energy market. Therefore, the imbalance prices are based on marginal regulation prices, i.e. the bid prices of the last activated balancing energy bids in price order.

Model input A first input assumption concerns the number and portfolio size of Balance Responsible Parties. Different BRPs are indicated by different rows in an input matrix (MATLAB variable). The portfolio size (in MW) is a BRP-specific property that represents the total capacity of production and consumption connections the BRP has balance responsibility for. The standard deviation of the forecast error that is used to calculate unintentional imbalances, which is a second input assumption, is also a BRP-specific property. Thirdly, a fixed day-ahead market spot price is assumed (in €/MWh), and fourth, fixed upward and downward regulation bid ladders are assumed. These bid ladders consist of multiple balancing energy bids, with each bid containing a bid volume (in MW) and a bid price (in €/MWh). These bids are ranked in order of increasing bid price (upward regulation) or decreasing bid price (downward regulation). A fifth input assumption concerns all the decision rules that are applied by the BRPs to decide upon an intentional imbalance volume each round, which is represented by the decision-making algorithm (see below). The most important input is formed by the imbalance pricing mechanism, the object of analysis. This is embedded in the model in the form of alternative imbalance pricing rules. In addition, some more detailed parameters concern the activation of dual pricing, the activation of the additive component, and the size of the additive component (see below).

Alternative imbalance pricing mechanisms Six imbalance pricing mechanisms have been analysed with the agent-based model. These are represented by six cases. Case 1 is the reference case, from which the five other cases have been adapted. For two cases, some sub-cases have been defined. The cases are the following:

- Case 1) *Single pricing*. The long imbalance price and short imbalance price are identical, namely the marginal regulation price in the main regulation direction[9].

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[8] This means that the agents do not receive any real-time information regarding the development of the system imbalance, which could trigger passive balancing.

[9] The main regulation direction is upward when there is a negative system imbalance (system shortage), in which case the imbalance price under the single pricing regime is equal to the bid price of the marginally activated upward regulation bid. When there is a system surplus, the imbalance price is the marginal downward regulation price.

BRPs with a surplus receive this price, and BRPs with a shortage pay this price.

- Case 2) *Dual pricing*. If both upward and downward regulation are activated ('two-sided regulation'), the short imbalance price is the upward regulation price and the long imbalance price is the downward regulation price. If regulation occurs in only one direction, single pricing is applied (see appendix F).
    - 2a) *Low activity*: Two-sided regulation occurs in a low number of STUs
    - 2b) *Medium activity*: Two-sided regulation occurs in a medium number of STUs
    - 3b) *High activity*: Two-side regulation occurs in a high number of STUs
- Case 3) *Two-price settlement*. The imbalance price for BRP imbalances in the same direction as the system imbalance is based on the marginal regulation price of the main regulation direction, but the other imbalance price is equal to the day-ahead market price. This means that the day-ahead market price is applied to the BRPs who passively contribute to system balance restoration (are helping the system).
- Case 4) *Additive component*. For the STUs in which a security-related criterion is met, an additive component is added to the short imbalance price and subtracted from the long imbalance price, turning the single pricing regime into a dual pricing regime. The criterion is here that the system imbalance exceeds a certain threshold (see appendix F).
    - 4a) *Low component & low activity*: The additive component is low, and activated in a low number of STUs due to a high system imbalance threshold.
    - 4b) *Low component & high activity*: The additive component is low, and activated in a high number of STUs due to a low system imbalance threshold.
    - 4c) *High component & low activity*: The additive component is high, and activated in a low number of STUs due to a high system imbalance threshold.
    - 4d) *High component & high activity*: The additive component is high, and activated in a high number of STUs due to a low system imbalance threshold.
- Case 5) *Imbalance pricing based on total costs*. In this case, the imbalance price is not based on the marginal regulation price, but on the total balancing costs, i.e. the total costs for the System Operator of activating balancing energy in both regulation directions. The imbalance price, which is the same for both BRP imbalance directions, is calculated by dividing the net total balancing costs (in euro) by the net activated balancing energy (in MWh). Finally, imbalance price limits are set, which are equal to the marginal upward and downward regulation price.
- Case 6) *Alternative payment direction*. The long imbalance price is applied to BRP surpluses and the short imbalance price to BRP shortages, but the direction of payment changes. Normally, BRPs pay when they are short and receive when they are long; in this case they receive when the BRP imbalance is opposite to the system imbalance (i.e. when the BRPs help to balance the system) and they pay when the BRP imbalance is in the same direction (i.e. when the BRPs cause the system imbalance).

The included mechanisms are based on existing designs in European balancing markets. Single pricing is applied in e.g. Spain and Greece (ETSO, 2003). Two-price settlement is applied in the Nordic region. Dual pricing and an additive component are applied in the Netherlands (Grande et al., 2008). However, dual pricing is only active in the Netherlands when a specific 'regulation state' has occurred, which was the case in about 10% of the STUs in 2009 (TenneT, 2011). Moreover, the additive component, called the 'incentive component' in the Netherlands, is almost always zero, as the criteria for its activation (increase) are usually not met (cf. TenneT (2011)).

To explore the impact of the 'degree of activation' on imbalance prices in case of dual pricing (case 2), which depends on the number of STUs in which both upward and downward regulation bids have been activated, three sub-cases are included with different degrees. For a similar reason, four sub-cases are included for the additive component (case 4), with different component sizes and degrees of activation. Imbalance pricing based on total costs is applied in Germany (50Hertz, 2009). It should be noted, however, that Germany applies pay-as-bid pricing to the pricing of regulation bids, whereas in this analysis marginal pricing is assumed to be used. An alternative payment direction is to our knowledge not applied anywhere, but is an interesting hypothetical design, that is based on the thought that alleviating the system imbalance should be rewarded and aggravating the system imbalance should be penalized.

Model steps The different model steps are shown Figure 4.7. The first model step in a round (STU) is the selection of an intentional imbalance option (in MWh) out of a fixed set of options by each BRP. This is the only decision that the agents need to make. The intentional imbalance options are represented by percentages; the options for a BRP will equal the product of the intentional imbalance percentage, the portfolio size (in MW) and the STU length (in hours). Then, a forecast error of actual generation and consumption (in MWh) is determined for each BRP by drawing a value out of a normal distribution with a mean of zero and a BRP-specific standard deviation. The unintentional imbalance is then the product of the forecast error, the BRP portfolio size and the STU length. The sum of the unintentional imbalance and the intentional imbalance of a BRP is his BRP imbalance. The net sum of all BRP imbalances equals the system imbalance (in MWh). Furthermore, the sum of BRP surpluses (positive BRP imbalances) is the 'market surplus' (in MWh), and the sum of BRP shortages (negative BRP imbalances) is the 'market shortage' (also in MWh). Subsequently, the activation of upward and downward regulation is based on the absolute and relative size of the market surplus and the market shortage, given the detailed input parameter settings that concern this calculation (see appendix F). Based on the activation of upward and/or downward regulation, marginal regulation prices for upward and downward regulation are determined.

Next, depending on the imbalance pricing mechanism, the long and short imbalance price are determined for the active round, applying the active imbalance pricing rules. The next step is the calculation of the Actual Imbalance Costs (AIC) for each BRP. The AIC is calculated by multiplying the BRP imbalance volume with the difference between the relevant imbalance price and the day-ahead price. The AIC better reflect the actual costs of imbalances for BRPs than simply the imbalance costs[10], because failing to buy/sell energy

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[10] The imbalance costs are the costs that are settled between the BRPs and the SO, and the product of the BRP imbalance volume and the relevant imbalance price (long or short) for each STU, aggregated over all STUs.

to balance the energy portfolio on the day ahead saves/incurs the costs the BRPs would bear if they had 'traded away' the imbalance on the day ahead of delivery. The use of the day-ahead price means we assume that trading on the day-ahead market is the alternative to leaving an imbalance, and that an intentional imbalance is created by over/under-contracting in the day-ahead market[11]. The AIC is calculated for the active round, for each BRP, according to Equation 4.1.

$$AIC_{n,m} = \begin{cases} (P_{si,m} - P_{da}) \cdot Q_{imb,n,m} & \text{if} \quad Q_{imb,n,m} < 0 \\ (P_{da} - P_{li,m}) \cdot Q_{imb,n,m} & \text{if} \quad Q_{imb,n,m} > 0 \\ 0 & \text{if} \quad Q_{imb,n,m} = 0 \end{cases} \tag{4.1}$$

In this equation, $AIC_{n,m}$ are the actual imbalance costs for BRP n in round m (in €), $P_{si,m}$ is the short imbalance price in round m (in €/MWh), $P_{li,m}$ is the long imbalance price in round m (in €/MWh), P_{da} is the day-ahead market price (in €/MWh), and $Q_{imb,n,m}$ is the imbalance volume of BRP n in round m (in MWh).

Finally, the expected AIC for all different intentional imbalance options are calculated for each individual BRP. These expected AIC values form an input for the decision upon an intentional imbalance option in the next round. This calculation is described below.

Model output Some important economic indicators for balancing market performance in relation to imbalance settlement are the total AIC aggregated over all BRPs and over all rounds (€) and the average AIC for different intentional imbalance options (considering all BRPs and all rounds) (€). Furthermore, the actual imbalance penalty (€/MWh), hereafter called 'penalty', is also of interest. The penalty for BRP surplus indicates the average costs of having a 1 MWh surplus as a BRP, and is calculated as the average of the day-ahead market price minus the long imbalance price over all rounds. The penalty for BRP shortage is calculated as the average of the short imbalance price minus the day-ahead market price over all rounds. This is similar to the calculation of the AIC, see Equation 4.1. Important operational security of supply indicators are the average system surplus (MWh), the average system shortage (MWh), the occurrence of system surplus (%) and the occurrence of system shortage (%).

Decision-making algorithm A crucial model assumption relates to the decision rules the BRPs apply to choose a specific intentional imbalance option in each round, i.e. the decision-making algorithm. A rich variety of learning algorithms exists in agent-based modelling literature, which often include a lot of parameters. It is usually not argued why a specific learning algorithm should be applied, or why it would generate better results than simpler algorithms. We have chosen to apply a simple algorithm based on the Erev-Roth reinforcement learning algorithm, which takes into account the relative performance of different actions, and values the results of recent rounds more (Erev and Roth, 1998; Weidlich and Veit, 2008). This algorithm has been used a lot by researchers, also for

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[11] Actually, over/under-contracting taking into account the most recent STUs would imply trading in the intra-day market. Intra-day prices are typically higher than day-ahead prices. The use of a higher intra-day price would lead to lower AIC for BRP shortages, but higher AIC for BRP surpluses, so its effect on total AIC may be limited.

agent-based simulation of electricity markets, and integrates the aspects of experimentation and forgetting (Weidlich and Veit, 2008). Each round, agents choose from a fixed set of options proportional to the expected utility of these options (experimentation), where expected values are calculated based on the result of past rounds (learning), and the results of recent rounds are weighed more (forgetting).

The incorporated decision-making algorithm lets the BRPs strive for low Actual Imbalance Costs. For each option, each BRP calculates an expected AIC value. At the end of a round, the expected AIC value for the option that the BRP selected in that round is updated. This involves a 'recency parameter', which makes the results of more recent rounds weigh heavier in the decision-making of the BRPs (Nicolaisen et al., 2001; Weidlich and Veit, 2008). For each round and each BRP, the expected AIC of the selected intentional imbalance option in that round is updated according to Equation 4.2:

$$E(AIC)_{n,X} = \frac{E(AIC)_{n,X} \cdot \rho + AIC_{n,r,X}}{\rho + 1} \tag{4.2}$$

In this equation, $E(AIC)_{n,X}$ is the expected AIC for BRP n for option X (in €), ρ is the recency parameter, and $AIC_{n,r,X}$ is the Actual Imbalance Costs for BRP n in active round r (in €) that is related to option X selected in that round. The final choice of a BRP for a specific option occurs through a draw from a probability distribution function, with probabilities being inversely proportional to the expected AIC of the different intentional imbalance options. We have opted for this, because choosing the option with the minimum expected AIC could lead to the selection of the same option during most of the simulation run, right from the start of the run. This would result in bad estimations of the relative value of different options. It can be said that, thanks to the included decision rules, the agents in the simulation keep on experimenting, while they also keep on learning from the results of past rounds and make informed decisions based on those results.

Input parameter values The input parameter values that are used in the model simulation are presented in appendix F. Most importantly, there are ten BRPs with different portfolio sizes, and there are seven intentional imbalance options, represented by percentages of the portfolio size, namely -2%, -1%, -0.5%, 0%, 0.5%, 1% and 2%. Furthermore, the simulation run length is 1,000 rounds, with each round equalling a STU of 15 minutes (as is the case in the Netherlands), the recency parameter is 0.9, and the day-ahead price is 36 €/MWh.

Analysis results – overview In the model simulation, 50 runs have been executed per case, and the averages of the results of those runs have been calculated. The results are listed in Table F.3 and Table F.4 in appendix F. This appendix also includes a model validation, on the basis of a comparison of the simulation results with balancing market results from the Netherlands in 2009. The significance of the difference between cases is indicated by the standard deviations of the total AIC values across runs, which are small compared to the differences between the average total AIC values of different cases.

As BRPs learn throughout the rounds about the financial risks of different balancing strategies (i.e. intentional imbalance options), they optimize their balancing strategies, leading to a kind of 'balancing market equilibrium' that results in the lowest imbalance costs for the market as a whole[12]. On overall, the results of different cases are not very dissimilar, indicating that this balancing market equilibrium is not affected to a very large degree by the choice of the imbalance pricing mechanism.

Looking first at the size and occurrence of system surpluses and shortages, we find that these are quite similar for the different cases, which signifies that the imbalance pricing mechanisms give similar incentives to Balance Responsible Parties, i.e. the relative height of expected AICs for different intentional imbalance options is similar for different mechanisms. On the other hand, the total AIC, i.e. the total actual imbalance costs aggregated for all BRPs and all rounds, are quite different for different cases: The difference between the highest value (case 2c) and the lowest (case 1) is more than one million euro, which is about 61% of the total AIC of case 1. Furthermore, the average penalties vary quite a bit, and only weakly correlate with the earlier-mentioned indicators.

The main conclusion of the analysis is that the imbalance pricing mechanism has a large effect on the total Actual Imbalance Costs, as BRP shortages and surpluses are priced differently depending on the adopted mechanism. Regarding the balancing strategies of Balance Responsible Parties, it can be concluded that BRPs should apply a strategy of slight over-contracting, because this generally leads to the lowest AIC. Regarding the choice between imbalance pricing mechanisms, single pricing (case 1) comes out as the mechanism with the lowest AIC for BRPs and for the market as a whole, while system imbalance volumes and directions are the same as for the other mechanisms.

Analysis results – elaboration The occurrence of system surpluses is shown in Figure 4.8. It can be seen that in all cases (imbalance pricing mechanisms) a dominant occurrence of system surpluses exists (i.e., in more than 50% of the STUs a system surplus occurred). This shows that on overall Balance Responsible Parties have a positive imbalance, and that the imbalance pricing mechanism does not change this. However, there are small deviations in the dominance of system surpluses: from 57.6% in case 1 down to 51.4% in case 6. Considering that a system surplus poses a lower threat to security of supply than a system shortage, case 1 (single pricing) appears to provide the best result for this indicator. Below, it is explained why there is a dominant system surplus.

The total AIC values for different cases are illustrated in Figure 4.9. As can be seen, single pricing (case 1) comes out as the cheapest imbalance pricing mechanism for the market, followed by the additive component (case 4), imbalance pricing based on total costs (case 5), the alternative payment direction (case 6), and finally two-price settlement (case 3) and dual pricing (case 2) as the most expensive mechanisms. More in-depth results follow below. The average Actual Imbalance Costs of different intentional imbalance options deserve special attention. As it turns out, the relative height of average AICs (generalized over the BRPs) is very similar for the different cases. The typical proportion of average AICs is shown in Figure 4.10, which depicts the average AICs for case 1.

For all imbalance pricing mechanisms, large intentional imbalances result on average in higher AICs than small ones, and negative intentional imbalances result on average in higher AICs than positive ones. The first is obvious, as imbalances on overall create costs

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[12] Due to the implemented decision-making algorithm, this is only the case to a limited extent. See the paragraph on the algorithm.

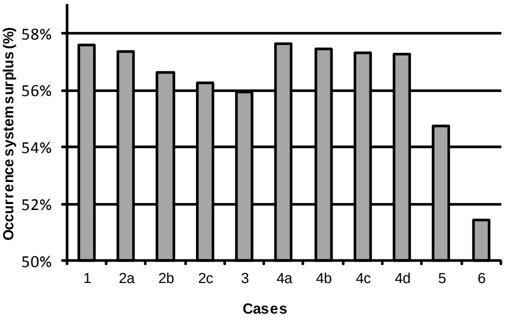

Figure 4.8 – Agent-based analysis results: Occurrence of system surpluses

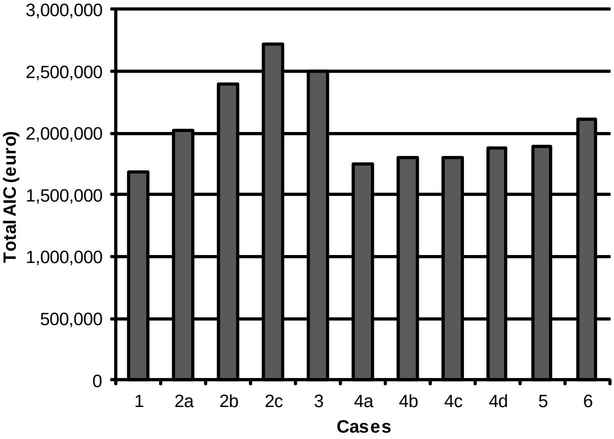

Figure 4.9 – Agent-based analysis results: Total Actual Imbalance Costs for different cases

for BRPs, and are settled per MWh of imbalance. The latter can be explained by the fact that negative BRP imbalances are often settled with an imbalance price that is equal to the marginal upward regulation price. Because the bid prices (costs) of upward regulation are higher than those of downward regulation, the short imbalance prices will be further from the day-ahead price than the long imbalance prices, making BRP shortages more costly than BRP surpluses. The reason why the average AICs are positive, while AICs can be negative and create income for BRPs, is that the majority of the BRPs will be in the 'wrong direction', i.e. have a BRP imbalance in the same direction as the system imbalance.

The simulation results show that the number of times that different options were selected is inversely proportional to the average AIC values shown in Figure 4.10. This is the result of the incorporated decision-making algorithm (see above).

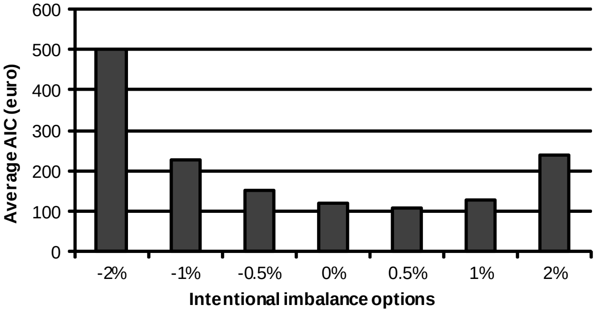

Figure 4.10 – Agent-based analysis results: Average Actual Imbalance Costs for case 1

The average actual imbalance penalties for BRP surpluses and BRP shortages for the six different cases are presented in Figure 4.11. We observe that the size of the penalties is not proportional to the size of the total AICs shown in Figure 4.9. This is because the average penalties do not take into account the imbalance volumes. Furthermore, it can be seen that the average costs of a BRP surplus are for most imbalance pricing mechanisms considerably lower than the average costs of a BRP shortage, which is in line with the relative height of average AICs shown in Figure 4.10. The imbalance pricing mechanisms that are most expensive to the market, dual pricing (case 2) and two-price settlement (case 3), also have the highest average penalties for surplus and shortage.

A last interesting indicator is the imbalance costs uncertainty indicator (see Table F.4). This uncertainty indicator is calculated by taking the difference between the penalty for system surplus and BRP surplus and the penalty for system surplus and BRP shortage, doing the same for the penalties for system shortage, and taking the average of both resulting values. The indicator shows that the financial imbalance risks for BRPs are lower for dual pricing and two-price settlement than for single pricing and the additive component, although the average AICs are much higher. For case 5 and 6, the uncertainty on imbalance costs is another negative aspect, next to the high Actual Imbalance Costs (compared to single pricing).

The above results are taken from a systems perspective. However, it is also interesting to look at the analysis results from a BRP perspective, and study the importance of portfolio size. Comparing the relative height of the average AICs of different options for different BRPs, we find that large BRPs have a more stable preference order of options. This preference order is the same as shown in Figure 4.10: Small and positive imbalances are less costly than large and negative imbalances. For small BRPs often very different pre-

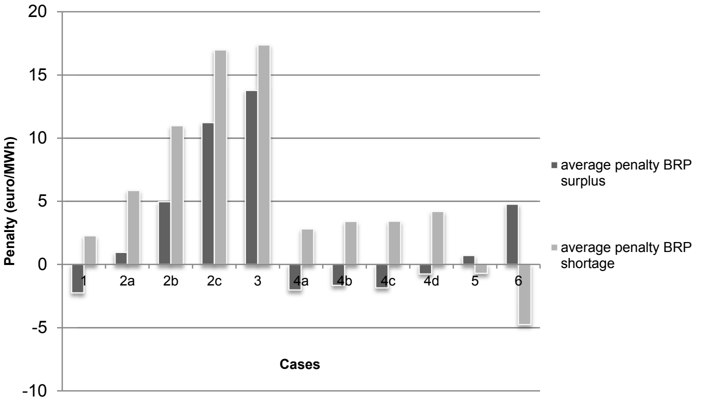

Figure 4.11 – Agent-based analysis results: Average actual imbalance penalties for different cases

ference orders emerge. These vary a lot between different small BRPs, and also between cases, but clear patterns have not been found. In general, the differences can be explained by the fact that large BRPs have a larger influence on the system imbalance size and direction, as a result of which they have a larger chance of being in the wrong direction. As case 3 is the only case that prevents BRPs from actually earning money for being in the right direction, this case is relatively expensive for small BRPs. Another effect of the difference in influence is that the AIC per MW of portfolio is several times higher for large BRPs than for small BRPs[13].

Analysis results – case specific results The single pricing mechanism (case 1) leads to symmetrical average penalties, which is caused by the fact that long and short imbalance prices are the same, but the dominant occurrence of system surpluses of 57.6% proofs that BRP surpluses generally produce lower imbalance costs than BRP shortages. Single pricing is clearly the imbalance pricing mechanism that is cheapest for the BRPs, while it is also the simplest one. Finally, the relatively large occurrence of system surpluses can be argued to be preferable from a security of supply perspective.

The dual pricing mechanism (case 2) has been tested by means of three sub-cases, with varying activity. These were 17% of the rounds in case 2a (same as ref. case 1), 39% in case 2b, and 68% in case 2c, which is controlled by a dedicated parameter (see appendix F). Compared to single pricing, dual pricing in 17% of the time creates a total AIC increase of 19%, dual pricing in 39% of the time gives an increase of 42%, and dual pricing in 68% of the time an increase of 61%. This is almost a linear relationship between the activity of dual pricing and the total AIC, which is caused by the reducing profits of being in the right direction for increasing activity.

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[13] In view of the fact that equal average unintentional imbalance percentages were assumed for all BRPs in the model, in reality the netting of unintentional imbalances within the portfolio of large BRPs may partly compensate for this.

The two-price settlement mechanism (case 3) has led to the highest Actual Imbalance Costs for the market, which is the effect of the absence of a possibility to make a profit when being in the right direction. The average penalties reflect this as well. The total AIC are comparable to dual pricing with 50% activity.

The additive component (case 4) has been tested in four sub-cases with varying components and activity rates. The simulation results show that the impact of the component increase from 2.5 to 5 €/MWh has a larger impact than the intensification of the activation criterion in the form of a system imbalance threshold from 75 to 50 MWh. Of course, different outcomes will emerge if other values are tested. Generally, the additive component can be applied to impose temporary, small 'designed' increases in penalties and AICs, providing stronger incentives to BRPs at times of reduced system security.

Imbalance pricing based on total costs (case 5) results in a large increase in the total AIC, compared to single pricing. This mechanism creates much higher actual costs and profits in case of system surpluses. This is probably caused by the relatively high added costs of activated upward regulation bids in STUs with a system surplus and both upward and downward regulation.

The alternative payment direction (case 6) creates an average penalty for BRP surpluses that is much higher than the penalty for BRP shortages, which is opposite to all other pricing mechanisms. This can be explained by the peculiarity of this mechanism. Because the short and long imbalance prices are still determined in the same way as in the single pricing regime, BRPs with a surplus pay the downward regulation price in STUs with a system surplus, whereas they would receive this price in case 1. Similarly, BRPs with a shortage receive the downward regulation price in STUs with a system surplus, whereas they would pay this price in case 1. Thus, the difference in penalty between case 1 and 6 for STUs with system surpluses is twice the downward regulation price. This causes much larger cash flows in case of system surpluses. However, a system surplus still occurs (a bit) more often than a system shortage, which puts forward that BRP shortages are on average still (slightly) more expensive than BRP surpluses in the balancing market equilibrium.

Analysis results – Bid ladder analysis The most important assumption in the agent-based analysis is formed by the fixed upward and downward regulation bid ladder. In electricity balancing markets, these bid ladders change all the time. Obviously, the shape of the bid ladders has a major impact on the simulation results, as they are used to determine regulation prices, and thereby imbalance prices. A sensitivity analysis has been conducted regarding the bid ladders. The clear finding is that the bid ladder curves stand on the basis of the eventual balancing market results: They determine the relative height of the Actual Imbalance Costs for the different intentional imbalance options, and thus the occurrence and size of system imbalances as well. In addition, the absolute heights of the average AIC values change as well, resulting in very different total AIC values. In short, higher or lower bid ladder curves change the imbalance costs, while alterations in the shape of the curves, as well as the relative position between the upward and downward curve, change the BRP strategies. If the upward and downward regulation ladders are completely point-symmetrical, with the central point defined by the volume-price coordinates of (0,36)[14], positive and negative intentional imbalance options will be equally attractive,

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[14] The bid ladder can be viewed as a coordinate system, with regulation volume on the x-axis and regulation price on the y-axis, and the y-axis separating the up- and down-regulation bids (cf. Figure 3.2).

resulting in a system balance state in which system surpluses and shortages both occur in 50% of the rounds.

Findings from analysis of imbalance pricing mechanism

Generally, the best contracting strategy for Balance Responsible Parties to minimize their actual imbalance costs is to create a long position (intentional surplus) rather than a short position (intentional shortage), and to opt for a small imbalance rather than a large one. The imbalance costs-minimizing behaviour of the BRPs creates a balancing market equilibrium which is similar for different imbalance pricing mechanisms, even though absolute imbalance costs differ a lot. The consistently higher occurrence of positive system imbalances (system surpluses) finds its origin in the shape of the bid ladders — the upward regulation bids being generally more expensive — in combination with the general feature of the imbalance pricing mechanisms that the short imbalance price is based on the marginal bid price for upward regulation and vice versa. It was found that single pricing is much cheaper for the market than any other imbalance pricing mechanism. Most expensive are two-price settlement and dual pricing (48% and 20-60%[15] more expensive than single pricing, resp.), but an additive component can also be really costly for BRPs when components become really high and/or activation criteria are very easily met. The size and shape of the bid ladders was found to have a much larger impact on balancing market results, i.e. imbalance costs and system imbalances, than the imbalance pricing mechanism. Still, the imbalance pricing mechanism has a large impact on the imbalance costs that are borne by the market and on the variability of these costs for individual BRPs (the latter of which reflects the uncertainty on financial imbalance risks). Furthermore, the impact of the imbalance pricing mechanism is different for BRPs with different portfolio sizes. Large BRPs have a larger influence on the system imbalance, and can therefore benefit less from imbalance pricing mechanisms that yield a profit for BRPs having an imbalance in the 'right' direction.

Regarding the choice between alternative imbalance pricing mechanisms, single pricing has been found to be preferable from an economic point of view: It results in the lowest imbalance costs for the market (Balance Responsible Parties). Moreover, the results show that the effectiveness of system balancing (security of supply) is unaffected by the lower penalties for energy imbalances, as small and positive imbalances remain the most attractive BRP strategy. Finally, single pricing also allows for internal balancing by BRPs, which has the potential to further improve the economic efficiency of real-time energy balancing. However, if the availability of balancing resources is scarce and effective system balancing often jeopardized, two-price settlement or dual pricing with a high activation rate would incentivize BRPs to minimize energy imbalances stronger. In case of occasional security threats, temporary additive components could be as effective, while limiting the increase in imbalance costs. Imbalance pricing based on total costs and the alternative payment direction appear inferior mechanisms, as they lead to more system shortages and higher financial uncertainties for the market.

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[15] The higher the degree of activation of dual pricing, the higher the total Actual Imbalance Costs.

4.5 Context dependence of impact of design

To be able to estimate effects of design variables on performance better, and to learn whether it is possible to generalize on the impact of design variables, the topic of context dependence of balancing market performance should be covered first. In view of the link between the balancing market and the electricity market, and between balance management and power system operation, it can be expected that the effects of balancing market design and internationalization depend not only on the balancing market design, but also on the particular context of national power systems and markets. Indeed, the fact that areas with different power systems and market have adopted different balancing market designs suggests a context dependence[16].

The dependency of the impact of internationalization on contextual factors is discussed by considering the influences of these contextual factors on the system factors of the balancing market, which is graphically summarized in Figure 4.12. The context dependence is relevant for both balancing market harmonization and integration, although the contextual factor of interconnection capacity is clearly most relevant to integration.

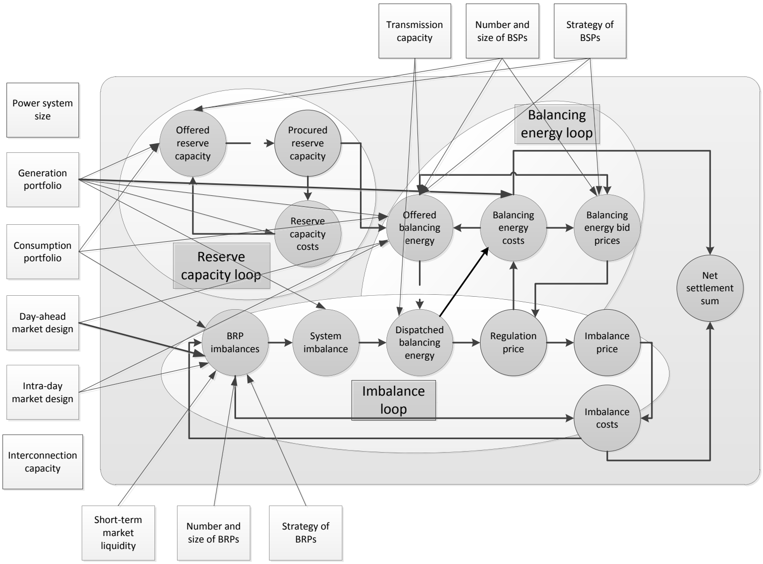

Figure 4.12 – Influence of contextual factors (rectangles) on system factors in the balancing market (circles)

Factors and interactions

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[16] The attuning of the national balancing market design to the overall power system design can actually be considered a form of path-dependency, or context bound rationality (Kay, 2005). However, in the scope of this research, we do not attempt to explain how balancing market designs have come about, but instead to uncover the functioning of balancing markets. Therefore, context dependence is the relevant concept here.

- *Power system size*: The size of a power system does not appear to have a clear effect on the impact of harmonization (or national balancing market design change). Looking at the causal loop diagram in Figure 4.1, it is obvious that a larger system requires more reserve capacity procurement and balancing energy dispatch due to higher system imbalances, but the power system size alone will not lead to higher balancing service prices and imbalances, and thereby costs for society and BRPs, and profits for BSPs. After all, there should also be more balancing resources in the system to choose from.

- *Generation portfolio*: This contextual factor has a clear impact on the offered balancing services, balancing costs, and system imbalances. First, this factor determines the amount of balancing resources present in the system. Generally, the higher this amount, the more balancing services can be offered, and consequently procured. Second, the contextual factor of the generation portfolio also determines the marginal costs of the balancing resources, which also has its effect on how much resources will actually be available in real-time. If marginal costs are high, the resources are likely to fall outside of merit order in conventional electricity markets, and remain for offering as balancing energy service. The marginal costs of balancing services fundamentally determine the balancing service prices and costs, and thereby also the imbalance prices and costs. Furthermore, the amount of offered balancing resources will also more indirectly influence balancing service bid prices and costs by changing the level of competition between BSPs. Third, the amount of unpredictable generation (notably wind and solar power) contributes to the size of system imbalances. With high penetration levels of wind and solar power, imbalance volumes and costs could become disproportionally higher than with low penetration levels, as regulation prices often increase exponentially for larger dispatched balancing energy volumes. A last aspect of this contextual factor is the level of inertia from synchronous generation units in the system, which reduces the size of the system imbalances (Frunt, 2011).

- *Consumption portfolio*: As mentioned above, the level of consumption compared to the installed and available generation capacity in a power system influences the availability of balancing resources. However, the consumption portfolio also influences the demand for balancing services. The higher the predictability of consumption, the lower the demand for balancing services. Another factor that reduces the size of the system imbalances is the level of inertia from synchronous motors (loads) in the system. Furthermore, some load resources may be eligible for the provision of balancing services. The technical characteristics (notably response speed, regulation speed, and activation duration) determine whether these resources may not merely be offered as emergency power, but also as Replacement Reserves and Frequency Restoration Reserves.

- *Transmission capacity*: The availability of internal transmission capacity in a power system determines the occurrences of internal congestions, and thereby influences the availability of balancing resources within the system for real-time system balancing. Furthermore, if balancing resources (often Replacement Reserves) are used a lot for redispatch, less resources remain available for balancing, which can lead to higher balancing costs.

- *Interconnection capacity*: Interconnection capacity influences the impact of multinational balancing market design and integration, but not the impact of national balancing market design and harmonization. In general, the more interconnection capacity is available for cross-border balancing (either remaining after cross-border intra-day trade, or reserved for this particular purpose), the larger the impact of integration will be.

- *Day-ahead market design*: This design basically consists of the gate opening and closure time(s) of the day-ahead market (which is considered to be a power exchange) and the time unit used for trading energy on a day-ahead basis. Most relevant is this time unit compared to the Schedule Time Unit (STU). If these are equal, Balance Responsible Parties are able accurately balance their energy portfolio by trading in the day-ahead market, i.e. on the STU-level. If the time unit in the day-ahead market is larger than the STU, this means of portfolio balancing is not very precise[17]. Another effect of more day-ahead trade for portfolio balancing is that it may commit more balancing resources to meet the adapted and possibly more fluctuating production and consumption plans. This would not damage the effectiveness of real-time balancing, because the system imbalance volumes would be reduced as well.

- *Intra-day market design*: With regard to the intra-day market, i.e. the intra-day market on the (voluntary) power exchange, the size of the time unit of intra-day trade compared to the size of the STU is probably more important than for day-ahead trade, because closer to real-time Balance Responsible Parties have more certainty on what the actual production and consumption energy volumes are going to be. Furthermore, the opening and closure times are more relevant. First of all, there are usually multiple closure times throughout the day for the trading for different time units. For example, the trading can be hourly, where the market for the trading for a specific time unit is cleared one hour before that time unit. Alternatively, there can be a more limited number of trading windows and gate closure times, where the market is cleared for multiple hourly time periods. The gate closure times influence the effectiveness with which BRPs can trade intra-daily to balance their portfolio (the shorter to real-time, the higher this effectiveness). Finally, another effect of intra-day trade on portfolio balancing is that it may commit more balancing resources to meet the adapted and possibly more fluctuating production and consumption plans resulting from the intra-day trade.

- *Short-term market liquidity*: The more market parties participate in the day-ahead and intra-day market, the larger the liquidity of those markets. This increases the possibilities for Balance Responsible Parties to balance their portfolio by means of trading in these short-term markets, and may thus decrease BRP imbalance volumes.

- *Number and size of Balance Responsible Parties*: The number and size of BRPs has an influence on BRP behaviour (balancing strategies), because the consequences of

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[17] The time unit will not be smaller, as BRPs are not interested in trading on time units smaller than the STU.

their strategies are different for different sets of BRPs in the power market. Larger BRPs, i.e. BRPs with balance responsibility for a larger portfolio of generation and consumption connections, have a larger impact on the system imbalance, and will thus be a causer of the system imbalance more often, which often means higher imbalance costs for these BRPs. On the other hand, imbalances from generation and load sources even out more within a larger BRP portfolio, leading to relatively smaller imbalance volumes. It is difficult to derive a clear effect of this contextual factor on balancing market performance. Many small BRPs have stronger incentive to balance, which may lead to lower system imbalances and imbalance costs than a system with a few large BRPs that put much less effort into portfolio balancing but have relatively low imbalance volumes.

- *Strategy of Balance Responsible Parties*: The strategy of Balance Responsible Parties influences the formulation and execution of balancing strategies, and thus BRP behaviour. Therefore, this contextual factor affects the BRP imbalance volumes. This factor concerns the attitude towards risk (taking risks to minimize imbalance costs), and the complexity of strategy formulation (using simple rules-of-thumb vs. detailed optimization calculations).

- *Number and size of Balancing Service Providers*: The number and size of BSPs influences their market power in balancing service provision, and thereby the degree to which they bid at marginal costs, and can exercise a capacity withholding strategy. Thus, this contextual factor influences the balancing service volumes, prices and costs: The lower the number of BSPs and the larger their size, the higher the balancing service prices and costs are likely to be.

- *Strategy of Balancing Service Providers*: The strategy of Balancing Service Providers influences the formulation and execution of bidding strategies, and thus BSP behaviour. Therefore, this contextual factor affects bid volumes and prices, and thereby balancing service prices and costs. This factor concerns the attitude towards risk (taking risks to maximize balancing service profits), the complexity of strategy formulation (using simple rules-of-thumb vs. detailed optimization calculations), and the inclination to abuse market power (which is related to the risk attitude).

Magnitude of influence The impact of the *power system size* on balancing market performance appears to be small. Conversely, the impact of *generation portfolio* in the power system is very high. Four sub-factors are particularly influential: 1) the marginal costs of balancing resources, 2) the share of flexible resources, 3) the share of non-dispatched generation, and 4) the share of intermittent generation. The first is the main determinant of the level of the balance management costs, although these are also influenced by 2 and 3, which affect the level of competition in the balancing service markets, and by 4, which has a large effect on the demand for balancing services. It follows that the generation portfolio has a very large impact on the availability of balancing resources, price efficiency, balance planning accuracy, and balance quality. Compared to this contextual factor, the *consumption portfolio* has a small impact on performance. The demand of balancing services is affected by the predictability of consumption, and the supply of balancing services by the controllability of consumption, but effects are limited. This might change in the future, however, if more large unpredictable load resources are introduced, or if the development demand-side management results in more (aggregated) load resources being offered as balancing resources.

The contextual factor of *interconnection capacity* does not influence the impact of balancing market harmonization, but the availability of internal *transmission capacity* does. This influence is likely to be small, unless there are large congestion problems in combination with a lot of (cheap) balancing resources located in the congested areas and/or an extensive use of balancing resources for redispatch. In that case, availability of resources and price efficiency will be affected.

Regarding the *day-ahead market design* the important sub-factor is the trading time unit used, compared to the STU length. When both are equal, BRP portfolio balancing by means of day-ahead trade could be much more precise. Therefore, this factor could have a significant impact on balance planning accuracy. The impact on the availability of balancing resources is less clear, but more resources could be committed as a result, reducing this availability. About the same can be said about the impact of *intra-day market design*. There are some differences however. As intra-day trading occurs closer to real-time, the impact of portfolio balancing by means of intra-day trade could be much higher. However, the practical feasibility of this depends on the liquidity of the intra-day market, which may be much smaller than that of the day-ahead market. Furthermore, the gate closure time of the intra-day market is also important: if this is closer to the STU of delivery, balance planning accuracy may further increase. The *short-term market liquidity* is considered to have a large effect if the liquidity is so low that buying and selling bids can often not be matched.

The *number and size of Balance Responsible Parties* probably affects balance planning accuracy, but the nature of these effects are unclear. In general, several large BRPs will put less effort into portfolio balancing than a lot of small BRPs, so this may lead to larger system imbalances. Therefore, this contextual factor could considerably improve balance planning accuracy. However, it could also damage utilization efficiency, because a high degree of internal balancing by BRPs reduces the more efficient central balancing by the System Operator. A peculiarity of this factor, however, is that the number and size of BRPs can be changed at will by the market parties. It is unsure how market parties decide on this, and even more how balancing market design variables affect this. The influence of the *strategy of Balance Responsible Parties* will probably be lower, because risk attitudes and balancing strategies are not expected to deviate that much: In general it is better to limit imbalance volumes, and to end up with a BRP surplus rather than with a BRP shortage (see subsection 4.4.3). Next, the *number and size of Balancing Service Providers* may have a large effect on the competitiveness in balancing service markets. In combination with the *strategy of Balancing Service Providers*, especially the inclination to abuse market power and the risk attitude of the BSPs, the price efficiency of balancing service markets can be affected to a very large extent. We conclude that the (mind)set of Balancing Service Providers is likely to have a larger and clearer effect on performance than the (mind)set of Balance Responsible Parties.

Impact of contextual factors vs. design variables An important and interesting consideration is how the magnitude of the effects of contextual factors relate to the magnitude of the effects of the balancing market design variables. This difficult issue will be treated in the multi-criteria analysis, but one important observation can be made on beforehand. Balancing market performance is for a large part determined by the availability and costs of balancing resources in the power system, as it set the limits on volumes and costs of available resources. In combination with the general predictability of consumption and generation in the power system, this also delineates a fundamental imbalance costs level. Therefore, the contextual factor of the generation portfolio (and the consumption portfolio) in the power system set the general performance level of a balancing market.

On the other hand, the balancing market design variables set the 'rules of the game' for BRPs and BSPs, which substantially influences their behaviour regarding portfolio balancing and the offering of balancing services. However, most design variables do not appear to be so influential on BRP imbalances and balancing service prices and volumes as the nature of consumption and generation in the power system. One exception is probably the allocation of balancing energy costs, because the absence of imbalance settlement would not give any incentives to the market to limit imbalances. Another exception may be the national reserve requirements: A procurement of reserve capacity that is much too low will negatively impact on security of supply, while a too high level of procurement may cause a huge rise of the procurement costs. On the multinational level, the cross-border balancing arrangement and the reservation of interconnection capacity are two design variables that might match the impact level of the production and consumption portfolio. After all, the introduction of cross-border balancing can fundamentally change the demand for and supply of balancing services.

4.6 Multi-criteria analysis of national design variables

In the multi-criteria analysis, the possible effects of each individual national design variable on the balancing market performance criteria has been evaluated qualitatively, taking into account the impact on market behaviour. The insights from the system analysis presented in section 4.1 have been used as a main input for this multi-criteria analysis. For each individual design variable, the assessment consists of the following three points: 1) Estimation of the impact level of the variable, 2) estimation of the influence of the contextual factors on the impact of the variable, and 3) consideration of the existence of a 'best' variable value. To obtain an evaluation of the total impact of national design, effect estimations are aggregated. The full effects estimation itself, including overview tables, have been placed in appendix H.

The impact level of a design variable reflects the degree to which balancing market performance is affected by this variable. The context dependence of the effects reveals the degree to which the impact of design variables is influenced by contextual factors. The consideration of a clear 'best' variable value that holds in any context (power market) helps to find balancing market design recommendations.

Because there is not an initial balancing market design (or set of designs, with respect to harmonization) and corresponding performance level against which the effects of design variables can be evaluated, the effects estimation is a generic exercise. Consequently, the results of this estimation do not show concrete impacts on balancing market performance. The multi-criteria analysis of national design variables provides a general insight into the scope, value and content of national balancing market design change and balancing market harmonization.

Total impact of national balancing market design on performance

The qualitative estimation of the impact level of the national balancing market design variables can first of all provide insights in the total impact of the design variables. With 'total impact' is meant here the aggregate of the effects of a design variable on all eleven performance criteria combined. By converting the qualitative effect estimations listed in appendix H into numerical values, this total impact can be quantified. The applied conversion is presented in Table 4.2.

Table 4.2 – Quantification of effects of national balancing market design variables in multi-criteria analysis

Estimated effect	Numerical value
small	1
moderate	2
large	3
very large	4
huge	5

This analysis approach has several implications. First of all, the scope of the impact of the national balancing market design on performance is reflected by the sum of effects across all criteria and variables. As effects were converted into a range from 0 to 5, the theoretical maximum is 5 times 11 (the number of criteria) times 24 (the number of variables), which is 1320. The actual sum of effects resulting from the MCA is 318, which is 24% of the maximum, and can be translated to an average impact level of 1.2 (between 'small' and 'moderate') on the 0-5 scale across all variables and criteria. This can be considered a high average, because the performance criteria set contains a wide range of criteria, and variables do not need to impact all criteria in order to have a large impact on performance. On the contrary, if a design variable affects only one criterion to a large degree, the variable could already be considered to have a large impact on performance. But such statements are of course value judgments; different people (decision-makers) will have a different viewpoint on what kind of impact levels can be called 'large'. Because we make frequent use of such statements, this should be kept in mind. Anyhow, we conclude from the MCA that the total impact of national balancing market design on balancing market performance is large.

Total impact of individual national design variables

Looking at the individual variables, we find that the total impact ranges from 24 (an average of 2.2 on each criterion) to 4 (an average of 0.4). Figure 4.13 shows a ranking and grouping of the national variables on the basis of total impact values. The variables with a value in the range [0,11] form one group, variables within the range [12,22] form another, and variables with a value larger than 22 form the third group.

The first group of variables in the range [0,11] consists of eight variables, the second group consists of fourteen variables, and in the third group only two design variables are included. It is striking that the relative impact levels found here differ substantially from the simple estimation of the magnitude of effects of design variables as presented in

Table 4.1. This can be explained by the fact that the simple estimation has been made with effects on particularly balancing service and imbalance volumes and costs in mind, which means that, implicitly, mostly the availability of balancing resources, utilization efficiency, price efficiency and balance planning accuracy were considered, and the other criteria much less.

Apart from this, it is not easy to explain the specific order in impact level of individual design variables, or to conclude anything out of it. The specific order is not meaningful; it is more the general position of design variables that gives an indication of their importance. Notably, the relative impact levels show that there is an evenly spread range of varying total impact levels among national design variables.

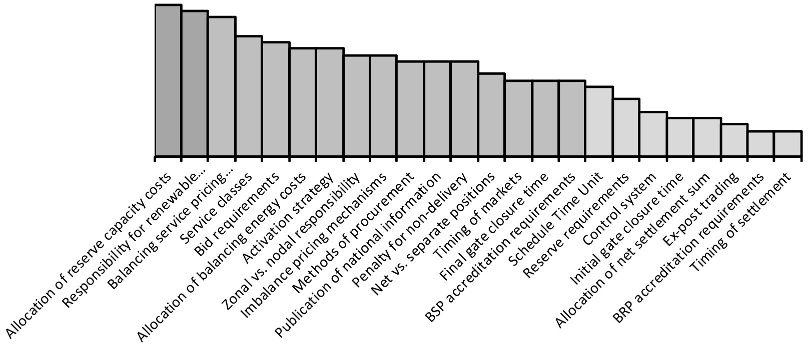

Figure 4.13 – Multi-criteria analysis results: Total impact of national balancing market design variables

Total impact on individual performance criteria

Next, the total impact of national balancing market design on the individual balancing market performance criteria can be extracted from the effects estimation. For this, the sum of the quantified effects (see above) of all the national design variables on the same performance criterion have been added up to come to a total score for the criterion. The ranked total scores are visualized in Figure 4.14.

Here, the maximum possible score is 24 times 5, i.e. 120. The highest score (availability of balancing resources) is 51 (43% of the maximum), and the second-lowest score (operational efficiency) is 18 (15% of the maximum). On overall, we conclude from this that the national balancing market has a large impact on all performance criteria. After all, a score of 18 already means that e.g. 75% of the design variables have a small effect on the performance criterion, and this adds up to a large total impact on this criterion[18].

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[18] It must be considered, however, that these effects could also cancel each other out on an aggregate level. Because interaction effects between variables have not been studied, and because their inclusion requires the specification of specific variable values, net effects of balancing market design are not incorporated in this general multi-criteria analysis.

Looking at the relative scores, the performance criterion 'availability of balancing resources' has come out as being affected the most by the national balancing market design. This makes sense, as there are a lot of national balancing service provision variables (see Figure 3.6), and because this criterion is directly affected by design variables that alter the balancing service prices as well. This is because these prices form the incentives to Balancing Service Providers to offer balancing services. For largely the same reasons, the four performance criteria related most to balancing service provision, i.e. the availability of balancing resources, balance quality, price efficiency and utilization efficiency are affected more than the other criteria. Slightly less affected is balance planning accuracy, which relates much more to balance planning and settlement. This criterion is directly affected by design variables that impact on the imbalance prices that incentivize Balance Responsible Parties to balance their portfolio. Thereby, it is also indirectly affected by design variables that impact on the balancing energy price, which explains the high score. Furthermore, we find several national design variables that have a large impact on cost allocation efficiency. These are notably the design variables dealing directly with the allocation with balancing costs and design variables that directly influence balancing service and imbalance costs.

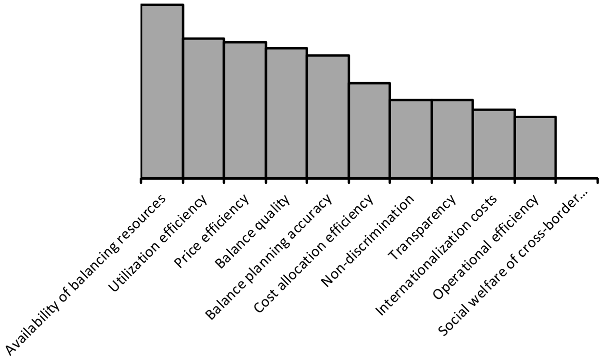

Figure 4.14 – Multi-criteria analysis results: Total impact of national balancing market design on performance criteria

Next in order are non-discrimination and transparency, which are both affected by about 12 national design variables, although usually not to a large degree. The estimation has revealed for both of these criteria that there are many design variables where the choice of a specific design variable value has an influence on the clarity and complexity of balancing rules, and on the equality of market conditions for balancing market participants. Subsequently, the internationalization costs are affected to an even smaller degree. Under this criterion, the change in design variable value has been considered as internationalization costs, because balancing market harmonization (which is considered in this chapter) requires that the different control areas in the balancing region adopt the same values. As most of the design variables concern institutional rules that can be changed without physical or large financial consequences, the impact on this criterion is limited. Next in line is operational efficiency, which is about the level of transaction costs. It has been found that most national design variables do not impact significantly on these transaction costs. Finally, the social welfare of cross-border exchanges is not affected at all by national balancing market design, because national design and balancing market harmonization do not involve cross-border balancing.

It is interesting to compare the importance of the performance criteria based on the criterion groups shown in Figure 3.5, i.e. to compare between market facilitation criteria, security of supply criteria, economic efficiency criteria, and multinational criteria. If we add up the total scores of the criteria within the same group, we obtain the following results:

- Economic efficiency criteria: 40%
- Security of supply criteria: 39%
- Market facilitation criteria: 15%
- Multinational criteria: 6%

Thus, the impact of national balancing market design on economic efficiency and security and supply has been estimated as being as good as equal. The values of the remaining criteria add up to only half the impact of either of these fundamental requirements. Logically, the market facilitation criteria are affected much more than the multinational criteria. The most important conclusion here is that the choice for a national balancing market design in its entirety has a major impact on the two fundamental balancing market requirements of security of supply (effective balance management) and economic efficiency (economic efficiency of the balancing market).

Total influence of contextual factors on performance

Subsequently, we can have a look at the influence of the contextual factors. In the MCA, the influence of eleven contextual factors has been qualitatively estimated for all variables, using the same conversion method outlined above. See appendix H. The evaluation of the 'total context dependence' of individual variables has led to a similar ranking of design variables as in Figure 4.13, but has not provided any specific insights, and is therefore not presented. We have found a large variation in context dependence among design variables. More interesting is the discovery of a certain correlation between the context dependence and the impact level of design variables. We come back to this in chapter 6.

The total influence values of individual contextual factors are presented in Figure 4.15. The sum of these total influence values equals the value of '200', which comes down to an average influence per criterion of 8.3, which e.g. means that eight of the contextual factors have a small influence for all design variables. Because the maximum possible influence would have been '1320', this sum is 15% of the maximum possible influence, which converted to the 0-5 scale means an average value of '0.76' (between insignificant and small) across all contextual factors and variables. Based on this, we can conclude that the impact of national balancing market design and harmonization are dependent to a large degree on the contextual power systems and markets.

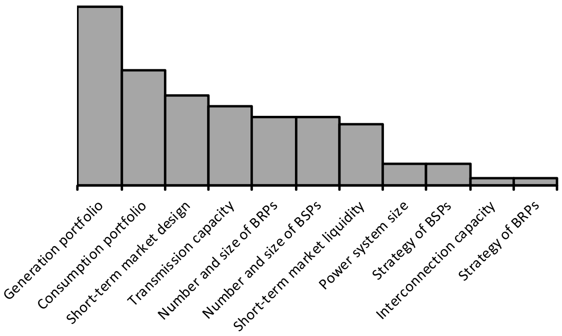

Figure 4.15 – Multi-criteria analysis: Total influence of contextual factors on national balancing market design

The contextual factor that comes out as having the largest total influence is the generation portfolio. This results from the fact that the incorporated aspects of the presence of unpredictable generation in the power system and the general availability of flexible generation resources have a large influence on the availability of balancing resources, price efficiency, and balance planning accuracy, and thereby change the magnitude of the effects of the design variables that affect these same criteria. Noticing from Figure 4.14 that these criteria are significantly affected by the national variables, it is logical that generation portfolio has a large influence. The consumption portfolio is the second-most influential contextual factor, which relates to the elementary factor of the predictability of consumption in the power system, which for a large part determines the demand for balancing services. As this demand is a fundamental determinant of balancing costs and competition in balancing service markets, this high score appears realistic.

Next in line are five contextual factors with a similar total influence score: ‘short-term market design’, ‘transmission capacity’, ‘number and size of BRPs’, ‘number and size of BSPs’, and ‘short-term market liquidity’. Short-term market design and short-term market liquidity have an influence mostly on national design variables related to balance planning and settlement, and thus on BRP behaviour. This is because these contextual factors impact on the opportunities that BRPs have to balance their portfolio. The number and size of BRPs has an influence on the effects of balance planning and settlement variables, because this contextual factor affects the average BRP imbalance volumes (the size of BRPs appears more important than the number). The number and size of BSPs have an influence on the effects of balancing service provision variables, because this contextual factor affects market power of BSPs in balancing service markets, and thereby their bidding strategies. Transmission capacity influences the effects of design variables for which the occurrence of congestions form a relevant consideration, including both balance planning variables and balancing service provision variables.

Finally, the four contextual factors 'power system size', 'strategy of BSPs', 'interconnection capacity' and 'strategy of BRPs' only have a small influence on the effects of national balancing market design. The power system size has been estimated to be relevant only for the design variables of reserve requirements and net vs. separate positions. The functioning of balancing markets appears to be size-independent. For the national variables, the contextual factor 'interconnection capacity' only influences the variable of reserve requirements. The strategy of BRPs and of BSPs are very intangible contextual factors. It has been estimated that BRPs and BSPs do not have much leeway with regard to bidding and portfolio balancing strategies, and that their risk attitudes will not play a large role in the balancing market results. Most substantial is the tendency of BSPs to try to drive the balancing service prices up. Of course, this depends also on the degree of market power, and thus on the contextual factor of the number and size of BSPs. Because of the uncertainties on the nature of different balancing market strategies, the evaluation of these last two contextual factors is least solid.

To conclude on the total influence of individual contextual factors, it can be said that there are large differences between contextual factors. The generation portfolio, the consumption portfolio, the short-term (day-ahead and intra-day) market design and the transmission capacity are revealed as the most important contextual factors.

Generalizability of design variable values

In the multi-criteria analysis, for each national design variable the effects of alternative variable values have been discussed, in order to determine the impact level of the variable. This has led to the specification of a 'best' design variable value for each variable, as far as this was possible. See appendix H. These specifications have been made taking into account different possible power system/market contexts. Based on these specifications, we have ordered the design variables into three groups on the basis of the ability to generalize on a 'best' design variable value. The three used qualifications are 'high', 'medium' and 'low' generalizability. The results of this exercise are shown in Table 4.3.

Table 4.3 – Generalizability of 'best' national design variable values

High	Medium	Low
Service classes	Zonal vs. nodal responsibility	Schedule Time Unit
Methods of procurement	Timing of markets	Reserve requirements
Allocation of reserve capacity costs	Publication of national information	Bid requirements
Allocation of balancing energy costs	Responsibility for renewable generation	Timing of settlement
Final gate closure time	Net vs. separate positions	
Control system	Activation strategy	
Ex-post trading	Balancing service pricing mechanisms	
Penalty for non-delivery	Imbalance pricing mechanism	
Initial gate closure time	BRP accreditation requirements	
Allocation of net settlement sum	BSP accreditation requirements	

Although this classification of design variables is based on a rough exercise, it provides us with some additional insights. Most importantly, it generally shows that in-depth (qualitative) analysis can generate numerous arguments to support the superiority of specific national design variable values. Next, the list of 'best values' indicates that which variable value has the most positive impact on performance often depends on the power system/market context. This is reflected by Table 4.3, where these variables have been classified under 'medium' or 'low' generalizability. So on the one hand we have been able to find superior design variable values, but on the other hand the system/market environment has been found to have a large influence. This appears to be conflicting, but there is a reason why it is sometimes not: The fact that contextual factors change the magnitude of effects of alternative variable values for a specific design variable does not imply that a superior variable value does not exist, because the relative effects of the different variable values may remain unchanged. The classification suggests that this is the case for ten variables (those classified by 'high'), while for the 14 other variables the context dependence does imply uncertainty on the ranking of variable values. Ergo, paradoxically, the high context dependence of the impact of national balancing market design does not always prevent the formulation of generic design recommendations.

Conclusion

In short, the multi-criteria analysis has brought us to conclude the following. The total impact of national balancing market design on balancing market performance is large, especially on the performance criteria corresponding with the fundamental requirements of security of supply and economic efficiency. Therefore, the impact of balancing market harmonization, which encompasses the equalization of national balancing market designs, can also be expected to be high (although the impact level depends on the number and identity of the design variables being harmonized). The next section will further cover this. Furthermore, the impact of design is to a large degree influenced by the contextual power systems and markets. These results point out the importance of the balancing market design and of a careful decision-making process on balancing market harmonization.

4.7 Case study of Northern Europe: impact of harmonization

In this case study, the aim is to estimate the impact of the possible harmonization of the balancing market designs of the Nordic region, Germany and the Netherlands. This enables the consideration of the specific initial balancing market designs and contexts in Northern Europe, and also the current performance. The current design and performance are shortly considered in subsection 4.7.1. Then, in subsection 4.7.2, the impact of harmonization for Northern Europe is evaluated and discussed.

4.7.1 Current design and performance in Northern Europe

Current balancing market designs The current balancing market designs of the North-European areas are shown in Table C.1 in appendix C. The current designs were already described in subsection 2.1.1; for more information we refer this subsection.

Remarkably, the balancing market designs of the Nordic region, Germany and the Netherlands do not have the same variable value for any national design variable but for the fundamental variable 'allocation of balancing energy costs'. This indicates that there is no single 'best' variable value that is applicable to all power systems and markets, which is in line with our conclusions from the MCA, but also that it will be very challenging to fully harmonize the balancing markets in Northern Europe.

Current balancing market performance The current performance levels of the North-European balancing markets are reflected in Table C.2 in appendix C, by means of quantitative performance indicators. The presented figures are averages from the year 2010 (unless expressed otherwise), and are based on data retrieved from Nord Pool Spot (2011), Amprion et al. (2011), and TenneT (2011).

To first get an idea of the size of the balancing markets, we take a look at the differences between the day-ahead forecasts and the realized system load for the North-European areas in 2010, based on hourly data from ENTSO-E (2010). The (absolute) average load deviation was about 2% for each of the Nordic countries, about 6% in Germany, and 9% in the Netherlands. As the short-term electricity demand forecast error should be in the order of 2% (Taylor et al., 2006), these last two values appear quite high. The high German load deviation can be explained by the high wind power share in Germany. The Dutch value seems wrong, which might be caused by the conversion to hourly data. Indeed, TenneT data shows an average load deviation of 1% (TenneT, 2011). Lower deviations in the Netherlands compared to the Nordic region may be caused by the Dutch net position, the smaller STU, and the passive balancing enabled by the net position and the imbalance pricing mechanism.

The total AIC for the Netherlands in 2009 are, based on the market imbalance values, about 46 million euro (TenneT, 2011). To put this into perspective, the annual traded electrical energy on the APX in 2009 (day-ahead, intra-day and strips market) was about 29 TWh (APX-ENDEX, 2010), and the average Dutch day-ahead price was 39.2 €/MWh, adding up to a total value of 1,137 million euro. Thus, the actual imbalance costs in the Netherlands represent about 4% of the monetary value of the energy traded on the Dutch power exchange in the day-ahead timeframe. Furthermore, as the total 'actual balancing energy costs'[19] for 2009 amount to 32 million euro (TenneT, 2011), we observe that the total Dutch imbalance costs were more than 40% higher than the total balancing energy costs. It should be kept in mind, however, that the annual 'imbalance energy' volume in a power system is usually a lot higher than the annual activated balancing energy, because BRP imbalances even out. For example, for the Netherlands in 2009, the first was 3,270 GWh and the second was 780 GWh, which is about four times smaller. The proportion between both will depend on the number of BRPs, and on design variables influencing BRP imbalance volumes.

Two important system factors are the reserve capacity costs and the balancing energy costs. The reserve capacity costs of the Nordic region and the Netherlands cannot be found on the web, while the total actual balancing energy costs for Germany are very hard to calculate due to the pay-as-bid pricing. Based on very rough calculations using 2009/2010 data from TenneT (2011) and Amprion et al. (2011), and a rough estimation of reserve capacity costs in the Netherlands from TenneT, we have found that the proportion between total reserve capacity costs and total actual balancing energy costs for Germany is in the order of magnitude of 1:1, and for the Netherlands is in the order of magnitude

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[19] These are the actual profits that Balancing Service Providers earn, which are calculated by taking the difference between the regulation price and the day-ahead price, instead of the regulation price.

of 2:1. This is in line with proportional balancing service costs in Germany and the Netherlands found in other studies, as well as in actual market data[20] (LichtBlick, 2008; TenneT, 2011; TenneT et al., 2011; Amprion et al., 2011).

Although the intended purpose of a data overview table like Table C.2 is to provide a good picture of the current performance level of national balancing markets, the analyses in this chapter have made clear that this table actually explains little. After all, the shown variables have more of the system factors than of balancing market indicators (see subsection 4.1.4). In other words, it is not clear what these variables can tell us about the performance of balancing markets. More data about specifically the predictability of generation and consumption, the presence of flexible resources in the power systems, and the marginal costs of these resources, in other words important contextual factors, are needed to interpret these values.

4.7.2 Impact of harmonization for Northern Europe

In order to discuss in a meaningful way what is the impact of the possible development of balancing market harmonization in Northern Europe, we should know what are the current national balancing market designs, what is the desired 'harmonization design', and what is the current performance level in the national balancing markets. If we know these three things, the findings of the multi-criteria analysis in section 4.6 may be applied to evaluate the expected effects of realizing the harmonization design in Northern Europe. However, some uncertainties surround the last two points, and also the estimation of the effects of harmonization itself is subject to uncertainty. In this subsection, a harmonization design for Northern Europe is proposed and evaluated shortly, indicating the potential impact of harmonization in Northern Europe and in general, and illustrating the nature of uncertainties.

Current performance level

It is difficult to compare the balancing markets of the Nordic region, Germany and the Netherlands, especially because their power systems are so different. In order to assess and compare the current balancing market performance levels in these three areas, we should know about the exact generation portfolios, merit order cost curves, predictability rates of production and consumption, et cetera. We did not obtain this information, or the data required to assess the values of all balancing market indicators, and can therefore not estimate how well the balancing markets currently perform (see subsection 4.7.1).

A harmonization design proposal

What harmonization design is desired depends on the views and preferences of the decision makers. In view of present uncertainties on effects (see below), different governments, regulators and System Operators are likely to have different preferences. In addition, decision makers representing a specific control area will tend to favour designs that are close the current design in their area, because of the familiarity with this design (the certainty of a satisfactory performance level) and due to lower switching costs.

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[20] This difference may be explained by the fixed monthly secondary control market in Germany causing high balancing energy costs (see subsection 4.4.2), vs. the high reserve capacity costs in the Netherlands resulting from the yearly procurement cycle.

Following up on the findings of the effects estimation in appendix H and the general guideline to stick closely to the current national designs, we come up with the harmonization design proposal for Northern Europe presented in Table 4.4.

Table 4.4 – A harmonized balancing market design proposal for Northern Europe

Design variable	**Proposed value**	**Rationale**
Schedule Time Unit	15 minutes	Applied in DE and NL
Methods of procurement	Separate RC and BE market	Higher market liquidity
Timing of markets	Weekly reserve capacity market	Higher price efficiency
Responsibility for renewable generation	BRPs	Non-discrimination and appropriate incentives
Final gate closure time	45 minutes before RT	Applied in NO and DE
Net vs. separate positions	Net position	Applied in DE and NL
Balancing service pricing mechanisms	Marginal pricing of BE	Applied in NO and NL
Imbalance pricing mechanism	Single pricing	Prevalent in DE and NL; applied to consumption in NO

The rationale behind this design is the following. A Schedule Time Unit of 15 minutes is applied in Germany and the Netherlands, and leads to higher balance planning accuracy. Separate reserve capacity and balancing energy markets exist in the Nordic region and the Netherlands, and improve the liquidity of balancing service markets. A weekly reserve capacity market exists in Germany and Norway, and substantially increases the economic efficiency of reserve capacity procurement in the Netherlands compared to the current yearly market. Responsibility for renewable generation fully borne by the BRPs is applied in the Netherlands, and will introduce non-discriminatory market rules and balancing incentives to BRPs responsible for renewable generation in Germany and the Nordic region. A final gate closure time of 45 minutes is applied in Germany and the Nordic region, and will slightly improve balance planning accuracy in the Netherlands. A net position including both generation and consumption is applied in Germany and the Netherlands, and will reduce imbalance volumes in the Nordic region, thanks to netting and internal balancing. Marginal pricing of balancing energy is applied in the Nordic region and the Netherlands, and will improve price efficiency and incentive compatibility in Germany. Single imbalance pricing is applied in Germany, partly applied in the Nordic region and the Netherlands (it will be fully applied after harmonization), and may reduce imbalance costs and simplify imbalance settlement somewhat in the Nordic region and the Netherlands.

Impact of harmonization

A quick estimation of the effects of the harmonization design on balancing market performance in the three North-European areas has been carried out on the basis of the overall effects estimation in the MCA. Effects have been evaluated from 'huge reduction' up to 'huge increase', with these extreme values being converted to '-5' and '5', respectively (see Table 5.4). The results are shown in Table 4.5.

As can be seen, the harmonization design has been estimated to have a very large net positive impact on balancing market performance in all three North-European areas. We also observe that there are multiple performance criteria for which performance has been found to decrease. Furthermore, the positive impact on Germany has been found to be much larger than for the Nordic region and the Netherlands. This is caused by the evaluation that the separation of the combined balancing service markets (for secondary and

Table 4.5 – Estimated impact of harmonization design for Northern Europe

Performance criterion	Nordic region	Germany	Netherlands
Availability of balancing resources	small increase	large increase	large increase
Balance planning accuracy	small increase	small reduction	no change
Balance quality	moderate reduction	small increase	no change
Price efficiency	small increase	very large increase	very large increase
Utilization efficiency	small reduction	very large increase	very large increase
Cost allocation efficiency	very large increase	huge increase	small increase
Operational efficiency	no change	moderate reduction	moderate reduction
Non-discrimination	huge increase	huge increase	large increase
Transparency	huge increase	huge increase	very large increase
Social welfare of cross-border exchanges	no change	no change	no change
Internationalization costs	small reduction	small reduction	moderate reduction
Total net impact	*15*	*28*	*15*

tertiary control) into a reserve capacity market and a balancing energy market and the introduction of marginal pricing of balancing energy have a very large positive impact on the performance of the German balancing market. The higher positive impact on Germany is despite the (small) net negative effect of the change to full balance responsibility for renewable generation for BRPs that results from the higher BRP imbalance volumes and imbalance prices.

The main conclusion that can be drawn from the impact assessment of the harmonization design is that the potential impact of balancing market harmonization in Northern Europe is highly positive.

Interaction effects

Apart from the individual effects of design variables, specific combinations of design variable values could also create particular effects, i.e. interaction effects. For example, the application of dual pricing without the option of ex-post trading, or a small STU in combination with BRP responsibility for wind, could lead to excessively high imbalance costs for BRPs. Another example is that compulsory and uncompensated provision of balancing resources in combination with loose bid requirements could cause a major reduction in the quality of provided balancing services. These interaction effects add to the complexity of assessing the impact of specific balancing market designs, including harmonization and integration designs. They have not been studied within our analysis, but we expect that interaction effects play a substantial role.

4.8 Impact of harmonization

By means of the multi-criteria analsysis of the impact of national balancing market design variables on balancing market performance, we have at the same time studied the possible effects of balancing market harmonization. The main findings were that the national balancing market design as a whole has a large total impact on performance, that there is a wide range of varying impact levels among national design variables, that the national balancing market has a large impact on all performance criteria, that the impact of national design is dependent to a large degree on the contextual power systems and markets, and that despite all dependencies generic design recommendations can be made for a large share of the national design variables.

The five national design variables that were found to have the largest effects are allocation of reserve capacity costs, responsibility for renewable generation, balancing service pricing mechanisms, service classes, and bid requirements. Regarding performance criteria, the national balancing market design was found to have the largest impact on the availability of balancing resources. In addition, the total impact on economic efficiency criteria has been estimated to be as large as the impact on security of supply criteria. Regarding contextual factors, the generation and consumption portfolio, the short term market design and the transmission capacity have been identified as most important. Last, for ten out of twenty-four national design variables we have estimated that a generic design recommendation can be made (see Table 4.3).

As balancing market harmonization is about changing national design variable values, the same things can be said about harmonization. However, harmonization will in practice never involve all existing national balancing market design variables. From the fact that different variables have a different impact level on balancing market performance can be concluded that the impact of harmonization depends very much on the particular design variables that are to be harmonized. If we add to that the large influence of contextual factors, the existence of interaction effects and the uncertainties on actual changes in market behaviour, it becomes clear that we cannot make strong generalizations about the impact of balancing market harmonization.

Theoretically, it has become apparent that the net effect of harmonization can range from very small to very large, from very negative to very positive, and will probably differ for the different areas involved, all depending on the specific changes in national design variable values and the specific context in the areas. However, the evaluation of the proposed harmonization design for Northern Europe, as well as the overall multi-criteria analysis of national design variables, have shown that *in practice* performance-improving harmonization designs can be composed *for specific cases*. Considering that, the potential impact of balancing market harmonization is concluded to be highly positive.

5 Analysis of multinational balancing market design and integration

The structure of this second analysis chapter on multinational design and integration is quite different from that of the first analysis chapter on national design and harmonization. This is because a system analysis of multinational balancing markets is not necessary: A multinational balancing market is a set of harmonized and/or integrated national balancing markets, and the core of its content and functioning involves the same factors and interrelations as in national balancing markets[1]. Moreover, there is one key multinational design variable: the cross-border balancing arrangement. In effect, balancing market integration can be considered to be the implementation of (a) cross-border balancing arrangement(s), and thus is the main object of study in this chapter.

First, we study some important multinational variables in detail in section 5.1. Then, in section 5.2, a qualitative multi-criteria analysis of the multinational design variables is presented. This is followed by a multi-criteria analysis of the impact of the four main cross-border balancing arrangements in section 5.3. The same analysis approach is applied for these two analyses as for the MCA of national design variables in the last chapter. Next, in section 5.4, the impact of the possible implementation of cross-border balancing arrangements in Northern Europe is studied by means of an agent-based analysis, in which the impact of integration on the behaviour of Balance Responsible Parties is taken into account. This case study allows for an actual impact assessment of integration, in which specific market characteristics can be considered. Finally, all the above allows us to draw some general conclusions on the impact of integration in section 5.5.

5.1 Detailed study of multinational design variables

5.1.1 Control area boundaries

To evaluate the effect of the control area boundaries, it is useful to compare balancing market integration with and without control area merging. Because the merging of the

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[1] This is reflected by the fact that the multinational design space consists of the national design space, plus a relatively small amount of multinational variables.

control areas means that a single balancing market will develop, this has to be compared with the most advanced form of balancing market integration, i.e. a common merit order list. As the German balancing market integration process in 2009-2010 has proven, a common merit order list can be introduced for a region consisting of different control areas (see subsection 2.3.3). A comparison has been made by Technical University of Dortmund and E-Bridge (2009) in the light of the integration in Germany.

The report by Technical University of Dortmund and E-Bridge (2009) presents a comparative assessment of the financial impact of the 'Optimierten Netzregelverbund (ONRV)' (optimized grid control cooperation) and the 'Zentrale Leistungs-Frequenz-Regelung (ZNR)' (central load-frequency control) for Germany. The ONRV is an 'optimized' cooperation between different control areas concerning balance management, which means a common merit order list. The single control area in the ZNR also implies the presence of a common merit order list. The main difference is that the real-time balancing energy dispatch requires much more coordination between System Operators in the ONRV (regarding energy schedules, exchange programs, control signals, and Area Control Errors (ACEs)). The ONRV is the concept that has eventually been implemented in Germany.

The main result of the study is that the impact of the two 'conflation concepts' is comparable, as they realize the same kind of costs reductions. For both concepts, system imbalance netting is estimated to reduce the yearly balancing costs by 56 M€, and the decrease of procured reserve capacity to reduce yearly costs by 140 M€. Thus, the total costs reduction lies for both concepts around 200 million euro per year.

In the report, it is stated that the implementation of the ZNR does not require a different control structure, and can be realized relatively quickly as well. On the other hand, the ONRV has the advantage of being a flexible control concept, which can be more easily reversed or extended. A main difference between the ONRV and the ZNR concepts is that the centralization of balance planning caused by the ZNR will simplify energy trade, because Balance Responsible Parties will need to submit only one schedule for the whole of Germany, instead of one per control area. This will reduce the administration costs for both the TSOs and the market parties[2]. In addition, congestion management costs may differ. Finally, the ZNR concept may create a need to better coordinate tasks and responsibilities of the different TSOs within the single control area.

Although the total costs reduction lies for both concepts around 200 M€, a slightly larger balance management costs decrease has been found for the ZNR concept compared to the ONRV concept, due to the lower balance planning costs. Thus, the comparative study by Technical University of Dortmund and E-Bridge (2009) suggests that the influence of the control area boundaries on the impact of the introduction of a common merit order list is insignificant. Indeed, the differences between the ONRV and the ZNR lie in the realm of coordination and administration; the overall control concept is the same.

However, the study did not consider the broader changes that are required to merge control areas. Merging control areas basically means going to a single power system and electricity market, including a single balancing market. After all, if the balance suddenly is maintained for a larger geographical area, the same balance planning and settlement rules, and a single balancing service market design must apply to that larger area. This

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[2] If different congestion areas / price areas are defined that match the original control areas, the number of energy schedules and the related administration costs will not change.

appears to imply that, if the control areas are part of different countries, the legislation of balance management, i.e. the balancing market design, needs to be harmonized. Nevertheless, the case of the Nordic region, which contains one large control area, shows that differences in balancing market design (and overall electricity market design) may still exist, despite the installation of a regional balancing energy market and a centralized control system. Before 2009, this even included different scheduling and imbalance pricing rules (see subsection 2.1.1). Still, we derive that control area merging may require more balancing market design changes and would therefore be harder to realize.

We conclude that the impact of control area merging is equally large as the introduction of a common merit order list, but that it may be harder to implement, and may not provide additional benefits once a common merit order list has been introduced.

5.1.2 Reservation of interconnection capacity for balancing

Guideline 5 of the balancing market integration guidelines by ERGEG briefly states that ‘no interconnection capacity shall be reserved for cross-border balancing’ (ERGEG, 2009). To this it adds that ‘in the special case of DC interconnectors, interconnection capacity reservation might be possible when such reservation can be demonstrated to increase socio-economic welfare in integrated markets’. The arguments given to support the first statement are that reservation could limit competition in wholesale markets, that it could prevent the full utilization of scarce interconnection capacity, and that (related to this) ‘it is not compatible with the principles laid down in the Regulation (EC) No 1228/2003, in particular with the provisions of Articles 6.3[3] and 4[4]’. However, ERGEG (2009) does also state that ‘demonstration shall be made by TSOs that reservation of interconnection capacity would increase socio-economic welfare taking into account impacts on neighbouring countries and other timeframes’. Although this might be meant to apply just to DC interconnectors, which are considered cases for which the economic case is easier to determine given their high controllability and fewer security issues, no reason is given why social welfare increase may not be found for AC interconnectors.

Next, Frontier Economics (2009) has written a report dedicated to the design option of reserving interconnection capacity for balancing service exchange. It is argued that it is ‘highly unlikely that always allocating 100% of capacity to day ahead exchange will be the social welfare maximizing outcome’. An argument the report gives is that social welfare is determined by price differences, and that supply and demand of day-ahead energy and balancing energy are determined by different factors. It is concluded that the benefit of balancing exchange will in some cases be higher than the loss of value in day-ahead exchange, making reservation of interconnection capacity for balancing worthwhile. Regarding the potential of reservation, the report states that the social welfare benefits of optimal interconnection use are likely to be material. A simplified analysis of a stylized interconnector show that the constant reservation of 50 MW might enhance social welfare by up to 640 million euro over a 40 year interconnector lifetime, which is 16 million

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[3] “...the maximum capacity of the interconnections and/or the transmission networks affecting cross-border flows shall be made available to market participants, complying with safety standards of secure network operation.” (European Commission, 2003)

[4] “...any allocated capacity that will not be used shall be reattributed to the market, in an open, transparent and non-discriminatory manner.” (European Commission, 2003)

euro per year. However, it is added that part of this economic benefit will also be captured without reservation, namely through utilization of capacity that remains unused and through exchange in the direction opposite to the day-ahead flow. Finally, an interesting remark in the report by Frontier Economics (2009) is that in view of the expected increase in both interconnection capacity and intermittent generation, day-ahead prices are likely to converse while balancing prices become more volatile, which will increase the potential of interconnection capacity reservation for balancing.

In ENTSO-E's 2011 position paper on cross-border balancing, the main viewpoints of Frontier Economics (2009) have been included. First of all, that interconnection capacity reservation should only be carried out if social welfare can be demonstrated. Secondly, that interconnection capacity reservation for balancing service exchange should not be explicitly prohibited, but assessed on a case by case basis. However, ENTSO-E does not make a distinction between AC and DC interconnectors; for both the socio-economic impact of reservation should be calculated periodically. In addition, it is put forward that a common set of calculation principles or criteria for determining the optimal levels of interconnection capacity reservation will need to be agreed and defined, considering among others the foregone value of energy trades in the intraday market, the timing of the reservation and the impact on system security.

An in-depth quantitative analysis of the socio-economic impact of reservation in Northern Europe has been carried out by (Jaehnert and Doorman, 2010a). With a three stage optimization model, an integrated North-European regulating power market is simulated, as well as a common, regional day-ahead market. The geographical representation includes different day-ahead market areas, consisting of one node each, and transmission lines between these areas. The first stage is the day-ahead market clearing, which includes data on power plants, transmission system, demand, import and export, hydro inflow and wind speeds as input, and an optimal generation (and transmission) dispatch, water values[5] and area prices as output. In the second stage of reserve capacity procurement, a socio-economically optimal redispatch of the optimal generation dispatch from the first stage is executed, meeting the given reserve requirements in the control areas. Procurement of foreign resources, i.e. reserve capacity exchange, is possible here. In the third stage, the regional system imbalance is removed by least-cost activation of regulating reserves, i.e. balancing energy dispatch. The first two stages are executed on an hourly basis, and the third stage on a quarterly-hour basis. The modelled power system represents the system state in 2008. In the analysis, three cases have been compared: A) No interconnection capacity reservation, B) reservation of 5% of interconnection capacity on the lines connecting the Nordic region and continental Europe for balancing service exchange, and C) reservation of 10% of the interconnection capacity. The outcome is that case B and C reduce the socio-economic welfare by about 4% and 8%. Strikingly, cases B and C reduce the socio-economic outcome of the day-ahead market compared to case A by 80 million euro and 260 million euro, whereas the balancing market costs only reduce by 12 million euro and 23 million euro. It is noted, however, that full integration itself has been found to decrease balancing service costs by 180 million, which strongly indicates that without reservation a lot of interconnection capacity is already available after day-ahead market clearing. The main conclusion by Jaehnert and Doorman (2010a) is that the decrease in

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[5] The water values are the opportunity costs of the stored water and are used as production costs for the hydropower plants in the next steps (Jaehnert and Doorman, 2010a).

the socio-economic benefit in the day-ahead market, resulting from interconnection capacity reservation in Northern Europe, is far higher than the decrease in balancing costs.

We tend to agree with Frontier Economics (2009) and ENTSO-E (2011d) that it cannot be ruled out that reservation of interconnection capacity for cross-border balancing is in some cases social-economically optimal. As argued by Frontier Economics (2009), there are many factors that influence the economic impact of reservation, with day-ahead prices, balancing service prices, typical supply and demand volumes and interconnection capacity as the main determinants. In our view, there is no reason to assume that reserve capacity price differences will always be smaller than day-ahead price differences, let alone that the total economic value of interconnection capacity reservation for CBB will always be smaller than the economic value for conventional cross-border trade. After all, interconnection capacity reserved for balancing purposes cannot only be utilized for reserve capacity exchange but also for balancing energy exchange. The negative outcome of the analysis by Jaehnert and Doorman (2010a) could be explained by the fact that most of the economic potential of balancing service exchange is already exploited by utilization of interconnection capacity remaining after day-ahead market clearance. Indeed, the loss in day-ahead and intraday trade value caused by reservation should be compared with the additional balancing costs reduction realized thanks to this reservation.

5.1.3 Cross-border balancing arrangements

Cross-border balancing arrangements, being the core balancing market design variable concerning integration, is analysed both qualitatively in section 5.3 and quantitatively in section 5.4. Here, we summarize other studies of the effects of this design variable, ordered on the basis of the four main arrangements (see subsection 3.1.2).

System imbalance netting

In Technical University of Dortmund and E-Bridge (2009), in which a cost comparison is made between two conflation concepts for the German balancing market (see subsection 5.1.1), only the costs of system imbalance netting and of a reduction of reserve capacity procurement appear to have been taken into account, not the cost reduction due to the activation of the cheapest balancing energy bids. The costs reduction from system imbalance netting has been estimated at 56 million euro per year, and the costs reduction from reduced reserve capacity procurement at 140 million euro per year.

Jaehnert and Doorman (2010b) find that the activated volumes of balancing energy in Northern Europe can be reduced by 20% due to system imbalance netting. In Jaehnert and Doorman (2012), this is 25%. The related balancing energy costs reductions are not mentioned. Furthermore, Vandezande (2011) find in their quantitative assessment of full balancing energy market integration for the Netherlands and Belgium that system imbalance netting reduces the total balancing energy costs by about 22%.

BSP-SO trading

In Abbasy et al. (2011), the impact of BSP-SO trading of balancing energy for the case of Norway and the Netherlands on BSP behaviour and regulation prices is examined by means of an agent-based model developed in MATLAB. In the model, Balancing Service

Providers decide autonomously on balancing energy bids in each round, taking into account the market results of previous rounds. The case of BSP-SO trading, in which BSPs are allowed to bid in the other balancing energy market, is compared with the reference case of separate real-time balancing. Each agent (BSP) submits two bids in both markets each round. The first bid is submitted at marginal costs (representing the 'risk-averse part' of the BSP portfolio) and the second bid is submitted with the intention to increase the market price (the 'risk-prone part'). The bid volumes are adapted each round on the basis of the relative profitability of both markets, with total capacity equalling the generation capacity in the BSP portfolio. A main finding is that the Norwegian balancing market energy market price does not change noticeably, due to the large excess supply and flat bid ladder in the hydropower-based Norwegian market. However, if the Netherlands exports downward regulation (during peak hours), the Dutch regulation price deteriorates. From this the authors conclude that the regulation price in Norway is more 'resistant to market integration', while the Dutch price is more likely to change. Furthermore, it is concluded that, because the positive effects on the Dutch regulation price are larger than the negative ones, BSP-SO trading has a positive effect on total balancing energy costs for this case. For more research results on the effects of cross-border balancing arrangements in Northern Europe, we refer to Abbasy (2012).

Additional voluntary pool

No quantitative studies have been found on the impact of the introduction of an additional voluntary pool, i.e. forms of balancing service exchange between System Operators without the presence of a common merit order list.

Common merit order list

In Abbasy et al. (2009), an optimization model has been created in Excel to investigate the effect of the integration of the regulation power markets in Northern Europe on the total balancing energy costs. This concerns the introduction of a common merit order list. Marginal pricing is applied, as well as market splitting. In the linear optimization model, the objective function is to minimize the total balancing energy costs, with continuous linear bid ladders as input. Between each of the areas there is an interconnection line with fixed capacity, which form constraints in the optimization problem. Balancing energy demand is included in the form of cases: For each area an average positive and negative system imbalance (plus a zero imbalance for the Nordic region[6]) has been determined on the basis of activated balancing energy data from 2007, and all possible combinations of these form the cases. Together with the probably of occurrence of positive and negative imbalances, the total balancing costs can be approached by solving the optimization problem for all the cases. The main result is that the total annual balancing energy costs for Northern Europe drop from 180 million euro without cross-border balancing to 100 million euro in a scenario with 10% of interconnection capacity available for cross-border balancing. This is a reduction of 80 million euro per year, or a 44% reduction. This is caused both by surplus energy exchange and balancing energy exchange. Furthermore, it was found that area regulation prices do not necessarily decrease after integration: Because

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[6] For the Nordic region in 2007, in 20% of the time, there was no regulation power activated at all.

prices will merge (in case of marginal pricing), some areas may face a price increase, even though the regional balancing costs generally decrease substantially.

Jaehnert and Doorman (2010b) have carried out an optimization study of the impact of balancing market integration in Northern Europe, which also involves a common merit order list. The analysis is carried out by means of the same extensive optimization model as in Jaehnert and Doorman (2010a) (see subsection 5.1.2), including a simplified modelling of the network, power plant scheduling, and common day-ahead market. Also, a wet year and a dry year have been simulated. Regarding balancing energy costs in a wet year, the main outcomes are a total balancing energy costs value of 180 million euro for separate markets, and a cost reduction of 120 million for full balancing energy market integration in Northern Europe. Relative to an already integrated German balancing market, a balancing energy costs reduction of 37% has been found. The balancing energy costs in a dry year are 15-25 million euro higher than for a wet year in the case of separate markets, but the balancing energy costs decrease in percentage is similar to that of a wet year. Regarding reserve capacity procurement in a wet year, the main outcomes are a total reserve capacity costs value of 92 million euro for separate procurement, and a 42 million euro reduction in case 25% of the required national reserve capacity can be imported. This comes down to a 46% costs reduction. Strikingly, the figures are much higher for a dry year: A total cost value of 436 million euro for separate markets, and a 348 million euro cost reduction for 25% import possibility. The differences between the wet and dry year are much higher than for balancing energy, which is probably caused by the overall scarcity of hydropower plants and the increase in water values that this causes[7]. Finally, it is interesting to compare the proportion of balancing energy costs reduction with reserve capacity costs reduction for integration in Northern Europe. Where a common merit order list for balancing energy reduces real-time costs by 36 million euro (37%), the common merit order list for reserve capacity (with a 25% import limit) reduced procurement costs by 42 million euro (46%), which are comparable sums. Moreover, the proportion of total reserve capacity costs and total balancing energy costs in Northern Europe are, according to the analysis results, 0.9:1 before integration, and 0.8:1 after integration. Thus, the proportion of reserve capacity and balancing energy costs also remains comparable in this case. We note that an improved version of this modelling study has been presented in Jaehnert and Doorman (2012), in which somewhat higher balancing costs reduction results have been obtained.

In Farahmand and Doorman (2012), the results of a mathematical model assessing the impact of balancing market integration in Northern Europe show an annual reserve capacity costs reduction of 153 million euro (a 78% reduction), and an annual balancing energy costs reduction of 204 million euro (a 52% reduction).

Vandezande (2011) includes a quantitative analysis of the impact of a common merit order list between Belgium and the Netherlands, using quarter-hourly data from 2008. In the optimization model, built in MATLAB, Belgian system imbalance volumes are based on net activated balancing energy data, and Dutch system imbalance volumes on settled imbalance volumes. Bid ladders are based on available data on specific points of the actual bid ladder curves, and available interconnection capacity is based on available transfer

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[7] Hydropower resources are resources used for balancing in the Nordic region. The level of rainfall and temperature have a large impact on the production capacity of hydropower plants, which has a very large impact on electricity prices, and therefore also on balancing prices.

capacity values after day-ahead closure. An important assumption is that BSPs are remunerated through pay-as-bid pricing. Three cases are compared: 1) a reference case without cross-border balancing, 2) a common merit order list with limitation of available interconnection capacity, and 3) a common merit order list with unlimited interconnection capacity. The main results are that, considering the available interconnection capacity, the total balancing energy costs for the Netherlands and Belgium can be decreased by more than 17 million euro, or 37%. In case of infinite interconnection capacity, the cost reduction is 18 million euro (39%). Based on this, Vandezande (2011) concludes that 'the implementation of cross-border balancing between Belgium and the Netherlands is - from a global perspective - a beneficial goal'. Also, the results show that only a small amount of interconnection capacity is needed to exploit most of the cost reduction potential, and that the remaining capacity after day-ahead closure is large enough to realize that. For this reason, it is also concluded that no 'unrealistic or overly expensive preconditions' are required for this integration.

In Technical University of Dortmund and E-Bridge (2009), which compares two alternative integration models for Germany (see subsection 5.1.1), only the costs of system imbalance netting and of a reduction of reserve capacity procurement appear to have been taken into account, not the cost reduction due to the activation of the cheapest balancing energy bids. The costs reduction from lower reserve capacity procurement volumes has been estimated at 140 million euro per year. Unfortunately, this cost reduction is neither compared to the total balancing service costs before integration, nor to cost reductions from optimal balancing energy dispatch.

In LichtBlick (2008), the potential cost reductions of full balancing market integration for the four German control areas using data from the years 2006 and 2007 are calculated. Costs reductions are not only based on system imbalance netting and activation of the cheapest bids, but also on the reduction of reserve capacity due to a lower (total) reserve requirement[8]. Furthermore, the reduction in primary control capacity costs is included. Thus, the considered integration option is a common merit order list along with control area merging. Reductions of 314 million euro and 341 million euro were found for 2006 and 2007. This would have caused a balancing service costs reduction of 38% in 2006 and of 48% in 2007. If excluding the cost reduction due to lower primary control capacity procurement, the specific results are a 142 M€(36%) / 164 M€(44%) reserve capacity costs reduction and a 146 M€(43%) / 155 M€(60%) balancing energy costs reduction in 2006 / 2007. Here too, we observe comparable cost reduction sums for reserve capacity and balancing energy.

Comparison of results

Regarding the cross-border balancing arrangements of system imbalance netting, BSP-SO trading and the additional voluntary pool, it is not possible to compare results due to a lack of studies on these arrangements. However, multiple studies have been carried out on the impact of a common merit order list. In Table 5.1, the found reserve capacity and balancing energy cost reduction in these studies are listed. For the results of LichtBlick (2008), the average values for the studied years of 2006 and 2007 have been included.

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[8] In the study, the reduction of the reserve requirement is based on the maximum system load. The maximum system load for the whole of Germany is lower than the sum of the maximum system loads of the four control areas.

Table 5.1 – Comparison of external research results on annual balancing service cost reductions realized by a common merit order list

Research	**Region**	**Annual reserve capacity cost reduction**	**Perc.**	**Annual balancing energy cost reduction**	**Perc.**
LichtBlick (2008)	Germany	153 M€	40%	151 M€	48%
Abbasy et al. (2009)	Northern Europe			80 M€	44%
Jaehnert and Doorman (2010b)	Northern Europe	42 M€	46%	36 M€	37%
Farahmand and Doorman (2012)	Northern Europe	153 M€	78%	204 M€	52%
Vandezande (2011)	Netherlands and Belgium			17 M€	37%

Remarkably, despite the fact that these results concern different areas and are the result of different modelling exercises, most of the found balancing service costs reductions are between 35% and 50%. Thus, it might be concluded that the introduction of a common merit order list can generally be expected to reduce balancing service costs by 35-50%. A second conclusion from this comparison could be that the level of the reserve capacity costs reductions are similar to the level of balancing energy costs reductions (in case a common merit order list for both types of balancing services is introduced). More generally, we can conclude from the compared studies that the common merit order list results in large balancing service costs reductions, and that the reductions are comparable for reserve capacity and balancing energy.

5.2 Multi-criteria analysis of multinational design variables

The multi-criteria analysis of multinational design variables has the same structure as the multi-criteria analysis of national design variables in section 4.6. The effects estimation consists of three points: 1) Estimation of the impact level of individual design variables, 2) estimation of the influence of the contextual factors on the impact of each design variable, and 3) consideration of the existence of a 'best' variable value. The full effect estimation itself, including overview tables of the results, have been placed in appendix I.

The impact level of a design variable reflects the degree to which balancing market performance is affected by this variable. The context dependence of the effects reveals the degree to which the impact of design variables are influenced by contextual factors. The consideration of a clear 'best' variable value that holds in any context (power system) helps to find balancing market design recommendations.

Because there is not an initial multinational balancing market design (or set of national designs) and corresponding performance level against which the effects of design variables can be evaluated, the effects estimation is a generic exercise. Consequently, the results of this estimation do not reveal concrete impacts on balancing market performance. The multi-criteria analysis of multinational design variables provides a general insight into the scope, value and content of multinational balancing market design change and balancing market integration.

The results of this multi-criteria analysis are presented in a similar way as for the national design variables in section 4.6.

Total impact of multinational balancing market design on performance

The qualitative estimation of the impact level of the multinational balancing market design variables can first of all provide insights in the total impact of the design variables. With 'total impact' is meant here the aggregate of the effects of a design variable on all eleven performance criteria combined. By converting the qualitative effect estimations listed in appendix I into numerical values, this total impact can be quantified. The applied conversion is presented in Table 5.2.

Table 5.2 – Quantification of effects of multinational balancing market design variables in multi-criteria analysis

Estimated effect	Numerical value
small	1
moderate	2
large	3
very large	4
huge	5

Starting with the sum of the total impact levels for all design variables combined, the estimation has resulted in a total score of '230', which is 38% of the theoretical maximum of '605' (5 times 11 criteria times 11 variables). This can be translated into an average impact level of 1.9 on the 0-5 scale (almost 'moderate') across all variables and criteria. Compared to the 1.2 found for the national design variables, this is substantially higher. As the impact of the national balancing market design on performance was evaluated to be high, the impact of the multinational design on performance should be evaluated as very high. After all, the average impact level of 1.9 is caused by a high amount of impact levels that have been estimated as 'very large', spread out over different multinational design variables.

Total impact of individual multinational design variables

Looking at the individual variables, we find that the total impact ranges from 44 (an average of 4 on each criterion) to 5 (an average of 0.45). Figure 5.1 shows four groups of multinational variables, sorted by total impact values. The variables with a value in the range [0,11] form the group with the lowest values, followed by the variables in the range [12,22], the range [23,33], and the range [34,44]. In increasing order, these groups contain two, four, three, and two multinational design variables.

Because of the small number of multinational variables (11) compared to the national variables (24), it is easier to check the obtained ranking of variables. The variable 'balancing region boundaries' has been estimated to have the highest impact, which is obvious, because the choice of the participating control areas in balancing market integration determines what are the initial national designs and performance levels. 'Cross-border balancing arrangements' is found to have the second-highest total impact, which makes sense given that it is the key variable determining the level of balancing market integration. 'Regional service provision rules' are most relevant if a common merit order list is introduced, in which case this variable deals with the procurement method, pricing mechanism, bid requirements and timing applied to the regional balancing service market. Looking at the impact of the corresponding national variables, this justifies a high

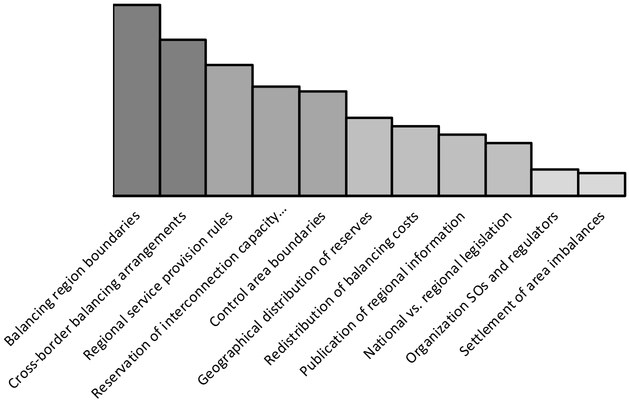

Figure 5.1 – Multi-criteria analysis results: Total impact of multinational balancing market design variables

score. Next, the 'reservation of interconnection for balancing' can have a large impact on the cross-border balancing potential and the social welfare of cross-border exchanges, which makes a high impact score explainable. 'Control area boundaries' and 'geographical distribution of reserves' both have a major impact on the demand for and supply of balancing resources. The 'redistribution of balancing costs', which is merely about additional settlement between System Operators, logically has a lower total impact than the variables already mentioned. 'Publication of regional information' only influences the transparency of rules and data, which is not expected to have a major impact either. 'National vs. regional legislation' sounds like a very influential design variable. However, this variable does not so much deal with the content of the regulatory balancing regime, but much more with the choice of legal documents in which to specify which rules. Finally, the most important aspect of 'organization of SOs and regulators' is the appointment of a regional SO in the case of a common merit order list, and 'settlement of area imbalances' is about a small multinational design aspect of balance management. All in all, the found order of multinational variables based on total impact level appears straightforward and realistic.

Total impact on individual performance criteria

The total impact of multinational design variables on the individual balancing market performance criteria has been uncovered by summing up the quantified effects of all the multinational variables on the same performance criterion. The ranked total scores are shown in Figure 5.2.

Here, the maximum possible score is 11 times 5, i.e. 55. The highest score (price efficiency) is 28 (51% of the maximum), and the lowest score (operational efficiency) is 12 (22%). On overall, we can conclude from this that the multinational balancing market

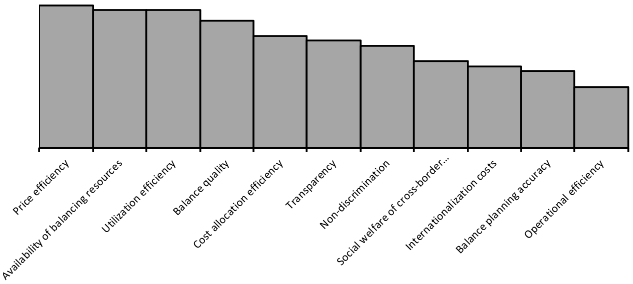

Figure 5.2 – Multi-criteria analysis results: Total impact of multinational balancing market design on performance criteria

design, i.e. the part of it not belonging to the national balancing market design[9], has a large impact on all performance criteria. After all, a score of 12 already means that e.g. all of the design variables have a small effect on the performance criterion, and 12 times a small effect adds up to a large total impact on this criterion[10].

Looking at the scores, and comparing these to the total impact of national balancing market design on individual performance criteria, a couple of observations can be made. To start, the total impact level of multinational balancing market design (i.e., the sum of impact levels of all multinational variables), is 72% of the total impact level of national design. Thus, the set of multinational variables has been evaluated to have a smaller impact than the set of national variables. The most important cause is the smaller number of design variables. But as follows from the fact that the number of multinational variables is only 46% of the number of national variables, the impact levels of individual multinational variables are higher. This reflects that the multinational design variables are generally more high-level than the national variables, affecting multiple national balancing markets in many ways.

Furthermore, the ranking of total impact scores of individual criteria for the multinational variables is similar to that of the national variables. The top four performance criteria are the same, only the order is different. Here too, a lot of variables have a significant impact on balancing service volumes and prices, and thereby on the criteria that are directly linked to these factors. Several multinational variables have to do with balancing market integration, and thereby with the balancing costs reductions that such integration can achieve. For multinational design, price efficiency is affected more than availability of balancing resources and utilization efficiency, but the difference is minimal. It can be attributed to the estimated effect of the variable ‘redistribution of balancing costs’ on price efficiency, and the absence of such an effect on the other two criteria (see appendix I). The next three performance criteria in order of decreasing total impact level are costs al-

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[9] As mentioned earlier, multinational balancing market design actually includes all the national variables as well. Here, we consider just the multinational design variables.

[10] It should be kept in mind that effects of different variables could cancel each other out on an aggregate level, and that the actual impact of a multinational design depends on the included variables and variable values. Thus, we have estimated potential (maximum) total impact levels in the MCA.

location efficiency, transparency and non-discrimination, which is also similar to national balancing market design. Those criteria are estimated to be significantly affected by balancing market integration, which is not only represented by the variable of cross-border balancing arrangements, but also by balancing region boundaries, reservation of interconnection capacity for balancing, regional service provision rules, publication of regional information, and redistribution of balancing costs. Finally, the four least affected criteria are social welfare of cross-border exchanges, internationalization costs, balance planning accuracy and operational efficiency, which is again similar to national design. The exception is balance planning accuracy, which ranked fifth in the importance order for national design. The reason for this is that balancing market integration predominantly influences balancing service costs and BSP incentives. Although imbalance prices are affected indirectly as well, effects of integration on BRP imbalance volumes are much less obvious. Of course, the social welfare of cross-border exchanges is significantly affected by the multinational variables linked to integration.

Like for national design, we compare the sum of the total impact levels for the market facilitation criteria, security of supply criteria, economic efficiency criteria, and multinational criteria (see Figure 3.5):

- Economic efficiency criteria: 39%
- Security of supply criteria: 29%
- Market facilitation criteria: 18%
- Multinational criteria: 14%

This time, the economic efficiency criteria are affected more than the security of supply criteria, which indicates that multinational balancing market design has a larger impact on the fundamental requirement of economic efficiency than on security of supply. This is caused by the relatively high effects on the economic criteria, compared to the effects on the availability of balancing resources. Indeed, balancing market integration principally influences the costs of balancing service provision. The market facilitation criteria have become a little more important, which relates to the larger transparency and non-discrimination issues resulting from the interactions between different national balancing markets. The multinational criteria are naturally more important than for national design, although this group still has the lowest importance of the four.

Wrapping up, also for the multinational design holds that it has a major impact on the two fundamental balancing market requirements of security of supply (effective balance management) and economic efficiency (economic efficiency of the balancing market), although their combined share in the total impact is 68%, compared to 79% for national design. This underlines the relevance of balancing market design.

Total influence of contextual factors on performance

Subsequently, we take a look at the influence of the contextual factors introduced in section 4.5, which has been estimated for all variables, using the same conversion method as outlined above. See appendix I. We have obtained a similar ranking of design variables as in Figure 5.1. As for the national variables, we found a certain correlation between the context dependence and the impact level of multinational design variables. We come back to this issue in chapter 6.

Second, the total influence values of individual contextual factors are of interest. These are presented in Figure 5.3. To start, the sum of the total influence values equals the value of '162', which comes down to an average influence per criterion of 14.7, which e.g. means all contextual factors have at least a small influence for all design variables, and about four factors have a moderate influence. Because the maximum possible influence would have been '605', this sum is 27% of the maximum possible influence, which converted to the 0-5 scale means an average value of '1.34' (between small and moderate) across all contextual factors and variables. Based on this, we can conclude that the impact of multinational balancing market design and integration are dependent to a large degree on the contextual power systems and markets. Compared to national design, the total context dependence of effects of multinational design has been estimated to be a bit smaller, but the average context dependence per variable is higher[11]. This higher context dependence (for individual multinational variables) is for an important part caused by the interaction between diverging power systems.

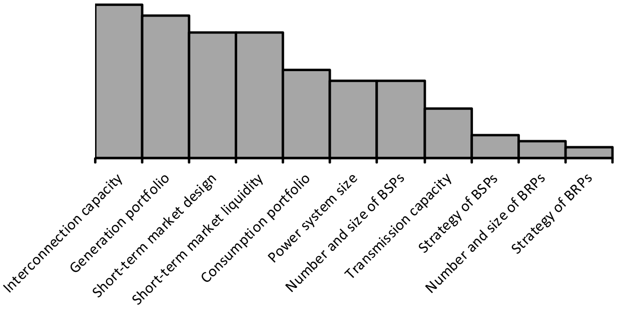

Figure 5.3 – Multi-criteria analysis results: Total influence of contextual factors on multinational balancing market design

For the discussion of the relative influence of different contextual factors on the impact of multinational balancing market design, we compare the ranking of factors with that for national balancing market design. This produces a significant difference in ranking for four contextual factors. The contextual factor with the largest influence on multinational design, 'interconnection capacity', scored second-last for national design. This makes perfect sense, because the availability of interconnection capacity is only relevant for the cross-border balancing taking place in integrated balancing markets. Next, the number

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[11] This is similar to the comparison between national and multinational design based on the impact on performance, and can be explained by the lower number of multinational design variables (see above).

and size of BRPs has been estimated as relatively uninfluential for multinational design, as opposed to national design. This is caused by the assessment that the effects national balance planning and settlement are influenced by this contextual factor, and the absence of such variables in the multinational part of the design space. Third, for multinational design the transmission capacity is a lot less influential, which is because the multinational variables are about cross-border trade and multinational balancing, rather than balancing within national power systems. Last, the short-term market liquidity is a more important contextual factor for multinational design. This is because the liquidity of short-term markets is assumed to have a large impact on cross-border trade, and thereby on the remaining available interconnection capacity for balancing service exchange.

Generalizability of design variable values

In the multi-criteria analysis, for each multinational design variable the effects of alternative variable values have been discussed, in order to determine the impact level of the variable. This has also led to the specification of a 'best' design variable value for each variable, as far as this was possible. See appendix I. These specifications have been made taking into account different possible power system/market contexts. Based on these specifications, we have ordered the design variables into three groups on the basis of the generalizability of a 'best' design variable value. The three used qualifications are 'high', 'medium' and 'low'. The results of this exercise are shown in Table 5.3.

Table 5.3 – Generalizability of 'best' multinational design variable values

High	Medium	Low
Organization SOs and regulators Settlement of area imbalances	Control area boundaries Cross-border balancing arrangements Regional service provision rules Publication of regional information National vs. regional legislation	Balancing region boundaries Geographical distribution of reserves Reservation of interconnection cap. for balancing Redistribution of balancing costs

Although this classification of design variables is based on a rough exercise, it provides us with some additional insights. Most importantly, it generally shows that in-depth (qualitative) analysis can generate arguments to support the superiority of specific multinational design variable values. Next, the list of 'best values' indicates that which variable value has the most positive impact on performance often depends on the power system/market context. Also, it is relatively difficult to specify best designs for the multinational variables (compared to the national variables), because their scope is much broader and richer. This is reflected by Table 5.3, where most variables have been classified under 'medium' or 'low' generalizability, whereas national variables were classified mostly under 'medium' and 'high'. This difference could be explained by the higher context dependence of the effects of multinational design variables.

Conclusion

In short, the multi-criteria analysis of multinational balancing market design has brought us to conclude the following. The total impact of multinational balancing market design on balancing market performance is large, especially on the performance criteria corresponding with the fundamental requirements of security of supply and economic efficiency. Therefore, the impact of balancing market integration, which encompasses the introduction of (a) cross-border balancing arrangement(s), can also be expected to be high (even though integration does not include all multinational variables). The remaining sections in this chapter will focus more on the impact of integration. Furthermore, the impact of multinational design is to a large degree influenced by the contextual power systems and markets. These results point out the importance of multinational balancing market design and of a careful decision-making process on balancing market integration.

5.3 Multi-criteria analysis of cross-border balancing arrangements

In this section, the results of an in-depth multi-criteria analysis carried out for the main cross-border balancing arrangements are presented. The effects of the cross-border balancing arrangements on the balancing market performance criteria have been assessed qualitatively, taking into account the impact on market behaviour, as well as the dependency on contextual factors. The assessed effects are relative to the performance of separate balancing markets. Possible detailed design options within each of the cross-border balancing arrangements have been considered as well. Importantly, it has been assumed in the MCA that the most beneficial detailed design options are introduced. In other words, the potential benefits of alternative arrangements have been evaluated. Finally, we have estimated the overall effects on the balancing region level, although diverging effects in different areas have been considered as well. This analysis is an extension of our work presented in van der Veen et al. (2009) and van der Veen, Abbasy and Hakvoort (2010b).

For this analysis, a distinction has been made not only between the four main cross-border balancing arrangements presented in chapter 3, but also between reserve capacity and balancing energy. This is because reserve capacity exchange and balancing energy exchange are two forms of cross-border balancing of different nature, with a different potential and impact. Besides, the arrangements of BSP-SO trading and an additional voluntary pool can be used for both reserve capacity exchange and balancing energy exchange. The arrangement of the common merit order list can be applied to balancing energy only, but not to reserve capacity exchange only. Considering all this, seven arrangements have been included in this multi-criteria analysis:

- System imbalance netting
- BSP-SO trading of balancing energy
- BSP-SO trading of reserve capacity
- A voluntary pool for balancing energy
- A voluntary pool for reserve capacity
- A common merit order for balancing energy
- A common merit order for reserve capacity

It must be noted that some of these seven cross-border balancing arrangements could be introduced and applied simultaneously. Indeed, for different reasons, the above arrangements overlap to some extent. A common merit order list does by definition include system imbalance netting, because the regional system balance is maintained there. Furthermore, a common merit order list for reserve capacity implies the introduction of a common merit order list for balancing energy. And although this does not apply to BSP-SO trading and the voluntary pool, the fact that the interconnection capacity reservation required for reserve capacity exchange has much greater value if balancing energy exchange takes place on a larger scale leads to the assumption that the reserve capacity arrangements include the balancing energy arrangements. Regarding the availability of interconnection capacity for balancing in general, we have assumed that there is a limited amount of capacity left after final gate closure for cross-border balancing in the direction of the power flow. Of course, balancing service exchange in the direction opposite to the power flow is always possible. Furthermore, we have assumed that interconnection capacity will only be reserved when it improves the social welfare of cross-border exchanges, and that this will in practice occur on a regular basis. Another important simplification is that the impact of harmonization of national design variables is not included in this multi-criteria analysis, even though some harmonization is required for a common merit order list (see chapter 6). This is to keep the multi-criteria analysis dedicated to the arrangements.

This multi-criteria analysis makes use of the same performance criteria and contextual factors as the earlier analyses, but here the estimated effects are relative to the situation of separate national balancing markets. The detailed effect estimation of the seven cross-border balancing arrangements can be found in appendix J. Below, the results are presented and discussed.

Total impact on balancing market performance

The most important result of this multi-criteria analysis is the total impact on performance of each of the seven cross-border balancing arrangements. To quantify this, the qualitative effects have been converted to numerical values. The used values are listed in Table 5.4. Adding up the quantified effects on all eleven performance criteria for each individual arrangement, and ranking the arrangements in order of decreasing total impact, results in the bar chart shown in Figure 5.4.

We emphasize that equal weights were assumed for the performance criteria, as we have also done in the earlier MCAs, and has been validated (see appendix E). This may underestimate the generally positive effects of cross-border balancing arrangements on balancing costs (price efficiency and utilization efficiency) and the effectiveness of system balancing (availability of balancing resources).

To put the estimated total impact values into perspective, we note that the maximum possible impact is '+/- 55' (5 times 11 criteria). As can be seen, the largest total impact of an arrangement is rated at '8', which is 14.5% of the maximum. A value of '8' comes down to an average effect score per performance criterion of '0.73' (between zero and 'small increase'). We consider this score to reflect a large total impact.

The arrangements that come out as the ones with the highest total impact (score '8', 14.5% of maximum) are system imbalance netting, a common merit order list for balancing energy, and a common merit order list for reserve capacity. However, individual

Table 5.4 – Quantification of effects of cross-border balancing arrangements in multi-criteria analysis

Estimated effect	Numerical value
huge reduction	-5
very large reduction	-4
large reduction	-3
moderate reduction	-2
small reduction	-1
small increase	1
moderate increase	2
large increase	3
very large increase	4
huge increase	5

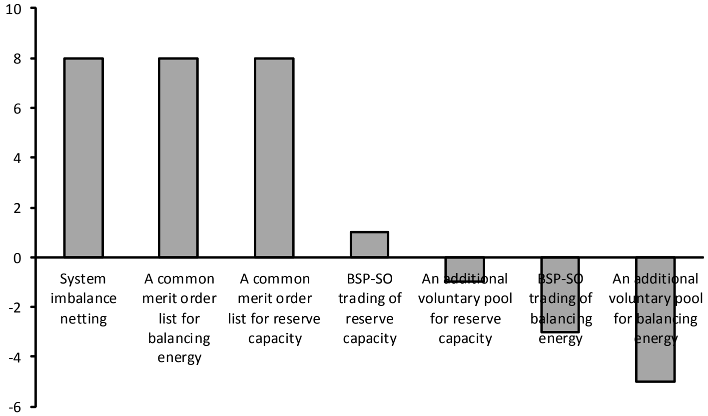

Figure 5.4 – Multi-criteria analysis results: Total impact of cross-border balancing arrangements on balancing market performance

effects on performance criteria were evaluated quite differently. The common merit order list arrangements have a large to very large effect on availability of balancing resources, price efficiency, utilization efficiency and social welfare of cross-border exchanges, but a negative effect on cost allocation efficiency, operational efficiency, transparency, and internationalization costs. System imbalance netting has a lower positive effect on the criteria on which the common merit order list arrangements scored high, but hardly has any negative effect. As a result, the net effect of system imbalance netting has been found to be the same as that of the common merit order list arrangements. Indeed, system imbalance netting does not alter the balancing market designs, whereas it still reduces the activated balancing energy volumes. Comparing both common merit order list arrangements, the common merit order list for reserve capacity has been estimated to have a higher positive effect on the abovementioned criteria thanks to the utilization of the reserved interconnection capacity for both reserve capacity exchange and balancing service exchange, whereas the effects on operational efficiency, transparency and internationalization costs have been estimated as more negative.

Next to these three arrangements, BSP-SO trading of reserve capacity is the only one of the remaining arrangements for which a positive total impact has been found. This positive score is minimal, though (score '1', 1.8% of maximum). Compared to the common merit order list arrangements, the positive effects of BSP-SO trading of reserve capacity also has on availability of balancing resources, price efficiency, utilization efficiency and social welfare of cross-border exchanges have been estimated to be smaller. This is due to the absence of system imbalance netting and the volume limit on balancing energy exchange that prevents adverse effects on security of supply and BSP strategies (see appendix J).

An additional voluntary pool for reserve capacity has been estimated to have a minimal negative impact (value '-1', 1.8% of minimum). This is despite the higher positive effects on the four abovementioned criteria (compared to BSP-SO trading), caused by the higher estimated cross-border balancing volumes enabled by the full control by SOs over exchanged bids. Most importantly, negative effects on cost allocation efficiency, non-discrimination and transparency have been estimated to develop for this arrangement, mainly because of the same SO control, and corresponding uncertainties on exchanged bids and resulting balancing service and imbalance prices.

Next, BSP-SO trading of balancing energy has been estimated to have a slightly more negative total impact on balancing market performance (value '-3', or 5.5% of the minimum). The difference with BSP-SO trading of reserve capacity can be explained by the fact that the latter also includes the positive effects of reserve capacity exchange.

Finally, an additional voluntary pool for balancing energy has been estimated to have a small negative total impact (a value of '-5', or 9.1% of the minimum). The difference with the additional voluntary pool for reserve capacity can again be explained by the absence of reserve capacity exchange. Compared to BSP-SO trading of balancing energy, the negative effects on cost allocation efficiency, non-discrimination and transparency have made a larger contribution than the higher positive effects on availability of balancing resources, price efficiency and utilization efficiency.

Average impact on individual performance criteria

The average impact of the cross-border arrangements on the individual performance criteria is presented in Figure 5.5. This figure confirms the above observations that the arrangements typically have a positive impact on the availability of balancing resources, utilization efficiency, price efficiency and the social-welfare of cross-border exchanges, all which result from the cross-border balancing enabled by the introduction of a cross-border balancing arrangement. The level of other performance criteria decreases on average. Obviously, the introduction of an arrangement brings internationalization costs (the increase of these costs has been converted to a negative effect). Operational efficiency is often reduced, because the cross-border balancing requires much more transactions between System Operators. Furthermore, the interactions introduced between the national balancing markets will probably decrease the transparency, cost allocation efficiency and non-discrimination to some extent. Balance planning accuracy may decrease a bit a result of lower imbalance prices, while balance quality could decrease due to incentives for non-delivery to BSPs (see appendix J).

Comparing the order of importance of individual performance criteria with those

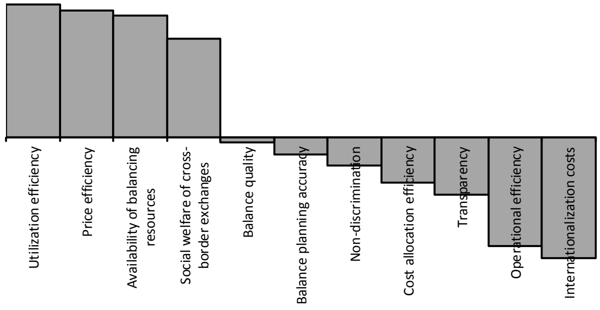

Figure 5.5 – Multi-criteria analysis results: Average impact of cross-border balancing arrangements on balancing market performance criteria

found for national/multinational balancing market design in the other MCAs (see section 4.6 and section 5.2), the three most striking differences are the high impact on social welfare of cross-border exchanges, internationalization costs, and operational efficiency. That the first two criteria are highly influenced by integration does not come as a surprise. The importance of operational efficiency is less straightforward. As it turns out, there are not many balancing market design variables that have a large effect on the number or complexity of transactions in the balancing market, whereas balancing market integration requires a lot of transactions between System Operators in order to plan for, carry out and settle balancing service exchange and surplus energy exchange.

Also, we can take a look at the average influence of contextual factors on arrangements. To quantify the average influence levels, the evaluation ‘small’ has been converted to a value of ‘1’, ‘moderate’ has been converted to ‘2’, ‘large’ to ‘3’, ‘very large’ to ‘4’ and ‘huge’ to ‘5’. The average influence values are shown in Figure 5.6. As can be seen, the generation portfolio has the largest influence on the effects of cross-border balancing arrangements. This is logical, as it stands at the basis of balancing service price level differences between control areas, which determines the economic potential of balancing service exchange. The high influence of interconnection capacity is even more obvious – no interconnection capacity means no cross-border balancing. More remarkable is the high influence of the power system size, because this contextual factor was found to have a small influence on the impact of balancing market design. Here, the relative size of power systems in an integrated balancing region determines the degree of mutual cross-border balancing that can take place. Furthermore, the number and size of BSPs is relatively important because balancing market integration has the potential to greatly improve the level of competition in balancing service markets. Transmission capacity has been estimated to have no influence because of its national scope.

Impact on different stakeholders The above findings apply to the balancing region as a whole, i.e. the regional balancing market performance has been evaluated to significantly improve for system imbalance netting and a common merit order list, and change

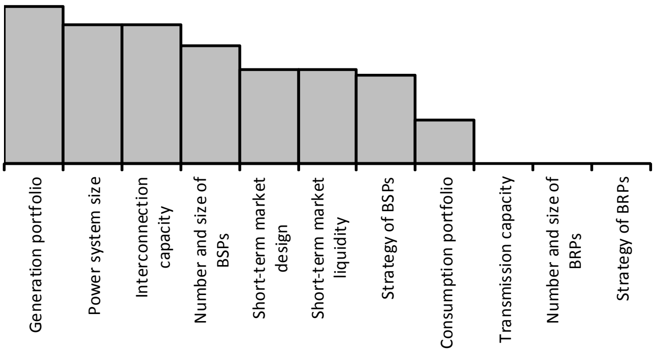

Figure 5.6 – Multi-criteria analysis results: Average influence of contextual factors on impact of cross-border balancing arrangements

in a smaller and more uncertain and design-dependent way for BSP-SO trading and an additional voluntary pool. But the impact of a cross-border balancing arrangement will be different for different System Operators, and for Balancing Service Providers and Balance Responsible Parties of different countries.

In the effects estimations in appendix J, effects of cross-border balancing arrangements have been evaluated by considering control areas that have national balancing markets with a different reserve capacity and balancing energy price level, which implies a relatively high value of balancing service exchange. This value is in some way distributed among parties as a result of cross-border balancing. This distribution is determined by detailed design choices in the cross-border balancing arrangements, and affects the value of integration for different stakeholders (SOs, BSPs and BRPs of different control areas). Furthermore, the introduction of arrangements will also affect the balancing service prices and imbalance prices, and therewith the overall economic performance of different national balancing markets, the balancing service profits for BSPs of different areas, and the imbalance costs for BRPs of different areas. Particularly important for this aspect is whether or not balancing service exchange directly influences the balancing service prices. Under BSP-SO trading, the bidding of BSPs from 'cheap areas' into balancing service markets of 'expensive areas' could lead to large price decreases in the expensive (importing) area, but at the same time to large price increases in the cheap (importing) area. However, such direct effects can be prevented by setting limits/rules to balancing service exchange. Similarly, for an additional voluntary pool, SOs could only exchange excess bids in order not to influence national prices, but they could also choose against a separate settlement of exchanged bids, which has several advantages (see appendix J). In fact, in a common merit order list, the regional pricing will by definition lead to price merging, increasing prices in cheap areas and decreasing prices in expensive areas.

One might argue that the SOs of areas in which prices increase 'lose' because of the increase in national balance management costs. The BRPs in these areas also 'lose' because of the higher imbalance costs, but the BSPs 'win' thanks to higher balancing service rewards. Exactly the opposite can be said for importing areas: prices decrease, and therefore the SOs and BRPs 'win', while BSPs 'lose'.

Of course, it is not as simple as that. First of all, the impact of integration on operational security of supply is also an important consideration. This is not easy to do: On the one hand, integration leads to a higher availability of balancing resources for all control areas in the balancing region, but on the other hand will a high degree of balancing service exchange introduce a dependency on availability of foreign resources and interconnection capacity. Second, market participants in the electricity sector often play both the role of Balancing Service Provider and of Balance Responsible Party. As a result, the net effect of price changes for individual market participants depends on their market activities, and also on their market position. This will differ per participant, and depend among others on the predictability of the energy portfolio and the ownership of flexible resources. Finally, cross-border balancing exchanges and benefits will never occur in one direction only, i.e. all included areas will benefit to some level.

Conclusion

On overall, we have observed that the impact of balancing market integration highly depends on the introduced cross-border balancing arrangement. The introduction of an arrangement could have a large effect or small effect, but huge changes in performance level have not been found. Furthermore, the net impact can be positive or negative. Considering the individual arrangements, BSP-SO trading and the additional voluntary pool appear to have limited effects, where the choice for a detailed design has a relatively large influence. On the other hand, system imbalance netting and the common merit order list appear to have a clear and large positive impact. Also, these arrangements require less design choices, so the impact is less dependent on them. Regarding types of exchanged services, the cross-border trade of reserve capacity has been found to have a more positive effect, because of the additional possibilities the interconnection capacity reservation creates for balancing energy exchange, and the assumption that balancing energy exchange takes place as well. However, an insignificant potential for such reservation, or adverse reservation reducing social welfare, would not have resulted in a higher benefit for reserve capacity exchange.

5.4 Case study of Northern Europe: impact of integration

In this case study, the aim is to estimate the impact of the possible integration of balancing market designs for the Nordic region, Germany and the Netherlands. This enables the consideration of the specific situation of Northern Europe (see subsection 4.7.1).

The impact of balancing market integration on balancing market performance in Northern Europe has been studied by means of an agent-based analysis of the impact of main cross-border balancing arrangements, which is described below. The analysis is confined to surplus energy exchange and balancing energy exchange arrangements. This analysis is based on our work presented in van der Veen et al. (2011a) and van der Veen et al. (2011b).

Agent-based analysis of impact of cross-border balancing arrangements Agent-Based Modelling, a suitable modelling paradigm for the analysis of balancing markets, has been used as well in the analysis of the imbalance pricing mechanism (subsection 4.4.3). The agent-based model used for that analysis has been expanded for the analysis of the impact of main cross-border balancing arrangements on performance in Northern Europe. This means that the effect of integration on the behaviour of Balance Responsible Parties (BRPs) is taken into account in the analysis. This is of interest, because integration will affect imbalance prices through the change in balancing energy prices, changing the system imbalances caused by BRPs. Thus, this means an indirect effect on total balancing energy costs, next to the direct costs reductions to be expected from integration. More generally, this generates insight into the interactions in the multinational balancing market.

Model description The agent-based model, which has been built in MATLAB, basically consists of the balancing markets of the Netherlands, Germany and the Nordic region. The only physical power system elements included are the cross-border capacities between the three areas, which need to be available for cross-border balancing. In Figure 5.7 the fundamental structure and functioning of the balancing market, as embedded in the model, is shown. It is the same as the structure used in the analysis of the imbalance pricing mechanism, but here it is used in triplicate, to represent the three markets. Thus, in all three markets, there is a set of BRPs who decide on an intentional imbalance option for each round (Schedule Time Unit) and thereby aim to minimize their Actual Imbalance Costs. Furthermore, fixed day-ahead market prices and up- and down-regulation bid ladders are used as well. The latter means that it is assumed that bidding strategies by Balancing Service Providers are not affected by integration; they keep bidding at marginal costs. Finally, the imbalance pricing mechanisms for the different areas are also fixed here (except for the common merit order list, where a uniform imbalance pricing mechanism is used). For the details of this model structure, including the decision-making algorithm used by the Balance Responsible Parties, we refer to subsection 4.4.3.

Model steps The model steps are the same as described in subsection 4.4.3, but the different cross-border balancing arrangements, represented by different model versions, lead to some interaction between the balancing energy markets, as a result of which an additional step takes place in which bid ladders are formulated. Also, regional pricing mechanisms are adopted for the common merit order list. See below.

Model input The model input for each area consists of four main data sets. First, there is a list of BRPs that contains two properties: the portfolio size (in MW) and a standard deviation of the forecast error, which is used to determine unintentional imbalances. Second, the upward and downward bid ladder consist of a fixed set of bids, each with a specific bid volume (in MW) and a bid price (in €/MWh). Third, a fixed day-ahead market price is assumed (in €/MWh). Furthermore, a fourth type of input concerns the cross-border capacity: The transfer capacity values for the three interconnections between the areas, and the physical cross-border flows (both in MW). The model input is described in appendix G.

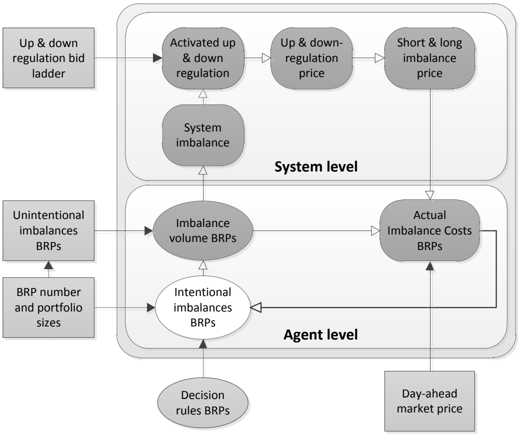

Figure 5.7 – Structure of the agent-based balancing market model, which is used to analyse the impact of cross-border balancing arrangements in Northern Europe, taking into account the behaviour of Balance Responsible Parties.

Cross-border balancing arrangements In the analysis, six alternative cross-border balancing arrangements, 'arrangements' in short, are compared. They are visualized in Figure 5.8. They are presented in order of increasing degree of integration. Included are the four main cross-border balancing arrangements from the design framework (see subsection 3.1.2), a model that includes fully efficient cross-border energy exchange called 'balancing energy trading', and the reference case of separate markets. A short explanation of the modelled arrangements is given below.

- *Separate markets*: In this reference arrangement, with which the other arrangements will be compared, the three balancing markets of the Netherlands, Germany and the Nordic region are operating independently. The interconnection lines are not used.

- *System imbalance netting*: In this arrangement, the occurrence of opposite system imbalances will cause surplus energy flows from the surplus area to the deficit area, resulting in reduced activation of upward/downward regulation in the deficit/surplus area. If the amount of available interconnection capacity is insufficient, the surplus energy flows are capped to the size of this capacity. System imbalances are completely removed when possible. If the system surplus in one area is not large enough to cover the system shortages in the two other areas, the surplus energy flows are calculated according to Equation 5.1:

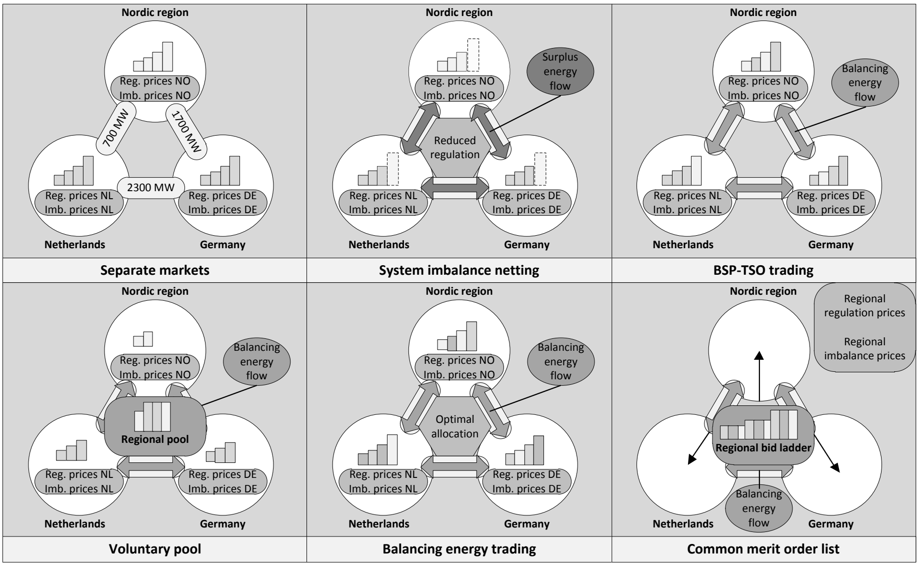

Figure 5.8 – The six modelled cross-border balancing arrangements in the agent-based analysis

$$
\begin{aligned}
f_{AB} &= \frac{S_B}{S_B + S_C} \cdot S_A \\
f_{AC} &= \frac{S_C}{S_B + S_C} \cdot S_A
\end{aligned}
\tag{5.1}
$$

Equation 5.1 applies only if the conditions in Equation 5.2 hold:

$$
\begin{aligned}
S_A &> 0 \\
S_B &< 0 \\
S_C &< 0 \\
S_A &< S_B + S_C
\end{aligned}
\tag{5.2}
$$

In these equations, S_A is the system imbalance in the surplus area A (in MWh), S_B and S_C are system imbalance volumes in deficit areas B and C (in MWh), and f_{AB} and f_{AC} are the surplus energy flows from A to B and from A to C (in MWh), respectively. Similar equations are applied in the situation in which the sum of the system surpluses in two of the areas is larger than the system shortage in the third area. As a result, the model applies a proportional redistribution of ACEs, which we consider is a fair and incentive compatible allocation of the netting potential.

- *BSP-SO trading*: Here, balancing energy bids mays be offered into the balancing energy market of another area instead of the own. Specifically for this arrangement, the BSPs are represented by agents that are responsible for the submission of one specific bid. Each round each BSP has to choose a market/area in which to bid, but the bid price and volume remain fixed. The chance of choosing a specific market is proportional to the average expected actual profits for each of the three areas, which are based on the actual profits that a BSP gained in previous rounds in which it bid in those areas. The actual BSP profits are considered equal to the difference between the regulation price and the national day-ahead price. The used calculation of the expected profit values for up-regulation bids (BSPs) is given in Equation 5.3, and that for down-regulation bids (BSPs) in Equation 5.4:

$$E(ABP)_{n,X,Y} = E(ABP)_{n,X,Y} \cdot \rho + \frac{Q_{n,r,X} \cdot (P_{\text{upreg},r,X} - P_{da,Y})}{\rho + 1} \tag{5.3}$$

$$E(ABP)_{n,X,Y} = E(ABP)_{n,X,Y} \cdot \rho + \frac{Q_{n,r,X} \cdot (P_{da,Y} - P_{\text{downreg},r,X})}{\rho + 1} \tag{5.4}$$

  In these equations, $E(ABP)_{n,X,Y}$ is the expected actual balancing energy profit for BSP (bid) n from area Y if offered into area X (in €), $Q_{n,r,X}$ is the dispatched balancing energy volume in the active round r (in MWh), $P_{upreg,r,X}$ and $P_{downreg,r,X}$ are the upward and downward regulation price for the active round in area X (in €/MWh), $P_{da,Y}$ is the day-ahead price in area Y (in €/MWh), and ρ is the recency parameter. With this, the decision-making algorithm of BSPs in this arrangement resembles that of the BRPs (see Equation 4.2), and leads to a rational distribution of bids over the areas. However, also included is a 10% chance that the BSP will randomly select a market, which is required to continue experimentation and thereby improve decision-making. Like in the remaining arrangements, the availability of cross-border capacity is checked before balancing energy is imported or exported. If there is capacity, the exchange is put through and the capacity value is reduced accordingly; if there is not, the bid is skipped.

- *Voluntary pool*: In the modelled version of the additional voluntary pool each market keeps a certain 'national share' of bids for national use, which is set equal to 2% of the total portfolio size of the areas. These include the cheapest bids of the area. Remaining bids are offered to the other areas. If the bid price of an offered bid is lower than the bid price of the last (most expensive) bid of the national share of the area it is offered to, it will be included in the bid ladder of that area. The use of 'foreign' bids is subject to the availability of interconnection capacity. The above procedure for the creation of three national bid ladders only takes place once at the start of the simulation run.

- *Balancing energy trading*: In this arrangement, a regionally optimal allocation of balancing energy services takes place for the real-time system balancing of the three areas. This includes system imbalance netting. The balancing market rules remain national, and are the same as in separate markets. Actually, this arrangement can be considered to represent a BSP-SO trading or voluntary pool arrangement in which an optimal allocation of balancing energy services occurs. However, it can also be considered to be a common merit order list where national pricing mechanisms still apply[12].

- *Common merit order list*: The balancing energy markets of the three areas are integrated into one regional bid ladder (separately for upward and downward regulation), and a regionally optimal allocation of balancing energy services takes place, like in the last arrangement. This is modelled in the following way. First, system imbalance netting is performed. Then, bids are considered for activation in order of increasing bid price. If a bid can be utilized to reduce the system imbalance of the own area, it will. Otherwise it will be utilized in one of the other areas, which is subject to the availability of cross-border capacity.

Analysis results Each model version, representing a different cross-border balancing arrangement, has been run ten times, and the averages over the runs have been calculated to obtain the final analysis results. The description of the analysis results is divided between general and arrangement-specific results. A comprehensive list of output data can be found in appendix G.

General results The surplus energy exchange in the system imbalance netting arrangement reduces the dispatched balancing energy in the three areas by less than 25% (see below), and thereby causes a limited reduction of the total real-time balancing costs and imbalance costs. In the last four arrangements however, the vast majority of the balancing energy that is dispatched in the Netherlands and Germany to restore the system balance is imported from the Nordic region. In Figure 5.9 it can be seen that for BSP-SO trading, balancing energy trading and the common merit order list the import percentages for these two areas are higher than 50% and can become as high as 80%. The Nordic region, however, imports nothing in all arrangements except for BSP-SO trading (see below). Instead, the Nordic region exports more balancing energy than is activated to restore its own system balance. These enormous exchange volumes are the result of the cheap and abundant resources in the Nordic region, and the availability of cross-border capacity, which proved to be large enough to enable this level of balancing energy exchange. Moreover, the detailed analysis results reveal that only the interconnector between the Netherlands and the Nordic region was a large constraint for energy exchange: in 60% of the rounds this line was congested in the direction from the Nordic region to the Netherlands.

In Figure 5.10, the total imported and exported balancing energy volumes over the entire simulation run are indicated for the three areas, broken down for up- and down-regulation. First of all, it can be seen that in terms of energy volumes, the largest balancing energy flows are the positive balancing energy flows (upward regulation) from the Nordic region to Germany. These flows total 60,000 MWh, which means an average of 240 MW over the simulation run, and cover virtually all the demand for upward regulation from

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[12] We note that optimal real-time balancing will not be achieved with BSP-SO trading or a voluntary pool, and that a common merit order list without regional pricing appears to be impractical and gives inappropriate incentives, so this arrangement is more interesting theoretically than practically.

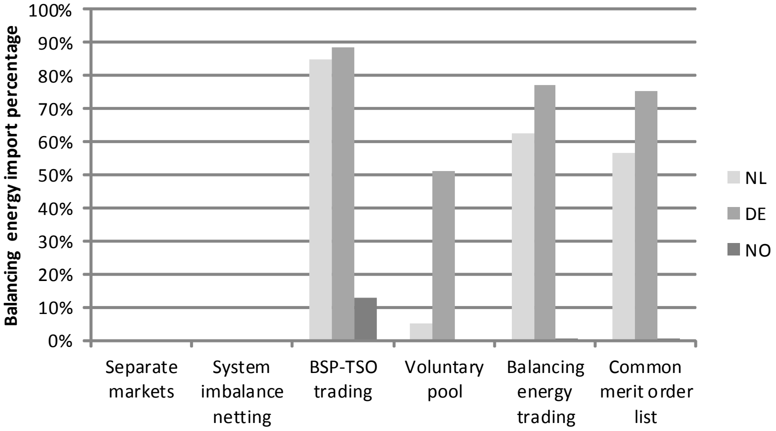

Figure 5.9 – Agent-based analysis results: Balancing energy import percentages

Germany[13]. The figure clearly shows that the energy volumes imported by Germany from the Nordic region are much higher than the volumes imported by the Netherlands, which is caused by the much lower demand and the limited available cross-border capacity. Furthermore, it can be seen that the level of import of Nordic upward regulation bids is higher than that of downward regulation bids. Also, it can be noted that the Netherlands exports a significant amount of balancing energy, which goes to Germany. This is partly caused by a suboptimal activation procedure in the model versions of the last two arrangements. Finally, some peculiar differences between arrangements stand out. These will be discussed below.

In general, balancing energy exchange results in reduced up- and down-regulation prices, which in turn leads to lower imbalance prices. However, the most important indicator from the perspective of the electricity market as a whole is formed by the total Actual Imbalance Costs (AIC). The AIC reflect the actual costs of real-time balancing for the market, because they can be considered the opportunity costs of trading in the day-ahead or intraday market to prevent imbalances. The 'total AIC' are the sum of all actual imbalance costs incurred by all Balance Responsible Parties in an area over the entire simulation run. Figure 5.11 gives the annual[14] total AIC for the three areas for all modelled cross-border balancing arrangements. It can be observed that the annual total AIC of the Netherlands and Germany generally decrease immensely, by 50-80%, but that the total AIC of the Nordic region remains on the same level, or even increases significantly (see below).

Of course, the total AIC reductions are based on reduced balancing energy costs. The arrangements generally result in a total balancing energy costs reduction of 20-50% for

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[13] The import of negative balancing energy by Germany from the Nordic region is somewhat lower, which explains why the balancing energy import percentage of Germany is well below 100%.

[14] The annual values have been calculated by extrapolating the simulation results.

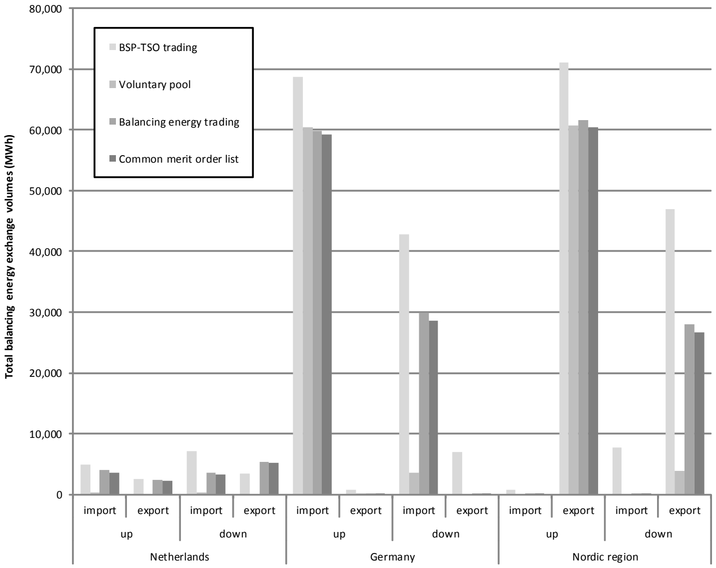

Figure 5.10 – Agent-based analysis results: Balancing energy exchange values

Germany and the Netherlands. For Northern Europe as a whole, these costs reduce by 30% in case of a common merit order list. These results are in line with the 35-50% balancing energy costs reduction found by other researchers for a common merit order list for various regions (see Table 5.1). An important cause of the total balancing energy costs reduction being lower than the total AIC reduction is that the total 'imbalance energy' volumes are much larger than the total balancing energy volumes. For the Netherlands, an additional reason is that the imbalance pricing mechanism shifts after integration from dual pricing to single pricing, which leads to lower imbalance costs for BRPs (see subsection 4.4.3).

The large costs reductions can be directly explained by the high degree of balancing energy imports of the Netherlands and Germany from the Nordic region: These significantly reduce regulation and imbalance prices, and thereby the regulation costs and Actual Imbalance Costs. Interestingly, the actual imbalance costs in the Nordic region may increase as a result of integration (see below). The Nordic balancing energy costs will generally decrease just like in the other two areas, thanks to system imbalance netting, but hugely increase in case of BSP-SO trading, because too many bids are offered abroad.

The reduction of Actual Imbalance Costs for the BRPs is also reflected by the average penalty (in €/MWh) for BRPs to be 'long' (BRP surplus) and to be 'short' (BRP shortage). These are just the day-ahead price minus the long imbalance price and the short imbalance price minus the day-ahead price, respectively, and are the basis for the calculation for the AIC (see Equation 4.1 in subsection 4.4.3). The penalties differ quite unsystematically between arrangements, and the sign of the penalties often changes. This is caused by

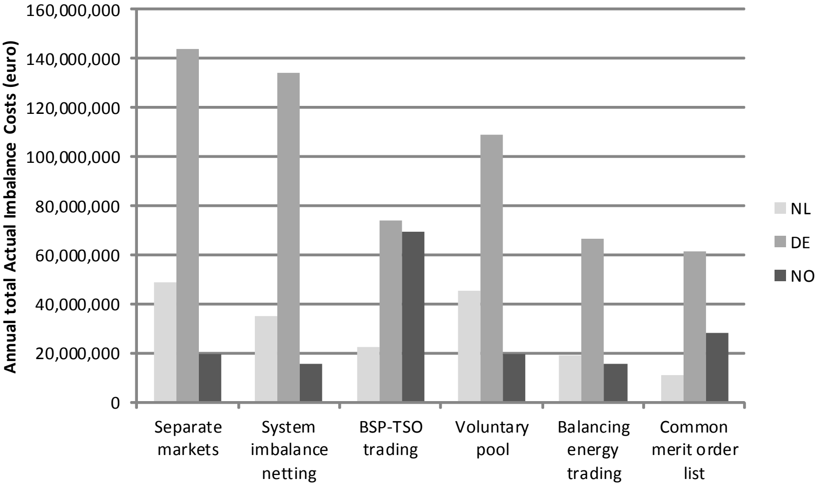

Figure 5.11 – Agent-based analysis results: Annual total Actual Imbalance Costs

changes in the relative shapes of up- and down-regulation bid ladders effectuated by the integration, as a result of which it can suddenly be more favourable for BRPs to opt for a BRP imbalance in the other direction. An important example can be provided by the comparison of separate markets with the common merit order list. In separate markets, there is a general incentive for German BRPs to be long and for Nordic BRPs to be short, whereas in the common merit order list these incentives are exactly the other way around. Such shifts in incentives bring the BRPs in the model to choose intentional imbalance options in the other direction, which leads to shifts in the dominant system imbalance direction. See Figure 5.12. This can be considered an effect on national security of supply, because system surpluses and system shortages pose different security threats.

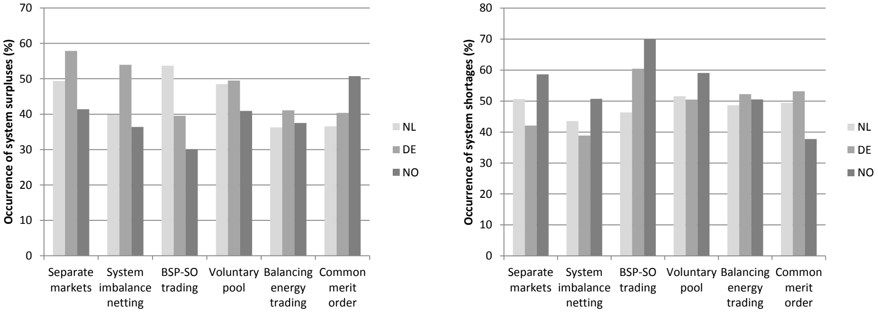

Figure 5.12 – Agent-based analysis results: Occurrence of system surpluses and shortages

Arrangement-specific results A discussion of the impact of individual cross-border balancing arrangements on balancing market performance in Northern Europe is given below.

- *Separate markets*: Most striking is that the total AIC of the Nordic region are more than 50% lower than those of the Netherlands, whereas the system is three times bigger. This is caused by the presence of an immense oversupply of cheap hydro-based balancing resources in the Nordic region, and by its use of single pricing.
- *System imbalance netting*: System imbalance netting reduces the activated up- and down-regulation volumes in all areas, which results in more favourable regulation prices, and therefore lower total AICs for the different areas. However, the AIC reduction is largest for the Netherlands, about 25%, because of its smaller system size and the use of dual pricing.
- *BSP-SO trading*: This arrangement leads to a much lower total AIC for the Netherlands and Germany, but a much higher total AIC for the Nordic region. This is caused by the massive export of bids from the Nordic region to Germany and the Netherlands, leaving the Nordic region with a relatively small amount of bids. As a result, the Nordic region imports 12% of the dispatched downward regulation, and the imbalance penalties are really high, with BRP shortages being much more favourable then BRP surpluses. The latter has led to a high system shortage occurrence of 70%.
- *Voluntary pool*: Compared with BSP-SO trading the total AIC reductions from the implementation of the voluntary pool are a lot smaller for Germany, and even more so for the Netherlands. On the other hand, the total AIC of the Nordic region remain about the same. This can be explained by the national share of bids that stays within the own area, which results in a much lower import of balancing energy from the Nordic region. The Dutch import percentage is only 5%, because the cheapest Dutch bids have a more favourable bid price than the cheapest Nordic bids that are shared with the other markets in this arrangement. This situation holds to a much lower extent for Germany.
- *Balancing energy trading*: The Dutch and German total AIC reductions are clearly lower than for the former arrangements, but here too the Nordic total AIC remain the same (as the Nordic region has the cheapest bids of the North-European region). The first is caused by the import of 60-80% of the balancing energy from the Nordic region, and the execution of system imbalance netting.
- *Common merit order list*: The total AIC values are even a bit lower for the Netherlands and Germany compared to balancing energy trading, which is probably caused by the change to single imbalance pricing. The Nordic total AIC is much higher than in the balancing energy trading arrangement, however, which is the effect of the imbalance prices being based on the bid price of the most expensive activated bid in the entire region. Furthermore, the results show that the uniform regulation and imbalance prices lie in the middle of the range of prices in separate markets, which means that prices within the region have converged.

Effects of price changes: wet vs. dry years in the Nordic region In the main analysis, the fixed day-ahead prices assumed for the Netherlands, Germany and the Nordic region were based on the 2009 averages. However, the average day-ahead prices from 2010 deviate a lot from those: the average prices of the Netherlands and Germany are significantly higher (+6 €/MWh), but that of the Nordic region is 50% higher compared to 2009 (+18 €/MWh). In an alternative simulation session, we have run the model with the fixed day-ahead prices based on the 2010 averages. We will call the main analysis the 'wet year scenario', and the alternative analysis the 'dry year scenario'. See Table 5.5.

Table 5.5 – Day-ahead prices used within the wet and dry year scenario in the agent-based analysis

Area	Average day-ahead price in 2009 (wet year scenario (main analysis))	Average day-ahead price in 2010 (dry year scenario)
the Netherlands	39 €/MWh	45 €/MWh
Germany	38.5 €/MWh	44.5 €/MWh
the Nordic region	35 €/MWh	53 €/MWh

In the dry year scenario, the fixed up- and down-regulation bid ladders have been adapted based on the fixed day-ahead prices in such a way that the relative price differences between national bid prices and the national day-ahead price (the mark-ups) remain the same. The dry year scenario does not only constitute a simple sensitivity analysis, but also allows the investigation of the differences in impact of integration for dry vs. wet years in the Nordic region. After all, the Nordic balancing energy prices are based on water values, i.e. the maximum economic value of hydropower production the hydropower producers can expect to get in the best hour in the future (Sandsmark and Tennbakk, 2010). The water values are significantly influenced by the yearly water inflow that is subject to hydrological patterns, in which one can distinguish between dry and wet years. Due to the high share of hydropower production in the Nordic region (ca. 50%), Nordic market prices are greatly influenced by these patterns. An important cause of the higher Nordic prices in 2010 was the occurrence of a dry year, creating a deficit in water levels (Nordic Energy Regulators, 2011).

The expected effects of the relatively higher day-ahead prices and bid prices in the Nordic region on the performance of an integrated North-European balancing energy market are a reduction of the large export volumes from the Nordic region to Germany and the Netherlands, but also an increase of the export of downward regulation from Nordic region, because the Nordic day-ahead price is higher than the German and Dutch ones while the down-regulation bid ladder lies closer to the day-ahead price. This is illustrated by Figure 5.13. It can be seen that the Nordic bid ladders are shifted upward in the dry year scenario (right) compared to wet year scenario (left), causing a large amount of Nordic downward regulation bids to be higher (more favourably) priced than all Dutch and German bids. For upward regulation, a small share of Dutch bids has become cheaper than the Nordic bids. Based on this, we can expect a large increase in the export of downward regulation bids and a small reduction of the export of upward regulation bids from the Nordic region to Germany and the Netherlands.

The results of the dry year scenario match our expectations rather well, as can be deduced from Figure 5.14. In this figure, the total balancing energy exchange volumes over the simulated period are shown for the wet year scenario (left) and the dry year scenario

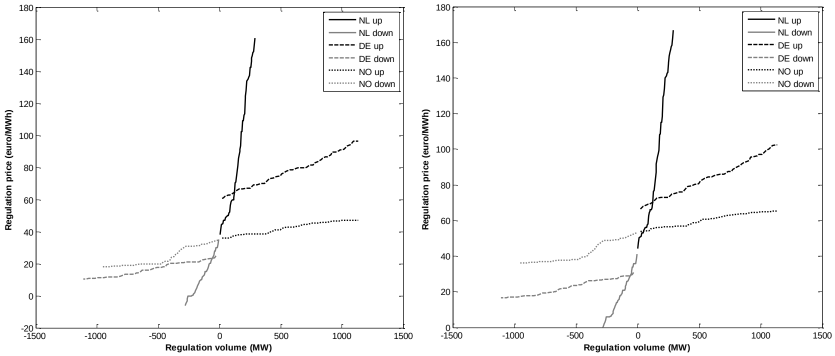

Figure 5.13 – North-European bid ladders in the wet year (left) and dry year (right) scenario in the agent-based analysis

(right). Indeed, the export of upward regulation from the Nordic region to Germany and the Netherlands is moderately reduced, but the export of downward regulation has increased immensely. Interestingly, as a result of the balancing energy exchange, compared to the wet year scenario described as the main analysis in the former subsections, the introduction of a common merit order list no longer removes the dominant occurrence of system surpluses in the Netherland and Germany, but the occurrence of system surpluses in the Nordic region further reduces to 25%, instead of increasing to 50%. This is caused by the massive export of Nordic downward regulation bids and the resulting deterioration of the downward regulation prices, and thereby imbalance costs for system surpluses. In the Nordic region, the average Actual Imbalance Costs for system surpluses become higher than for system shortages, driving Nordic BRPs to opt for BRP shortages.

Remarkably, the decrease in total Actual Imbalance Costs after the introduction of a common merit order list is significantly larger for all three areas in the dry year scenario, compared to the wet year scenario. For the Nordic region, the increase of the total AIC in the wet year scenario has even changed to a reduction. An explanation can be found in the changes in the average regulation prices under the common merit order list: The spread between the up-regulation price and down-regulation price is smaller in the dry year scenario than in the wet year scenario, reducing the penalties for BRP imbalances.

Findings Generally, we have found that the choice of a cross-border balancing arrangement has a large impact on balancing market performance. This is clearly shown by the varying impact on the total Actual Imbalance costs, which reflect the balancing costs for the market. The total AIC of the Netherlands and Germany are substantially reduced by most arrangements, whereas the Nordic total AIC remain the same or even increase, which is the result of the import of the vast majority of the balancing energy in the Netherlands and Germany from the Nordic region, which has a huge oversupply of balancing energy bids that are also cheapest in the North-European region. The varying changes in balancing energy prices between arrangements also cause varying imbalance prices and BRP incentives, causing different effects on system imbalance directions.

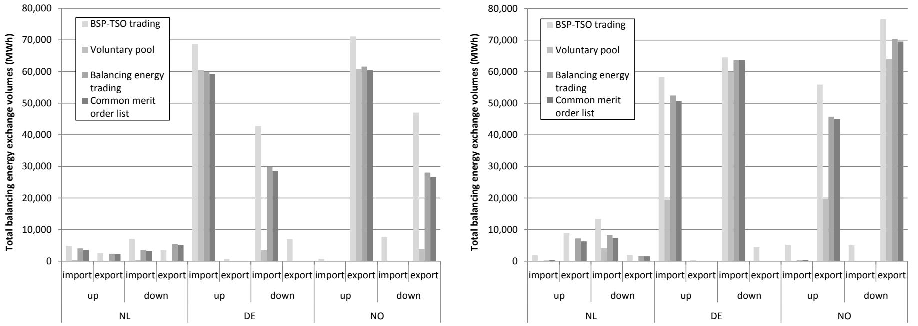

Figure 5.14 – Agent-based analysis results: Balancing energy exchange volumes in the wet year (left) and the dry year (right) scenario

The analysis shows that, for Northern Europe, system imbalance netting and a voluntary pool have a small positive effect on the total AIC for all three areas, but that balancing energy trading causes a very large AIC reduction for all three areas. The common merit order list leads to similar AIC reductions as balancing energy trading for the Netherlands and Germany, but the costs for the Nordic region are higher due to the regional marginal pricing. BSP-SO trading leads to a huge increase of total AIC for the Nordic region, because many of the cheapest Nordic bids are offered in another market. This does not occur in the voluntary pool due to the maintained national share, which however limits the AIC reductions for the Netherlands and Germany as well. The results of the balancing energy trading arrangement indicate that an optimally functioning voluntary pool might be preferable in order to prevent an imbalance costs increase in the Nordic region, but it is questionable if such an arrangement can be realized without creating adverse incentives for BSPs or SOs.

Reflecting on the analysis, it must be emphasized that this analysis has only taken a BRP perspective, that is, only the impact of arrangements on BRP behaviour has been taken into account. In reality, BSPs will probably adapt their bidding strategies as a result of integration, as new market opportunities and risks emerge. If, as literature implicitly argues, balancing market integration indeed enhances competition in balancing energy markets, balancing costs and imbalance costs can be expected to further reduce. This will only hold if gaming opportunities or new forms of market power do not emerge, which is something we expect will not happen for Northern Europe given the huge over-supply of cheap Nordic balancing energy bids (cf. Abbasy et al. (2011)). Furthermore, cross-border balancing will probably only be introduced after day-ahead market integration, which will change the effects of cross-border balancing. A final reservation regarding the results is that cross-border balancing arrangements can take many different forms (cf. section 5.3), whereas the modelled arrangements involve specific assumptions and operational rules, which prevent firm conclusions regarding the impact of different arrangements on balancing market performance for Northern Europe.

5.5 Impact of integration

In multinational design, the design variables on balancing market integration form an important part of the design space. The core variable is 'cross-border balancing arrangements', which reflects the choice for alternative arrangements that realize different degrees of integration. The impact level of integration has been estimated to be large, both qualitatively (by means of a multi-criteria analysis) and quantitatively (by means of an agent-based analysis). Significant differences have been found between alternative cross-border balancing arrangements with regard to the effects on balancing market performance. In addition, the nature of the effects depends significantly on contextual factors, and on the initial national designs.

In general, the arrangements of BSP-SO trading and an additional voluntary pool have been found to have a more uncertain impact on balancing market performance, both on the multinational (regional) and on the national level. This is caused for an important part by the fact that these are intermediate arrangements in which high degrees of balancing service exchange may develop, whereas the national balancing markets remain fundamentally separate. Adverse incentives for SOs and market parties could develop, but a well-designed detailed design of these two arrangements may mitigate this. In contrast, the arrangement of system imbalance netting is a much more simple arrangement with positive effects on economic performance in all participating control areas. Last, the arrangement of the common merit order list, which represents the change to a fully integrated balancing service market, leaves less market design issues open. The inherent presence of system imbalance netting and the systematic activation of the regionally cheapest bids make this option most beneficial. However, it is in particular this arrangement that requires effective coordination of cross-border balancing and the harmonization of balancing market design variables, which makes its establishment much more difficult (see chapter 6).

In general, we conclude that balancing market integration has a large positive impact on balancing market performance, if the multinational balancing market is carefully designed, taking into account the specific case.

6 Synthesis

In this chapter, the analysis results on the impact of balancing market design and internationalization from chapter 4 and chapter 5 are combined and interpreted, resulting in a synthesis of these two topics. In section 6.1, drivers and barriers to balancing market harmonization and integration are described. Then, we synthesize the insights on the impact of balancing market design in section 6.2 and on the impact of balancing market internationalization in section 6.3. Last, we describe the general and North-European design recommendations following from the analyses in section 6.4.

6.1 Internationalization drivers and barriers

6.1.1 Drivers to harmonization

Peculiarly, it is not only true that balancing market harmonization can facilitate balancing market integration, but also vice versa: Balancing market integration can facilitate balancing market harmonization. A real-life example is provided by the balancing market internationalization process in the Nordic region, which started with the creation of a common regulating power market in 2002, and ended with the harmonization of several balancing market rules in 2009 (see chapter 2). This has been put forward by Catholic University of Leuven and Tractebel Engineering (2009), who argue that liquid balancing energy markets are a precondition for the introduction of harmonization, and that this precondition can be brought about by integration.

In addition, Catholic University of Leuven and Tractebel Engineering (2009) mention that balancing market integration can trigger further balancing market harmonization, because integration without harmonization may entail ‘various distorting effects and inefficiencies’. We tend to agree with this, because an increasingly integrated balancing service market should lead to increasingly similar balancing service prices, and therewith similar incentives to BSPs. However, if many of the balancing market design variable values remain different, so will incentive compatibility in these markets. Unequal incentives are likely to result in one-directional balancing service exchange, which could perhaps even decrease competition if the imported bids push the local bids out of the market while not attracting new bidders in the connecting area. Next to this, incomplete harmonization could also limit the benefits of integration (and thereby introduce inefficiencies), or put differently, further harmonization could increase the value of integration (see below).

Thus, *balancing market integration will increase the value of balancing market harmonization*. Given the fact that it is harder to agree on a particular harmonization design than on an integration design, integration may indeed serve as a driver to harmonization. The advantage of this development path is that the benefits of integration can be reaped sooner, as also remarked by Catholic University of Leuven and Tractebel Engineering (2009). However, we add to this that the size of the distorting effects is uncertain. We have not researched these, but considering the possibilities for adverse incentives we have already found in the multi-criteria analysis of cross-border balancing arrangements (see appendix J), we believe they could be quite large. On the other hand, the same analysis has shown that a deliberate detailed design of the cross-border balancing arrangement will at least mitigate adverse incentives.

The opposite statement is also true: *Balancing market harmonization will increase the value of balancing market integration*. Thus, integration is not only a driver to harmonization, but harmonization is also a driver to integration (see below).

Furthermore, we may wonder if initial balancing market harmonization steps facilitate further balancing market harmonization. If the integration of national balancing markets is not considered in a balancing region, this is hardly the case. However, if the partial harmonization decreases the compatibility of a national balancing market design with its contextual power system and market, it will create a need for further harmonization.

Finally, the increasing day-ahead and intra-day market integration in Europe, which already creates inefficiencies, could drive both initial and further balancing market harmonization forward, as Catholic University of Leuven and Tractebel Engineering (2009) suggest.

6.1.2 Drivers to integration

If BSP-SO trading or an additional voluntary pool is introduced, balancing market harmonization will possibly resolve balancing service exchange limitations caused by design differences[1]. For example, a uniform Schedule Time Unit will prevent that, for BSP-SO trading, BSPs bidding into a control area with a smaller STU reduce their bidding opportunities in their own area. Another example is that different bid requirements limit the export of bids to control areas with stricter requirements. However, there are other drivers to balancing market integration which transcend the realm of balancing market design.

First of all, the integration of balancing energy markets may improve the economic efficiency of integrated day-ahead and intra-day markets, because of the links between these markets. After all, market parties consider both the regulation price and the imbalance price (which is directly linked to the regulation price) in their short-term market bidding strategies, because the balancing energy market provides another platform for selling energy, while the costs of imbalances influence the importance of a balanced energy portfolio. In a region with integrated short-term markets but separate balancing energy markets, different balancing prices will exist, which reduces the economic efficiency of

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[1] In a common merit order list, the balancing service exchange is optimized, which has been enabled by a prerequisite harmonization step. In this case, harmonization is a barrier instead of a driver. See subsection 6.1.4.

cross-border trade. To what extent this is the case depends also on the degree of balancing market harmonization, and is therefore difficult to evaluate.

A second important driver may be the increasing integration of wind power in European power systems. Higher wind power shares will increase the system imbalance volumes, and thereby real-time balancing costs. This will increase the potential balancing energy costs reductions (and thereby imbalance costs reductions) that can be achieved by cross-border balancing. In addition, higher reserve capacity procurement volumes may be required to ensure availability of balancing services. The large effect that wind power integration can have on system imbalances is reflected by the average production deviation percentage for the Nordic region in 2010 of 0.3%, against percentages of 28.3% for Denmark-West and 16.8% for Denmark-East (Nord Pool Spot, 2011), noticing that Denmark had a wind power share of 24.8% already in 2007 (European Commission, 2010). Jaehnert et al. (2011) have analysed this influence for Northern Europe in an optimization study. They have assessed that a wind power capacity increase from 34 GW in 2010 to a low estimation of 53 GW in 2020 (an increase of the wind power share from 17% to 27%) can increase the reserve capacity costs reductions realized by a common merit order list from 85 million euro to 307 million euro, and increase the balancing energy costs reductions from 118 million to 210 million. For the case of 96 GW wind power in 2020 (a 50% wind power share), the balancing energy costs reduction increases even to 720 million euro. These results indicate that under the emergence of a high wind power share the economic value of balancing market integration could double. Thus, wind power integration drives balancing market integration, but for the same reasons balancing market integration can also be said to facilitate wind power integration, something that is stressed by ENTSO-E (2011b).

6.1.3 Barriers to harmonization

There are different kinds of barriers to balancing market harmonization, i.e. obstacles to the equalization of design variable values across national balancing markets. These will be described below. We can distinguish between technical barriers, economic barriers and legal barriers. Furthermore, more generic barriers correspond to the context dependence of balancing market design, adverse effects of harmonization on stakeholders, and disagreement between decision makers.

Technical barriers Although the harmonization of balancing markets concerns institutional change, it may have technical implications. From this, technical barriers may arise. An important one relates to the design variable of balancing service classes. The decision makers in the balancing region may decide to harmonize towards a standard set of balancing service classes, but if in one of the control areas generation units do not possess the technical capabilities required therein, this set is not workable for that control area. The same holds for harmonization of the control systems and the reserve and bid requirements: If there are no balancing resources in the system that can be activated by the new control system or meet the new requirements, the availability of balancing resources would not be guaranteed anymore. In practice, implementation of such technically unrealistic design changes would lead to the frequent disregard of the new rules.

Economic barriers Economic barriers could arise, if changes in balancing market design incur significant costs of investment. This is covered by the performance criterion 'internationalization costs' and has been estimated for all national design variables (see section 4.6). Based on the detailed estimations, we have found that significant internationalization costs only materialize for four national design variables. This is because changes in rules and regulations are not considered to be costly. The first of these variables is that of service classes. The change of this variable may require the change of balancing service market designs (including administrative processes and systems) and the change of control systems. The control system is the second variable; adapting this requires a capital-intensive investment at the control centre of the System Operator. Thirdly, concerning responsibility for renewable generation, harmonization costs could be substantial if SOs need to install a forecasting business unit, in case SOs become balance responsible for renewable generation. Fourth and last, introducing a penalty for non-delivery would not only require the real-time measurement and monitoring of the output of activated balancing resources, but also an extension of the settlement process, which is expected to cost more than changes in other design variables.

Legal barriers Furthermore, legal barriers to harmonization may exist. Especially if the balancing region spans different countries, the national laws and codes, in which the balancing market rules are embedded, need to be adapted. Depending on the embedding of these rules in legal documents and on the procedures for change of legislation, the adaptation of balancing market rules may be more or less difficult and lengthy. This is likely to prevent a simultaneous and quick harmonization for a balancing region with multiple countries. But as harmonization does not lead to interaction between balancing markets, this does not appear a serious barrier. Besides, the detailed balancing market rules are usually stipulated in national codes, which are relatively easy to change.

Context dependence of impact The multi-criteria analysis presented in section 4.6 has shown that the influence of the contextual power system and market on the impact of national balancing market design change is high. Considering that national power systems and markets in Europe differ a lot, balancing market harmonization is hampered by possible incompatibilities between the systems and the harmonization design. An obvious power system example is that, if one control area in the balancing region does not include generation resources that can be activated by Load-Frequency Control, harmonizing to service classes and bid requirements incorporating LFC is not possible. An obvious market design example is that, if an intra-day market with a gate closure one hour before delivery exists in one of the areas, harmonizing to a final gate closure time of two hours before delivery is not possible.

Adverse effects on stakeholders Balancing market harmonization will usually have at least some negative effects on some of the stakeholders in the balancing region, i.e. Balance Responsible Parties, Balancing Service Providers, and System Operators. This becomes evident if we consider that the balancing market performance criteria set consists of eleven criteria, and that the magnitude and direction of the effects of harmonization in each balancing market depend on the initial balancing market design and on the power system context. Although we conclude that it is quite feasible to formulate a harmonization design that has a net positive effect on the performance of all national balancing markets (see section 4.7), the existence of adverse effects complicates the decision-making process of harmonization. Therefore, this barrier relates to the next one.

Disagreement between decision makers Decision makers on balancing market harmonization (TSOs, regulators, and legislators; see chapter 7) need to agree on a particular harmonization design, while there are thousands of possible combinations of design variable values. This forms a clear potential source of disagreement between decision makers from different countries. Another source is the unequal costs and benefits that arise from the harmonization; one control area / stakeholder will benefit more than another. Especially for areas for which the net benefit is relatively low, the hassle and uncertainties related to balancing market design adaptation may considered too high.

6.1.4 Barriers to integration

Regarding barriers to integration, we distinguish between the same categories as for barriers to harmonization. However, one additional barrier involves harmonization prerequisites to balancing market integration, which can also be considered a barrier to integration.

Technical barriers At a high level, balancing market integration could be hindered by inadequate technical characteristics of balancing resources and/or control systems in one or more control areas in the balancing region. In concrete, the bid requirements in one balancing market could be too strict for balancing resources from neighbouring areas, and/or control signals sent by national control systems could be incompatible. These may pose fundamental technical barriers to integration.

Another fundamental technical barrier may be the low availability of interconnection capacity for cross-border balancing. However, even if the interconnection capacity available to the market (Net Transfer Capacity) is usually fully utilized for wholesale cross-border energy trade, the economic potential of exchange in the direction opposite to the power flow could be significant. Although this potential may be limited by the fact that the profitable balancing energy exchanges often are in the same direction as the power flow, the potential for system imbalance netting is equally large in both directions. Besides, part of the Transmission Reliability Margin of HVAC interconnectors might be used for cross-border balancing, while the reservation of part of the interconnection lines could very well be socially optimal at times for cases with low remaining capacity available for balancing (see subsection 5.1.2).

Next, a technical barrier could be the need for SOs to perform real-time security checks, i.e. to calculate the effects of cross-border balancing on system security. Because the options for cross-border balancing are considered in real-time, such security checks should be executed quickly and immediately, which might provide a large barrier for cross-border balancing.

If the interconnection capacity consists of HVDC lines, the HVDC terminals need to be actively controlled to realize balancing energy exchange or surplus energy exchange.

In Grande et al. (2008), no serious impediments are identified with regard to this active control, which indicates that this does not form an important barrier.

However, a relevant low-level technical barrier may be formed by the coordination of the realization of balancing service exchange. In case of balancing service exchange, a control signal must be sent from the receiving SO to the external BSP (possibly through the connecting SO). At the same time, the exchange programs and the Area Control Errors for the connecting and receiving area should be adapted. Next, the energy schedule of the relevant BRP should be adapted. In case the interconnection line is a HVDC line, the HVDC terminal needs to be actively controlled at the same time as the cross-border activation of the balancing energy service. Thus, in case of cross-border balancing between synchronous control areas, the technical and administrative processes need to be coordinated, while in case of cross-border balancing between asynchronous control areas an additional coordination between balancing energy dispatch and HVDC control is needed. Coordination between these processes is essential to effective cross-border balancing.

Related to this, the larger amount and/or the lower compatibility of the processes required to realize cross-border balancing may cause time delays, making cross-border balancing less effective than national real-time balancing. If this becomes a reason for SOs to prioritize national bids, the economic benefits of balancing market integration will decline. A good coordination of all the cross-border balancing processes will help to minimize time delays.

Economic barriers The main economic barrier consists of the implementation costs of integration, which has been represented in the multi-criteria analyses by the performance criterion of 'internationalization costs'. Most important is the significant impact of the variable 'cross-border balancing arrangements' on internationalization costs, as this is the core variable of integration. The internationalization costs have been estimated to increase with an increasing degree of integration, i.e. these costs increase from system imbalance netting, through BSP-SO trading and an additional voluntary pool, to a common merit order list. For system imbalance netting, only a procedure for netting and redistribution of ACEs is needed. For BSP-SO trading, the cross-border submission of bids must be facilitated and coordinated, which may call for some harmonization and adaptation of operational processes of SOs. An additional pool requires setting up an additional pool by the SOs, whereas a common merit order list requires partial harmonization, the merger of balancing service markets and a change in the control structure of real-time balancing. In case of reserve capacity exchange, a procedure for the calculation of the optimal allocation of interconnection capacity is called for, which requires additional investment in a calculation and allocation mechanism.

Considering that these implementation costs are made only once, that these are not related to expensive investment in physical equipment (unless automatic control systems need to be installed), and that cross-border balancing processes can probably be embedded in existing processes and utilize existing communication, control and administrative systems, we estimate these costs to be insignificant compared to the potential economic benefits of balancing market integration (see section 5.2). Therefore, this main economic barrier is not a large one. An exception concerns the possible installation of automatic LFC systems. This is most relevant for the realization of a common merit order list in a region where LFC was not yet applied in some of the control areas. However, the introduction of a national LFC system can already contribute to the national improvement of balance quality, and be implemented for that reason too[2].

Legal barriers A legal barrier to the development of balancing market integration might exist if the national legislation specifically disallows cross-border balancing, or one of the required subprocesses of cross-border balancing. In Europe, EU policy clearly supports cross-border balancing (see section 2.3). However, the limits stipulated by the UCTE Operation Handbook on the cross-border exchange of reserve capacity do provide a certain legal barrier: 66% of the needed reserve capacity must be procured within the control area, and 50% of the total needed secondary and tertiary control capacity (UCTE, 2009a). This is necessary to maintain security of supply in the control areas.

Apart from the UCTE Operation Handbook restrictions, no limitations to the implementation of cross-border balancing have to our knowledge been expressed by European decision makers. However, the ACE control methodology applied in Europe is based on the assignment of national responsibilities for system balancing: Within 15 minutes, a control area (country) should remove the Area Control Error. This assignment is also motivated by reasons of security of supply: Control areas should be able to balance their own power system, to safeguard against cascading effects in the synchronous zone. The realization of cross-border balancing will create interdependencies between control areas with regard to system balancing, which might be considered to go against national responsibilities, and endanger security of supply in the synchronous zone. This might bring the EC or ENTSO-E to restrict the execution of cross-border balancing.

A more relevant legal barrier arises from the embedding of the rules for cross-border balancing in the different national balancing codes. If these rules cannot be embedded in a similar way into the different national codes, regulatory inconsistencies may arise, possibly hampering the realization of cross-border balancing. For a common merit order list, it may be best to lay down the rules on the regional balancing service market in regional legislation, in order to prevent conflicts about the legal status of the common merit order list. Such regional legislation could however be inconsistent with national codes and the ENTSO-E Balancing Network Code that is in the pipeline (ENTSO-E, 2011c).

Harmonization prerequisites With regard to prerequisite balancing market harmonization efforts for different cross-border balancing arrangements, we have found that only the common merit order list has clear harmonization prerequisites.

Because *system imbalance netting* requires no change in the national balancing market designs, there are clearly no harmonization prerequisites for this arrangement. For *BSP-SO trading*, it appears that there are no prerequisites for the offering of balancing services by BSPs to a balancing service market of a neighbouring control area. In Catholic University of Leuven and Tractebel Engineering (2009), gate closure times (final gate closure time) and the technical characteristics of balancing services (service classes and bid requirements) are mentioned as general harmonization prerequisites. However, differences in final gate closure time, service classes and bid requirements do not prevent BSPs from bidding into a foreign market, and are therefore not prerequisites. Instead, we regard such

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[2] See the Nordic case (Svenska Kraftnät and Statnett, 2010).

harmonization as a driver to integration (see above), because it facilitates the balancing service exchange.

For the *additional voluntary pool*, the same thing can be said: Although harmonization may facilitate balancing service exchange in a voluntary pool, harmonization of design variables for balancing service provision is not required to enable such exchange, which means no harmonization prerequisites exist here either.

However, the *common merit order list* requires the harmonization of the final gate closure time, service classes, Schedule Time Unit, methods of procurement, timing of markets, bid requirements, balancing service pricing mechanisms, and BSP accreditation requirements, insofar these design variables concern the regional balancing service market that is introduced in this arrangement. This is quite self-explanatory: The integration of balancing energy markets of different national balancing markets into one regional market implies a single procurement method, frequency of bidding and clearing, set of bid requirements, pricing mechanism, and set of BSP accreditation requirements. In Catholic University of Leuven and Tractebel Engineering (2009), the method for remunerating balancing services is mentioned as a barrier for the introduction of a common merit order list.

Context dependence of impact The multi-criteria analysis presented in section 5.2 has shown that the influence of the contextual power system and market on the impact of multinational balancing market design change is high. Considering that national power systems and markets in Europe differ a lot, balancing market integration is hampered by possible incompatibilities between the systems and the integration design.

An important physical system example is the existence of different balancing resource capabilities in different control areas, which would hamper balancing energy exchange. Another important one is the absence of interconnection capacity for cross-border balancing. A third one is the frequent occurrence of internal congestions in a control area, limiting the possibilities for balancing service exchange.

The important market design issue is that the absence of a cross-border day-ahead and intra-day market would mean that balancing market integration could cause economic inefficiencies (Catholic University of Leuven and Tractebel Engineering, 2009). Furthermore, the potential for balancing market integration could be overestimated under such absence, because short-term market integration will reduce price differences between areas. This suggests that the more 'natural' sequence of short-term market integration before balancing market integration is also the more viable sequence.

Adverse effects on stakeholders Balancing market integration will have at least some negative effects on some of the stakeholders in the balancing region, i.e. BRPs, BSPs, and SOs. This becomes evident if we consider that the balancing market performance criteria set consists of eleven criteria, and that the magnitude and direction of the effects of integration in each balancing market depend on the initial balancing market design and on the power system context (see above). Although we have found in the analysis of cross-border balancing arrangements in chapter 5 that large economic benefits exist for particularly system imbalance netting and a common merit order list, the existence of adverse effects complicates the decision-making process of integration. For a common merit order list, such an effect could be the increase of balancing energy prices and imbalance prices in the cheaper control areas, such as found for the Nordic region in the case study of Northern Europe (see section 5.4). Therefore, this barrier relates to the next one.

Disagreement between decision makers Decision makers on balancing market integration need to agree on a particular integration design, while there are several different cross-border balancing arrangements, a lot of detailed design options underlying these arrangements (especially for BSP-SO trading and the additional voluntary pool), and numerous facilitating harmonization options. This forms a source of possible disagreement between decision makers from different countries.

Another source is the unequal distribution of costs and benefits that arises from the integration; one control area / stakeholder will benefit more than another. Especially for stakeholders representing areas for which the net benefit is relatively low, the hassle and uncertainties related to balancing market integration may considered too high.

Looking at the main stakeholders, the finding that balancing market integration will generally improve balancing service market efficiency and operational security of supply means that regulators and system operators will generally have an interest in its establishment. The reduction in balancing energy prices and imbalance prices established by integration will be positive for the BRPs (i.e., imbalance costs drop) but negative for the BSPs (i.e., balancing energy profits drop). However, the sum of 'imbalance energy' (settled BRP imbalances) is usually much larger than the sum of activated balancing energy, which points out that the net effect of price reductions in a balancing market is positive. Moreover, market participants playing the role of BSPs, are often also a BRP, which means that market participants usually have an interest in lower prices. The most important concern is that integration might lead to higher balancing prices for some control areas in the balancing region, especially in the cases of unlimited BSP-SO trading and a common merit order list with marginal pricing. But even those areas will benefit to some level from integration.

6.2 Impact of balancing market design

6.2.1 Impact of design variables

To arrive at a generic conclusion of the value and potential impact of balancing market design, we take a look at the overall results of the qualitative multi-criteria analysis of balancing market design variables. To this end, the results of the analysis of national variables in section 4.6 and multinational variables in section 5.2 have been combined.

Total impact of individual design variables

We start from the conclusions in the last two chapters that both national and multinational balancing market design have a large potential impact on balancing market performance. These conclusions are built on the argument that multiple significant effects add up to a high total. A detailed look at the total impact levels of individual national and multinational design variables provides more insights in the nature of the overall impact of balancing market design. The total impact levels of the balancing market design variables, that have been estimated by adding up the estimated effects on the eleven balancing market performance criteria for each of the variables, are presented in Figure 6.1, ordered from high to low.

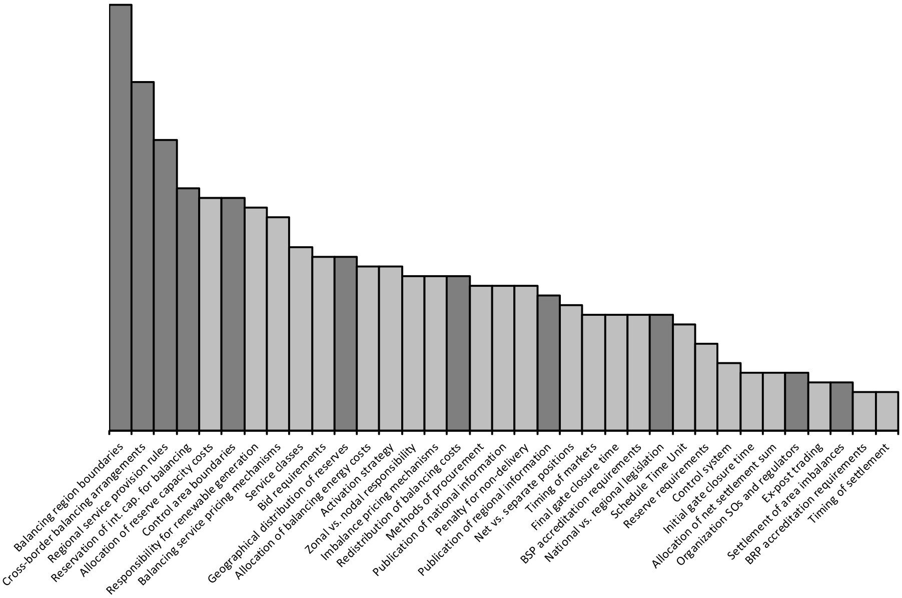

Figure 6.1 – Multi-criteria analysis results: Total impact of balancing market design variables

The first thing that can be noticed is the large number of national design variables (light-coloured) compared to multinational design variables (dark-coloured) and the high importance of five of the multinational variables. Of the total of 35 defined balancing market design variables, 24 are national and 11 are multinational. Therefore, national balancing market design has been found to have a larger potential impact on performance than multinational balancing market design. The aggregate of the impact levels of the national variables adds up to 58% of the aggregate of all variables. This is significantly lower than is to be expected from the relative number of variables, which means that multinational variables have on average a higher impact level. This makes sense, because the multinational variables deal with design issues that affect all the balancing markets in the balancing region, whereas among the national design variables there are a lot of less influential variables. The top five multinational variables contribute to 19% of the total impact of balancing market design (all variables) in the analysis results.

The sequence of impact level values is easier to explain for the multinational design variables, because these mostly concern balancing market integration, whereas the national variables concern all aspects of balance planning, balancing service provision and balance settlement. Furthermore, the sequence for the national design variables does not reveal that one balancing market design pillar is more important than the other, i.e. the most important (influential) national variables do not all belong to the same design pillar. As the multinational variables relate mostly to balancing service provision, it is not surprising that the most important multinational variables fall under this design pillar.

The three national design variables with the highest impact are 'allocation of reserve capacity costs', 'responsibility for renewable generation', and 'balancing service pricing mechanisms'. Why these three would have the highest impact cannot be explained easily. It is the result of using a diverse set of eleven balancing market performance criteria. Moreover, these criteria have been assumed to have an equal weight. We emphasize the outcomes of the multi-criteria analysis are substantially influenced by the choice of performance criteria, the choice of weights, and the estimation of effects of individual variables on the criteria.

The five multinational design variables with the highest impact are 'balancing region boundaries', 'cross-border balancing arrangements', 'regional service provision rules', 'reservation of interconnection capacity for balancing', and 'control area boundaries'. This result is more intuitive: The balancing region boundaries determine which balancing markets are incorporated in the balancing region, the cross-border balancing arrangement can have a very large effect on bid volumes and prices, regional service provision rules is about multiple design aspects of regional balancing service markets, the reservation of interconnection capacity has a large impact on cross-border balancing flows, and the control area boundaries affect balance planning and the reserve requirements.

Total impact of individual performance criteria The aggregated impact level of all balancing market design variables combined on each of the eleven performance criteria is illustrated in Figure 6.2. A comparison of these total impact scores with the ones for the national balancing market design only shows that the order of criteria (of decreasing total impact scores) is almost the same as for the national design. Given the 42% contribution of multinational design on total impact, this must mean that the order of criteria for multinational design is similar too. This is indeed the case, but here balance planning accuracy is much less important, and social welfare of cross-border exchanges is relatively more important. The first is due to the fact that balance planning takes place on a national basis, the second due to the focus of multinational design on balancing service exchange.

Dividing the performance criteria into economic efficiency criteria, security of supply criteria, market facilitation criteria, and multinational criteria (see Figure 3.5) by adding up the total scores of the criteria within the same group, we come to the following 'total impact shares' of balancing market design:

- Economic efficiency criteria: 39%
- Security of supply criteria: 35%
- Market facilitation criteria: 16%
- Multinational criteria: 10%

This shows that most of the impact of balancing market design is on economic efficiency and security of supply. If we compare the results with national balancing market

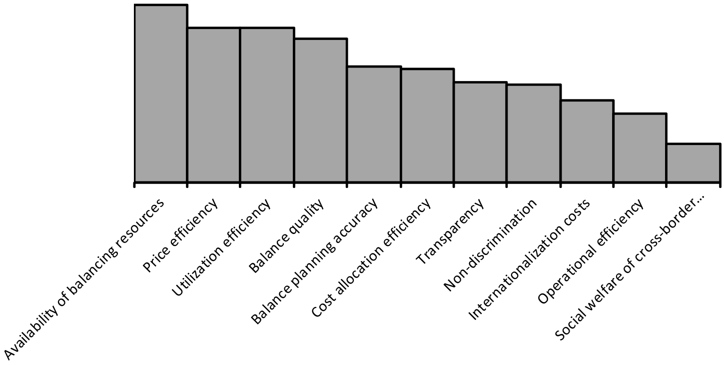

Figure 6.2 – Multi-criteria analysis results: Total impact of balancing market design on performance criteria

design, we can see that the impact on security of supply has become a bit smaller. Indeed, balancing market integration has a more obvious impact on economic efficiency, as balancing service exchange does not necessarily lead to a higher availability of balancing resources[3]. By contrast, market facilitation criteria, and especially multinational criteria are influenced more by multinational design. The first is the result of decreases in transparency and non-discrimination caused by the regional balancing provision, the second is quite self-explanatory. Importantly, it holds also for the overall balancing market design that economic efficiency and security of supply are equally important fundamental criteria, which together take up the lion's share of the total potential impact level of balancing market design on performance.

Regarding the different balancing market design pillars, the order of performance criteria clearly shows that balancing service provision can be influenced most by balancing market design, as the four criteria with the highest total impact score are the ones that relate most to balancing service provision.

The availability of balancing resources, which was affected the most by national balancing market design, is also influenced most by the overall balancing market design. Price efficiency, which was most affected by multinational design, is the second-most affected criterion for the overall design. Utilization efficiency has the same total impact score as price efficiency. These results are in accordance with the fact that the availability of balancing resources is indispensable for effective balance management, while efficient balance management obviously depends on cost-reflective balancing services, and the utilization of the cheapest services available. More interesting is the outcome that the two criteria dedicated to balance planning and settlement, balance planning accuracy and cost allocation efficiency, resp., have been found to be affected more than the market facilitation criteria.

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[3] Balancing service imports may replace the availability in the own control area, while foreign resources may also have additional unavailability risks. Besides, security of supply needs to be above a certain minimum threshold at all times, which suggests that the impact of integration on security is more marginal.

In turn, transparency and non-discrimination are affected more than the multinational criteria of internationalization costs and social welfare of cross-border exchanges. The reason for the latter is that the multinational criteria are most relevant to the multinational variables related to integration. Finally, operational efficiency is not affected a lot by balancing market design. This is because the basic information and money exchange processes are inherent to the balancing market. The overall design of the balancing market has little influence on this criterion (although it is substantially reduced by cross-border balancing arrangements).

6.2.2 Context dependence

Coincidentally, the number of contextual factors identified is the same as the number of performance criteria (eleven). As the same scale has been used to evaluate the influence of contextual factors as to evaluate the impact on performance criteria, the aggregate of the total influence values of contextual factors compared to the aggregate of the total impact values of performance criteria says something about the level of context dependence. We found the latter to be about 1.5 times higher than the former, which indicates that balancing market design is more relevant to consider than the influence of contextual factors, but that the context dependence cannot be ignored. In conclusion, the multi-criteria analysis results show that the context dependence of the impact of balancing market design is large.

The order of total influence values of the eleven contextual factors is depicted in Figure 6.3.

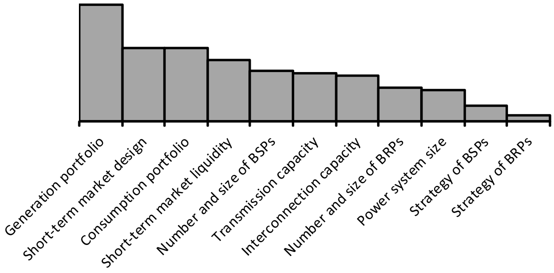

Figure 6.3 – Multi-criteria analysis results: Total influence of contextual factors on balancing market design

The generation portfolio stands out as the factor with the largest influence on balancing market design, which makes sense considering that this includes the generation mix, reserve margin, predictability of generation, marginal costs, and amount of flexible resources eligible for balancing. The other contextual factors are much less influential. The short-term market design, the second-most influential factor, is important for BRPs' balancing possibilities in the context of the national balancing market design, and important for BSPs'/TSOs' balancing service exchange possibilities in the context of the multinational balancing market design. The predictability of the consumption portfolio mainly determines the balancing energy demand; its large influence on the impact of national variables makes this factor rank third.

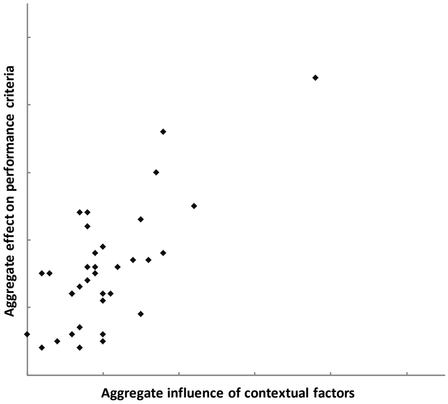

Figure 6.4 – Multi-criteria analysis results: Correlation of aggregate impact and the aggregate context dependence of balancing market design variables

Finally, it is interesting to compare for the individual balancing market design variables the total impact values with the total influence values, in order to examine the correlation between the impact level of a design variable on performance with the influence level of contextual factors. This correlation is represented by the scatter plot in Figure 6.4, with the total impact value on the y-axis and total influence value on the x-axis.

Generally, one can observe a positive correlation between the total impact level of design variables and the context dependence of this impact level. This can be explained by the following. Design variables with a large impact on performance have a large impact on the system factors relevant for the balancing market, and the contextual factors also have a large influence on multiple system factors (see section 4.1). It follows that the impact of these design variables is likely to be highly influenced by the contextual factors. From this we can derive the conclusion that the larger the impact of a specific balancing market design is on performance, the more dependent this impact is on the contextual power systems and markets.

6.3 Impact of balancing market internationalization

Regarding the possible internationalization of electricity balancing markets in Europe, we have made a distinction between balancing market harmonization and balancing market integration. The analysis of balancing market internationalization in this research has shown that this is a useful distinction. These two possible developments not only vary in nature and contribute to different goals, but also have a different impact on balancing market performance. This is shortly elaborated on below.

6.3.1 Impact of harmonization

An enormous amount of unique 'harmonization designs' can be formulated. First of all, we have identified 24 national variables, and the number of design variables included in the 'harmonization design' may vary from one to all of them. Second, the balancing market design space includes high-level variables such as 'methods of procurement' and 'timing of markets', which could easily be sub-divided into multiple lower-level variables. Third, each of the national balancing market design variables can take multiple values.

Next, the multi-criteria analysis of national design variables has shown that the range of possible effects is large for most of the design variables. Therefore, the effects of harmonization depend very much on the initial design variable values in the different national balancing markets, and on the uniform values incorporated in the harmonization design. Moreover, we have found that the effects are highly context dependent.

Thus, theoretically, the actual effect of a harmonization design could range from very small to huge, and from very negative to very positive. In practice, however, it is feasible to formulate promising, performance-improving harmonization designs *for a specific case*, as this allows one to take into account the initial balancing market designs and the contextual power systems and markets in the balancing region. Such a formulation can be based on the application of insights of generic system and multi-criteria analyses of national balancing market design, as we have done in chapter 4. Thus, from a practical perspective, the potential impact of balancing market harmonization is concluded to be highly positive.

6.3.2 Impact of integration

The key multinational balancing market design variable related to balancing market integration is that of cross-border balancing arrangements. Therefore, the impact of integration is reflected by the impact of alternative arrangements.

According to the results of the multi-criteria analysis of arrangements presented in section 5.3, the arrangements with the highest total impact are system imbalance netting, a common merit order list for balancing energy, and a common merit order list for reserve capacity. However, individual effects on performance criteria were evaluated quite differently. The common merit order list arrangements have a very large positive effect on the important economic efficiency and security of supply criteria, i.e. availability of balancing resources, price efficiency and utilization efficiency, and also on social welfare of cross-border exchanges, but negative effects on multiple others. System imbalance netting has smaller positive effects on the same criteria, without the negative effects on others. As a result, the net effect of system imbalance netting has been found to be the same as that of the common merit order list arrangements.

Furthermore, we have carried out an agent-based analysis of arrangements in order to assess their impact on balancing market performance for the case study of Northern Europe. There, we have observed that the annual total Actual Imbalance Costs (the sum of the AIC of all BRPs) of the Netherlands and Germany generally decrease immensely as a result of integration, i.e. by 50-80%, but that the total AIC of the Nordic region remain on the same level, or even increase significantly. Of course, the total AIC reductions are based on reduced balancing energy costs. The arrangements generally result in a total balancing energy costs reduction of 20-50% for German and the Netherlands. For Northern Europe as a whole, these costs reduce by 30% in case of a common merit order list. The large costs reductions can be directly explained by the high degree of balancing energy imports into the Netherlands and Germany from the Nordic region: These significantly reduce regulation and imbalance prices, and thereby the regulation costs and Actual Imbalance Costs. Interestingly, the total AIC in the Nordic region may increase as a result of integration. The Nordic balancing energy costs will generally decrease just like in the other two areas, thanks to system imbalance netting, but increase in case of BSP-SO trading, due to inefficient offering of Nordic bids.

Comparing both analyses of cross-border balancing arrangements, a main finding is that the four main options are clearly different not only in market design, but also in terms of effects. An overarching conclusion is that system imbalance netting and a common merit order list have a large positive impact on balancing market performance, while the effects of BSP-SO trading and an additional voluntary pool depend much more on the detailed design of the arrangement. Furthermore, a well-designed cross-border balancing arrangement, taking into account the initial balancing market designs and contextual factors, can be expected to significantly improve performance. In general, we conclude that balancing market integration has a highly positive potential impact on balancing market performance.

6.4 Design recommendations

6.4.1 General recommendations

In the multi-criteria analyses of balancing market design variables, for each design variable the effects of alternative variable values have been discussed, in order to determine the impact level of the variable. This has led to the specification of a 'best' design variable value for each variable, as far as this was possible. These specifications have been made taking into account different possible power system/market contexts. Based on these specifications, we have clustered the design variables into three groups on the basis of the generalizability of a 'best' design variable value; see Table 6.1.

It must be emphasized that the classification of design variables has been a short exercise. Nevertheless, it provides us with some additional insights. First of all, we notice that there appear to be many design variables with a limited (medium) generalizability, but also many design variables with a high generalizability, despite the existing interdependencies in balancing markets and overall power systems. Next, we have observed that it is relatively difficult to specify best designs for the multinational variables, because their scope is much broader and richer than for national variables, and context dependence is higher.

On the one hand we have been able to find design variable values that appear generally 'best', but on the other hand the system/market environment has been found to have a

Table 6.1 – Generalizability of 'best' balancing market design variable values

High	**Medium**	**Low**
National design variables		
Service classes	Zonal vs. nodal responsibility	Schedule Time Unit
Methods of procurement	Timing of markets	Reserve requirements
Allocation of reserve capacity costs	Publication of national information	Bid requirements
Allocation of balancing energy costs	Responsibility for renewable generation	Timing of settlement
Final gate closure time	Net vs. separate positions	
Control system	Activation strategy	
Ex-post trading	Balancing service pricing mechanisms	
Penalty for non-delivery	Imbalance pricing mechanism	
Initial gate closure time	BRP accreditation requirements	
Allocation of net settlement sum	BSP accreditation requirements	
Multinational design variables		
Organization SOs and regulators	Control area boundaries	Balancing region boundaries
Settlement of area imbalances	Cross-border balancing arrangements	Geographical distribution of reserves
	Regional service provision rules	Reservation of int. cap. for balancing
	Publication of regional information	Redistribution of balancing costs
	National vs. regional legislation	

large influence. This appears to be conflicting, but not necessarily: The fact that contextual factors change the magnitude of effects does not imply that a superior variable value does not exist, because the relative effects of the different variable values may remain unchanged. The classification suggests that this is the case for 12 variables (those classified under 'high' generalizability), while for the 23 other variables the context dependence does imply uncertainty on the ranking of variable values. Ergo, the high context dependence of the impact of national balancing market design does not entirely prevent the formulation of generic design recommendations.

The recommend values of the 12 balancing market design variables with estimated high generalizability of best values are listed in Table 6.2.

Table 6.2 – Recommended balancing market design variable values for variables with high generalizability

Design variable	**Recommended value**
Service classes	Distinction FCR, FRR and RR. Three service classes. Need for automatic FRR increases with larger frequency disturbances.
Methods of procurement	Tendering in markets. In case of endangered security: An obligation to install controllers to provide balancing energy (combined with competitive pricing).
Allocation of reserve capacity costs	Allocation by adaptation of system services tariff.
Allocation of balancing energy costs	Allocation to BRPs through imbalance settlement.
Final gate closure time	Final gate closure as close to real-time as possible. 30 minutes ahead is achievable.
Control system	Depends on service classes. A LFC system improves balance quality, and becomes more valuable when frequency problems increase.
Ex-post trading	The use of ex-post trading. In case ex-post trading interferes with imbalance pricing mechanism that must ensure system security: no ex-post trading.
Penalty for non-delivery	No penalty for non-delivery.
Initial gate closure time	Use of initial gate closure time on the day before delivery, after closure of the day-ahead market.
Allocation of net settlement sum	Allocation to BRPs with separate fees proportional to imbalance volumes.
Organization SOs and regulators	In case of regional codes: approval by national regulators and ACER. In case of common merit order list: one of the SOs functions as regional SO, unless objectivity is not guaranteed.
Settlement of area imbalances	Physical settlement (by means of compensation programs).

Finally, based on the detailed studies of three national design variables in section 4.4 and three multinational design variables in section 5.1, we draw some (more cautious) recommendations on these variables. These are summarized in Table 6.3.

Table 6.3 – Recommended balancing market design variable values for six studied design variables

Design variable	Recommended value
Schedule Time Unit	In range 15-60 minutes (15 minutes appears preferable). Depends on system imbalance patterns and short-term market design.
Timing of markets	High reserve capacity market clearing frequency. If no danger for security: daily reserve capacity market, which clears after day-ahead market. Bid submission up to clearing time.
Imbalance pricing mechanism	Single pricing. In case of weak security risks: an additive component for STUs with reduced system security. In case of strong security risks: two-price settlement.
Control area boundaries	No merging of control areas unless full harmonization and integration is feasible and costs of system operation reduce.
Reservation of interconnection cap. for balancing	Consider reservation per case. If worthwhile: Use of optimized variable reservation on a daily basis.
Cross-border balancing arrangements	System imbalance netting as the first step, and a common merit order list as the final step.

Comparing the estimation of effects of cross-border balancing arrangements with that of national balancing market design, it becomes apparent that, in general, balancing market harmonization has a higher potential to improve balancing market performance than balancing market integration. This is due to the high number of national design variables, many of which have a large effect on performance. However, a general statement on the relative values of harmonization and integration cannot be made, because integration and especially harmonization can take so many forms.

We conclude that it is very well possible that balancing market harmonization will improve balancing market performance more than balancing market integration, so both possible developments should be studied. This will take place naturally, if a common merit order list is strived for, which has been found to have the most positive impact of the cross-border balancing arrangements. After all, some balancing harmonization is required for integration. It is important to recalculate the potential value of balancing market internationalization after each internationalization step[4], as this step will have changed balancing market performance, and thereby the value of (further) internationalization. Wrapping up, harmonization and integration should be considered in unison, for the case at hand, and on a step-by-step basis.

6.4.2 Recommendations for Northern Europe

Harmonization For the concrete case of Northern Europe, if we follow up both the findings of the MCA of multinational design variables and the general guideline to stick closely to the current national designs, we could come up with a harmonization design such as presented in Table 6.4[5]. We have estimated in subsection 4.7.2 that this harmonization design significantly improves balancing market performance in all three North-European countries.

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[4] This holds also for short-term market integration, which will change the benefits of balancing market integration as well.

[5] The rational for this has been explained in appendix 4.7.2.

Table 6.4 – A harmonized balancing market design proposal for Northern Europe

Design variable	**Proposed value**
Schedule Time Unit	15 minutes
Methods of procurement	separate RC and BE market
Timing of markets	weekly reserve capacity market
Responsibility for renewable generation	BRPs
Final gate closure time	45 minutes before RT
Net vs. separate positions	net position
Balancing service pricing mechanisms	marginal pricing of BE
Imbalance pricing mechanism	single pricing

Integration Based on the results of the agent-based analysis of alternative cross-border balancing arrangements for the case study of Northern Europe (see section 5.4), which are consistent with the multi-criteria analysis and with research found in literature, system imbalance netting can be recommended as a beneficial first step for Northern Europe, and a common merit order list as a very beneficial second step. BSP-SO trading or the additional voluntary pool might be useful as intermediate steps, but this heavily depends on the detailed design, and also for an important part on its value as a step towards a common merit order list. After all, it appears that a detailed design is needed for these two arrangements that will be removed as soon as a common merit order list is introduced. This longer transition process incurs higher switching costs (internationalization costs). However, if for any reason the implementation of a common merit order list cannot take place soon, those costs may be compensated for by the additional balancing costs reductions effectuated by quick intermediate integration steps. A plausible reason for delay is the difficulty to reach agreement on the content of the harmonization step required for a common merit order list.

Internationalization An interesting question is how the separate possible developments of balancing market harmonization and balancing market internationalization should be looked upon, and in what way they could and should be combined into a single balancing market internationalization strategy, for Northern Europe.

A common merit order list requires the harmonization of the Schedule Time Unit, methods of procurement, timing of markets, a final gate closure time and balancing service pricing mechanisms, at least insofar these variables concern the regional balancing energy market. These are already five from the eight variables included in the proposed harmonization design for Northern Europe. Thus, System Operators and regulators in Northern Europe should, for the investigation of the introduction of a common merit order list in Northern Europe, study the desirability, feasibility and detailed effects of harmonizing the 'prerequisite variables' anyway. This goes a long way towards the realization of the proposed harmonization design. While the impact of a common merit order list is analysed, system imbalance netting can already be introduced as a first step. Simultaneously, the possible implementation of a carefully designed BSP-SO trading or an additional voluntary pool arrangement could also be studied, which might turn out to be a second-best final integration step, in case e.g. the prerequisite harmonization needed for a common merit order list turns out to be unfeasible.

Integration steps should be considered together with facilitating and performance improving harmonization steps, in order to end up with a smooth, well-chosen transition to the multinational balancing market decided upon.

7 Decision-making process of internationalization

A decision-making process design for decision making on balancing market internationalization is described in this chapter. In section 7.1, this process design is introduced, after the introduction of the main decision makers in European balancing market internationalization cases, and the connection to theory on process management. Then, the specific activities within this process design are explained per process design phase, i.e. the design phase, the analysis phase, and the decision phase. These explanations can be found in consecutively section 7.2, section 7.3, and section 7.4. Finally, a short conclusion is drawn in section 7.5.

7.1 Introduction

Decision makers In the context of balancing market internationalization, various actors may be part of a decision-making process on balancing market internationalization, and could therefore be considered 'decision makers'. The complete network of decision-makers for Europe is illustrated by Figure 7.1, and the involvement and interest of these decision makers is indicated in Table 7.1.

Table 7.1 – Involvement and interest of decision makers in Europe

Decision maker(s)	Involvement	Interest
European legislator	Low	Electricity market integration, European level-playing field
ACER	Low	Compliance with EU Electricity Directive and European Code on balancing
ENTSO-E	Low	European-wide security of supply
National legislators	Medium	National balancing costs, national electricity prices, national security of supply
National regulatory authorities	High	Compliance with national laws and codes
Transmission System Operators	High	National security of supply, ability to allocate costs
Electricity market participants	Low	Individual balancing costs, electricity prices, national and international trading opportunities

On the European level, the European legislator, consisting of the European Commission, the European Parliament and the European Council, enacts European Directives and

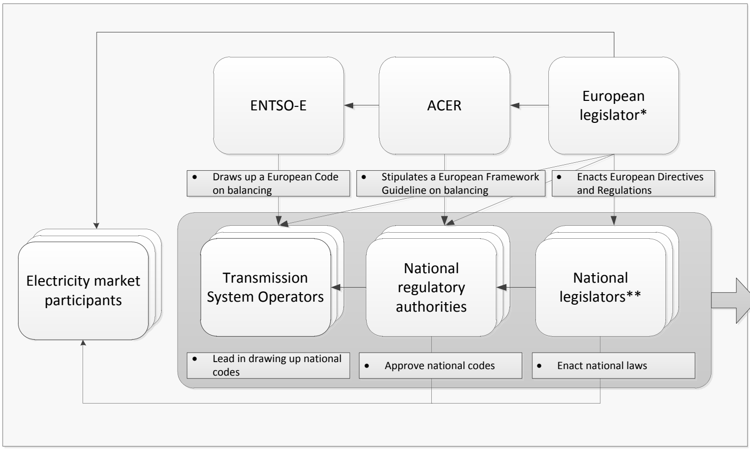

Figure 7.1 – Decision makers in the balancing market internationalization process in Europe. The arrows reflect institutional influence relationships. *: Consists of the European Commission, the European Parliament and the European Council. **: A national legislator consists of the national government and the national parliament.

Decisions. Electricity Directive 2009/72/EC only includes some general articles on balancing markets, mainly stating that these should be transparent and non-discriminatory. Considering also that balancing market internationalization will most likely start on a regional basis, following the Electricity Regional Initiative launched by ERGEG in 2006 (CEER, 2011), the European legislator will not be closely involved in European internationalization processes. However, it is likely to make sure that the internationalization will not conflict with the core values of electricity market integration and the creation of a European level-playing field.

The Agency for the Cooperation of Energy Regulators (ACER), which is the European organization of national regulatory authorities, will make sure that any multinational balancing market complies with the EU Electricity Directive and the European Code on balancing that is expected to be developed in 2013 (ENTSO-E, 2011c). Apart from this, however, ACER is not closely involved in the balancing market internationalization process either.

The European Network of Transmission System Operators for Electricity (ENTSO-E), the organization of Transmission System Operators in Europe, will not tolerate the development of balancing market integration that will jeopardize security of supply in Europe, but this is not expected to happen.

Much more relevant in a regional balancing market internationalization process in Europe are the national legislators (each consisting of the national government and the national parliament), national regulatory authorities and the Transmission System Operators (TSOs) of the countries/control areas that are included in the anticipated balancing region. Of these, the national legislators have a lower involvement in the process, being mostly concerned with balancing costs and its effects on electricity tariffs and prices, and security of supply in their respective countries. The TSOs, however, usually take the lead in drawing up the national code that includes the national rules on balancing, because they are most knowledgeable about balance management and balancing market functioning. It is likely, therefore, that the national TSOs will also take the lead in formulating a multinational balancing market design. Because the multinational balancing market rules should apply to all cooperating control areas in the balancing region, but not to other areas, these rules must be included in the national codes of all the cooperating areas. The national regulatory authorities must approve the proposed changes to the national codes, but they can also participate in the process of the code change proposal. Hence, it is essentially the national TSOs and the national regulatory authorities that participate in the balancing market internationalization process, in which the national TSOs will make sure that national security of supply is guaranteed and that the costs of cross-border balancing are recoverable, while national regulators will check consistency and compliance with the national codes and laws. In case balancing market rules are located in primary national legislation like laws, the national legislators are more directly involved.

Electricity market participants, i.e. power producers, traders, supply companies, and consumers, may have the opportunity to share their opinion on preferred balancing market internationalization developments, but they are generally less informed, and are inclined to think more about individual interest than national or regional interest.

Therefore, we will consider especially the Transmission System Operators and national regulatory authorities, but also the national legislators, as the relevant decision-makers on balancing market internationalization in Europe. The term ‘decision makers’ will in the remainder of this chapter refer to the TSOs, regulators and national legislators of the countries in the region (balancing region) for which balancing market internationalization is under consideration.

Decision-making process When the possibility of balancing market internationalization starts to receive serious attention in a region, a balancing market design decision-making process will be started up by the involved decision makers. Such a start-up does not need to mean that these decision makers already have made up their mind about balancing market internationalization; the final result of the process could also be the decision to refrain from internationalization. We advocate a systematic and deliberate approach to the decision-making process. Such an approach is necessary, in view of the uncovered myriad of concepts, terms, design variables, performance criteria, indicators, contextual factors, and stakeholder interests in the realm of balancing markets. Moreover, such an approach will prevent three core pitfalls: misunderstanding of the decision-making problem, failure to consider all important requirements and design options, and failure to accurately deal with the complexity of national and multinational balancing markets and existing uncertainties. In short, a systematic and deliberate approach is indispensable for effective decision-making on balancing market internationalization.

Connection to theory on process management of decision making (de Bruijn et al., 2002) The statement that a structured decision-making approach is needed for the balancing market internationalization process, appears to be in contrast with the theory on process management and process design for decision making on complex change processes by de Bruijn et al. (2002). They argue that decision-making processes tend to take place in a network, in which multiple actors must cooperate to reach a decision ('multi-actor decision making'). Such a network is characterized by interdependent and multiform actors that are not interested in cooperation, and join and leave the process at will. Furthermore, decision-making may be about 'unstructured problems', i.e. problems with a lack of objective information and a lack of consensus about the weight of the criteria used in problem solving. Moreover, the actors may have different interests, while being mutually dependent for reaching a decision. It is stressed by de Bruijn et al. (2002) that multi-actor decision-making dealing with unstructured problems should apply process management instead of the classical project management. This means that the number of decision makers, the problem definition and solution are not fixed, and that the focus lies on designing and managing the decision-making process. According to the authors, even the 'process design' itself is the outcome of a process in which the actors (decision makers) participate.

It is true that the decision-making process on balancing market internationalization has some similarities with the type of process requiring a 'process approach' according to de Bruijn et al. (2002). First of all, it is a multi-actor process, in which System Operators, regulators and governments pursue their national interests, and the successfulness of the decision-making depends on the cooperation of the decision makers. Second, the decision on a multinational balancing market design can be considered an unstructured problem, because there is uncertainty on the effects of alternative design options and performance criteria are bound to be valued differently between decision makers. However, a difference is that at least the general problem and solution areas are defined: The solution under consideration is balancing market internationalization, and the problem is the optimization of multinational balancing market design under uncertainty of effects. As a result, the general risk of a process approach of a lack of substance (cf. de Bruijn et al. (2002)) is relatively low: The process will logically revolve around the design and analysis of alternative designs, which guarantees that the process takes a meaningful course. Furthermore, all decision makers anticipate to gain from internationalization, considering our finding that a well-designed multinational balancing market can significantly improve performance in all involved areas. Therefore, the risk of obstructive behaviour by decision makers, another risk of process management, is low.

These differences reduce the complexity of the decision-making process, enabling a more structured decision-making approach. As we argue that such an approach is indispensable for effective decision making on balancing market internationalization, this is convenient. Besides, de Bruijn et al. (2002) themselves mention that 'process drives out substance', suggesting the need of at least some structure. We understand from the theory of process management that it is important not to unilaterally confine the problem and solution space on beforehand if this could provoke resistance from decision makers. The structure of the decision process for balancing market internationalization presented below defines different phases and activities that follow logically from the decision tasks at hand, i.e. on designing, analysing and deciding between design alternatives. This is a functional structure rather than a procedural one. The procedural structure, including the process rules and exact process plan, is not included, and no detailed specifications of the content of the design, analysis and decision processes are made. The structuration of phases and activities will, however, significantly reduce the risks of inefficient and ineffective decision making.

A structured decision-making process We have formulated a generic decision-making process that can be applied to decision-making on balancing market internationalization (in Europe). This process is depicted in Figure 7.2, and will be described in more detail in this chapter.

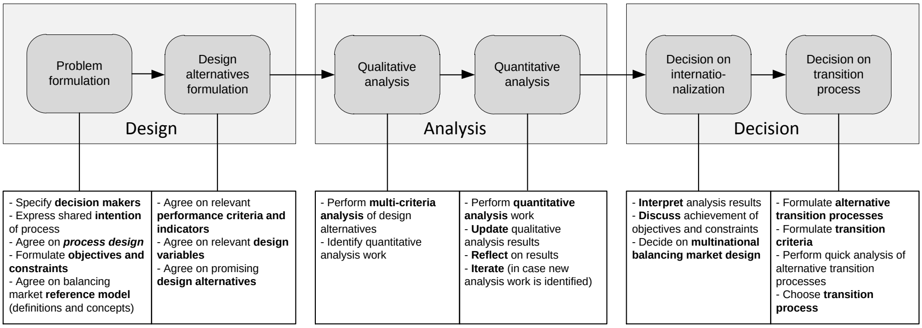

Figure 7.2 – Proposal for a structured decision-making process for balancing market internationalization

The balancing market internationalization decision-making process (here 'decision-making process' in short), can be divided into three main phases. Each phase contains two main steps, which can be subdivided again into multiple activities. The three main phases are the design phase, the analysis phase, and the decision phase. The design phase consists of the steps of problem formulation and design alternatives formulation, the analysis phase consists of qualitative analysis and quantitative analysis, and the decision phase consists of a decision on internationalization and a decision on the transition process. The activities included in these steps are listed at the bottom of Figure 7.2, and are described below.

The phases, steps and activities should in principle be followed in the same sequence as presented here. However, it is very well possible that e.g. new design options are discovered or that the set of relevant performance criteria changes as a result of developing insights of decision makers during the analysis phase, which calls for a return to the design phase. Thus, process iterations may occur.

7.2 Design phase

The design phase has been split up into a problem formulation step and a design alternatives formulation step, because before the formulation of design alternatives ('solutions') can be initiated, the decision makers must first agree on the decision-making problem at hand: objectives and constraints, concepts and definitions, and also the decision-making process design itself.

7.2.1 Problem formulation

The first activity in the **problem formulation** step is the *specification of the decision makers* that will together go through the decision-making process, and finally must agree on a specific multinational balancing market design to be introduced. Of course, all relevant parties in the balancing region responsible for balancing market decision making should be included, which are at least the System Operators and energy regulators of the control areas in the balancing region.

Secondly, a *shared intention* of the decision-making process should be formulated, to which all the decision makers should commit. This shared intention deals with common goals, and could also be about the nature and structure of the decision-making process. It makes sure right at the start that the decision makers have the same problem and solution space in mind, and are willing to work together towards the establishment of balancing market internationalization.

Thirdly, the decision makers should *agree on a process design* for the decision-making process. This is the very artefact we describe here. Thus, Figure 7.2 depicts a specific process design that we propose here to be used for decision making on balancing market internationalization (although this design still leaves a lot open). The decision makers can adapt and concretize the proposed decision-making process, but we do not recommend to deviate too much from the main design layout, in order to maintain the essential structured and deliberate approach to decision-making on balancing market internationalization. Furthermore, it is not necessary to include too much detail in the process design; there should be room for choosing and adapting activities along the way, answering to the issues at hand.

Next, *objectives and constraints* should be formulated regarding the performance of balancing markets in the balancing region. First and foremost, System Operators and regulators should specify the objectives and constraints they have regarding the impact of internationalization on the performance of balance management in the own control area. Next to that, objectives and constraints could also be formulated about the net impact of internationalization. All these should be combined into one set of requirements for the multinational balancing market. To support this activity, the evaluation set presented in section 3.2 could serve as a starting point. At a minimum, the two fundamental requirements to maintain a minimum level of security of supply and to maximize economic efficiency of balance management should be represented. If decision makers disagree about the importance of the different requirements, this should be settled at this stage. Agreement on the set of requirements sheds light on the likelihood of making a final decision to internationalize, and generates some confidence about an undisputed evaluation of design alternatives.

The following activity is the *agreement on a reference model* for balancing markets. This reference model includes standard terminology on balancing markets, and definitions of the concepts of the national balancing market and the multinational balancing market. The balancing market concepts provide a clear delineation of the topic (object of design/decision-making). The standard terminology provides a clear set of definitions. It is a prerequisite for decision making on balancing market internationalization to use standard terminology, because the decision makers need a shared 'language' in order to effectively design and analyse multinational balancing market designs. A list of standard definitions, in combination with a shared idea of the structure and functioning of balancing markets, will establish an early common understanding of the important topics. Therefore, the adoption of a reference model enhances the speed and effectiveness of the decision-making. We have introduced a balancing market reference model in section 3.1.

7.2.2 Design alternatives formulation

A first activity within the design alternatives formulation step is the *agreement on performance criteria and indicators*. In this step, the decision makers must define the relevant performance criteria for the evaluation of the design alternatives. These criteria should be easily deducible from the requirements formulated in the first step. The set of balancing market performance criteria presented in subsection 3.2.2 can serve as the basis for the formulation of the relevant set for the internationalization case. We believe that, at minimum, the security of supply criteria 'availability of balancing resources' and 'balance quality' and the economic efficiency criteria 'utilization efficiency' and 'price efficiency' should be represented. If balancing market integration is considered, we find that the multinational criteria 'internationalization costs' and 'social welfare of cross-border exchanges' should at least be included as well. The adopted performance criteria should be made operational by defining how they are evaluated as clearly as possible. This will usually involve the formulation of performance indicators. The identified balancing market performance indicators within our design framework can support this (see subsection 3.2.3 and subsection 4.1.4).

Next, the decision makers should reach *agreement on the design variables* that are relevant for the internationalization case. The balancing market design space presented in section 3.3 may serve as the starting point for this activity. Depending on the internationalization case and the preferences of the decision makers, the relevant design space may include just a couple of the design variables from our design space, or include more detailed, lower-level design variables. However, regarding harmonization, we recommend to include at least the national design variables that have been identified as important in this research, which are actually a majority of the identified variables (see section 4.6). Regarding integration, we recommend to include at least the multinational design variables that have been identified as most important, and at the same time represent the possible development of integration: 'cross-border balancing arrangements', 'regional service provision rules', 'reservation of interconnection capacity', and 'control area boundaries'.

The final activity in the design phase is the *agreement on design alternatives*, i.e. a set of promising multinational balancing market designs that will be studied and compared in the analysis phase. The more design variables have been included in the design space, the more design alternatives are available, and the more difficult this activity becomes. Choices of promising designs may be based on a first explorative analysis of the effects of design options, but also on practical issues as the feasibility or desirability of design options. Of much help can be the use of conceptual models that visualize the interrelations between design variables, in terms of a hierarchy or priority of adaptation/consideration. Figure 7.3 illustrates a priority of consideration of national design variables, along with an indication of different design pillars, dimensions (technical, institutional, economic), and feasibility (very hard/hard/easy to change).

From top to down, the design variables are ranked in order of decreasing 'priority',

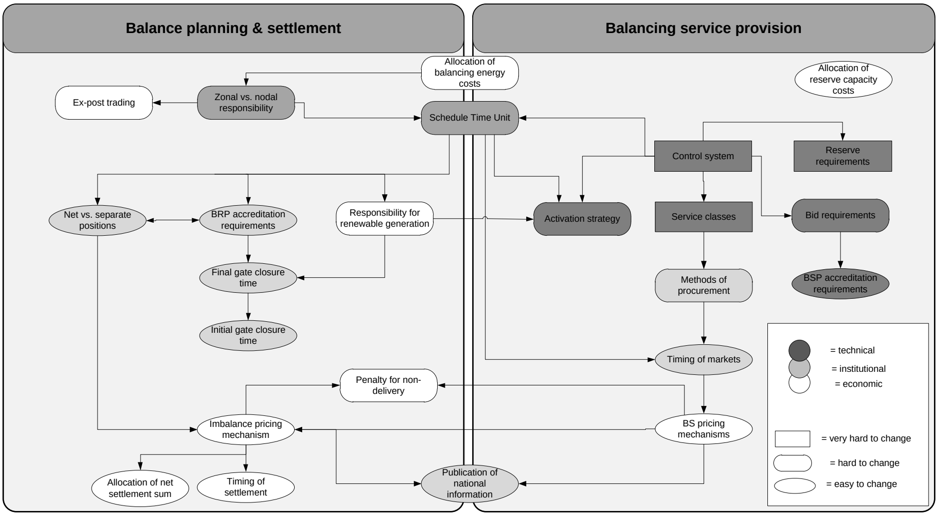

Figure 7.3 – A priority order for the national balancing market design process. The arrows indicate a sensible chronological order of decision making on national design variables.

which does not only reflect the importance (impact) of the design variables, but also the natural position in a balancing market design change process. Design variables that should typically be considered first, because of the implications they have for other design variables, are 'zonal vs. nodal responsibility', 'Schedule Time Unit', 'control systems', and 'service classes'. If feasibility and desirability of changing some variables high up in the hierarchy are estimated to be reasonable, main design alternatives should be built around these variables.

Figure 7.4 illustrates a priority of consideration of multinational design variables. Here, the main cross-border balancing market arrangements form the obvious design alternatives, complemented with the possibility to reserve interconnection capacity for cross-border balancing (if considering reserve capacity exchange), and possibly with the option of merging control areas.

With regard to the selection of alternative multinational balancing market designs, the decision makers should not limit themselves to either harmonization designs or integration designs, unless they aim specifically to realize either harmonization or integration. In general, however, the fundamental aim is always to improve balancing market performance, which can be realized both by harmonization and integration. Moreover, we have pointed out in chapter 6 that harmonization could have a larger impact than integration. There is no reason why harmonization and integration designs cannot be considered simultaneously. To the contrary, in order not to focus too much on either one of the internationalization developments and get a sense of their relative value, it is recommended to include at least one of both in the set of alternative designs to be analysed.

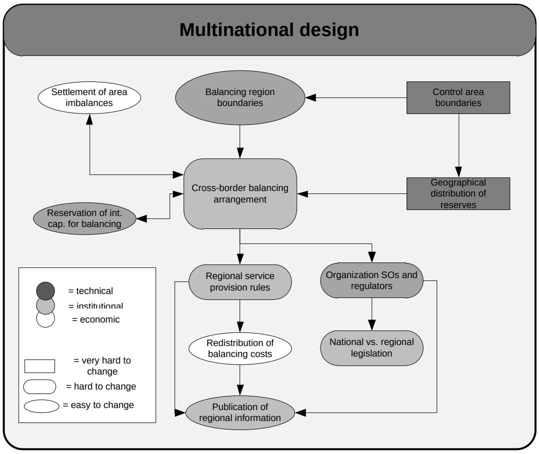

Figure 7.4 – A priority order for the multinational balancing market design process. The arrows indicate a sensible chronological order of decision making on multinational design variables.

7.3 Analysis phase

For the analysis phase, we distinguish between a qualitative analysis step and a quantitative analysis step, because these two forms of analysis not only differ substantially in nature, but also in value and function. In our view, qualitative analysis is useful for high-level analyses of systems that concern factors and effects of different nature (economic, technical, institutional, etc.). It is fundamentally impossible to embed this kind of multidimensionality into one quantitative model in a realistic way. On the other hand, quantitative analysis is more useful to analyse effects that can be quantified relatively well, but concern many factors and interrelations. Of course, the effort of building a quantitative model should be justified by its necessity to obtain a solid evaluation.

With regard to balancing markets, it is impossible to catch the complete set of design variables, performance criteria and interactions, i.e. all the social and technical complexity of balancing markets, into one quantitative model. However, with qualitative analysis, at least all design variables and performance criteria can be considered. Besides, qualitative analysis has the advantage that there are no modelling assumptions that limit the realistic representation of the balancing market. Conversely, the effects of many balancing market design variables can benefit from in-depth quantitative analysis.

Thus, we believe that, for the analysis of multinational balancing market design alternatives, qualitative analysis is more useful to perform an overall analysis including all design options and criteria, and that quantitative analysis is more useful to uncover the (possible) effects of specific design options involving high degrees of complexity and uncertainty. Therefore, both are incorporated in the proposed process design. The distinction between both emphasizes the different role they play in the analysis phase.

7.3.1 Qualitative analysis

The main activity in the qualitative analysis is the *execution of a multi-criteria analysis of the design alternatives*. Our research on balancing market design has shown that a lot of different performance criteria exist, which nevertheless can be used for the assessment and comparison of very different balancing market designs (including both harmonization designs and integration designs). In order to evaluate the different design alternatives, a multi-criteria analysis is useful as overarching analysis tool. This is proven by our multi-criteria analyses of national design variables in section 4.6, of multinational design variables in section 5.2, and of main cross-border balancing arrangements in section 5.3.

A useful input for the multi-criteria analysis is an (exploratory) system analysis of balancing market factors and interrelations such as presented in section 4.1. Such an analysis, together with the multi-criteria analysis itself, can also help to identify what design options and/or effects require a detailed quantitative analysis. Herewith, a second activity of *identification of quantitative analysis work* can be carried out.

7.3.2 Quantitative analysis

The main activity in the quantitative analysis is the *execution of quantitative analysis work* identified in the last activity. This work typically uncovers effects that are hard to assess qualitatively due to uncertainties and complexities in interactions between behaviour of market participants and system-level performance. The related analysis results can be fed into the overall multi-criteria analysis, which is the second activity of *updating of the qualitative analysis results*. Examples in this research are the agent-based analyses of imbalance pricing mechanisms (subsection 4.4.3) and of cross-border balancing arrangements for Northern Europe (section 5.4), which have helped to evaluate the effects of these two design variables.

In a further *reflection of the analysis results*, more knowledge gaps and uncertain effects are perhaps identified, to which further quantitative analysis could provide an answer. If this is the case, an *iteration* step should preferably be taken, including quantitative analysis, updating of the qualitative analysis, and another reflection on the results.

7.4 Decision phase

We also can distinguish between two steps in the decision phase: the decision on internationalization and the decision on the transition process. Only if the decision is made to introduce a particular harmonization and/or integration design (multinational balancing market design), the decision makers need to think about the transition process, i.e. the internationalization process that ends with the establishment of the intended multinational balancing market design. The transition process is relevant, because it can be unfeasible to introduce the intended design in one step, especially if this involves a common merit order list (which has been evaluated as the most beneficial arrangement). This lack of feasibility could be caused by time delays in decision-making, either due to delays in effective implementation (adaptation of legislation, installation of control systems, market platforms, administrative systems, etc.) or due to disagreement on the details of the final design.

Furthermore, there will be a lot of uncertainties on the exact effects of balancing market design changes, if only due to the unknown response of market participants to these changes, which can form a main reason to implement the multinational design in several steps. A multi-step transition allows for re-evaluation of the intended final multinational design at different points in the transition process.

7.4.1 Decision on internationalization

The first activity under the decision on internationalization step is the *interpretation of analysis results*. The results of the analysis of design alternatives will provide insights in the impact of design and internationalization, the influence of contextual factors, and in the interaction between market behaviour and system performance. Most importantly, the analysis results should lead to the evaluation of the meeting of the requirements. This is probably not a one-to-one translation, so a *discussion of the achievement of the objectives and constraints* for the different design alternatives will take place.

As soon as there is agreement on the absolute and relative value of the design alternatives, a *decision on a specific multinational balancing market design* (design alternative) can be made. In principle, the decision will be made to implement the design alternative that meets all the objectives and constraints. However, if there are multiple design alternatives that meet all the requirements, the one with the highest net benefit should be chosen. If none of the design alternatives meet all the requirements, the decision makers should enter into another decision-making round, in order to attempt to reach agreement anyway. This could involve the adaptation of the detailed design of the best-scoring design alternative, and possibly additional analysis as well. If the decision makers cannot reach agreement, the final decision will be to discard all design alternatives, and refrain from balancing market internationalization completely.

7.4.2 Decision on transition process

If a multinational balancing market design has been chosen, there is still a decision to be made on the transition process, i.e. the sequence of internationalization steps that are carried out towards the chosen multinational balancing market design. The more advanced the chosen degree of internationalization, the more relevant the transition process. The transition process itself can also be looked upon as a design, and it is advised to go through a quick miniature decision-making process for the decision upon a specific transition process design.

A lot of different transition processes are possible. This is illustrated by Figure 7.5. Basically, a transition process consists of different internationalization steps, which are represented by blocks. Different possible steps are the different cross-border balancing arrangements, either only for balancing energy, or only for reserve capacity[1], or for both. Furthermore, other steps represent different harmonization efforts. A distinction can be made between three types of harmonization: performance improving harmonization, facilitating harmonization, and prerequisite harmonization. Performance improving harmonization steps can be considered as steps in an independent balancing market harmo-

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[1] In case of reserve capacity exchange, balancing exchange will always at least take place for the bids corresponding to the reserve capacity exchanged across the border.

nization process. The other two types of harmonization steps are directly linked to the overall balancing market integration process. Facilitating harmonization improves the efficient and effective functioning in integrated balancing markets (not only by creating equal market conditions, but also by removing obstacles to balancing service exchange), while prerequisite harmonization fulfils the prerequisite steps for the common merit order list (see subsection 6.1.4).

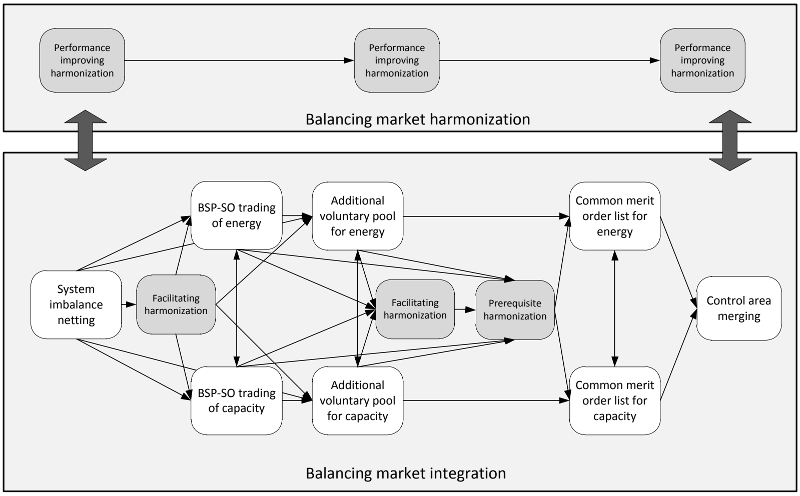

Figure 7.5 – Overview of possible transition processes from separate national balancing markets to a multinational balancing market. The blocks and arrows represent incremental balancing market internationalization steps.

A transition process to balancing market internationalization may include both harmonization and integration steps, only harmonization steps, or only integration steps (aside the prerequisite harmonization for a common merit order list). The harmonization steps could consider any combination of national balancing market design variables, so these are not well defined. The integration steps are better defined, but especially for the BSP-SO and additional voluntary pool arrangements, there are still a lot of detailed design options. Furthermore, the integration process typically starts with system imbalance netting, being a no-regret option with a large positive impact that does not require balancing market design changes. But after that, the integration process could skip BSP-SO trading, the additional voluntary pool, or both, or could just involve either reserve capacity exchange or balancing energy exchange. In addition, an arrangement for balancing energy could be introduced first, followed later by the same arrangement for reserve capacity, or vice versa. This might even be true for a common merit order list, if a common merit order list for reserve capacity is considered to be an arrangement where reserve capacity bids are optimally exchanged, but are still settled and utilized for real-time balancing nationally.

The first activity in this step is the *formulation of alternative transition processes*, which will include the main transition processes that the decision makers have in mind. This is expected to be a small number. Next, the decision makers should *formulate the transition criteria* that they find important. There are several transition criteria that could be considered. The most important ones are related to the number of integration steps, i.e. the choice between a small number of large steps vs. a large number of small steps. First of all, a low number of intermediate internationalization steps can be regarded as important, in order to minimize switching costs and to prevent that market participants need to adapt to changing market rules multiple times, creating operational risks for both the market and for the System Operators. On the other hand, a higher number of intermediate steps has the (possible) advantage of a more gradual development with a lower risk of large changes in balancing market performance. In addition, it builds in more flexibility to change, halt or even turn around the transition process, as a response to unforeseen effects of internationalization.

After the transition criteria have been chosen, the decision makers can *perform a quick analysis of alternative transition processes*, on the basis of these criteria. This will then lead to the *choice of a transition process*. Part of the decision for a transition process could be to enter into a new (smaller) decision-making process after the implementation of each intermediate step, and re-evaluate the impact of the intended final multinational balancing market design based on the newly gathered information.

7.5 Conclusion

The proposed decision-making process described above forms a structured and deliberate approach that can be applied by decision makers to decide on balancing market internationalization. The balancing market design framework from chapter 3 forms a useful input for the design phase, the analysis approach and results presented in chapter 4 and chapter 5 provide inspiration and insights for the analysis phase, and our conclusions and recommendations described in chapter 6 may support the decision phase.

8 Conclusions and recommendations

The topics of balancing market design, i.e. the design of market-based balance management arrangements in liberalized electricity markets, and balancing market internationalization, i.e. the possible development of harmonizing and/or integrating national balancing markets currently predominant in Europe, are relatively new and have not been studied systematically in scientific research (chapter 2). This research has provided such a systematic study.

In this research, we have created a balancing market design framework, including standard terminology, a general design space, and a performance criteria set (chapter 3). Using this framework, we have carried out a system analysis of balancing markets and performed a qualitative analysis of the effects of national design variables and of the impact of balancing market harmonization, in general and for the case of Northern Europe (chapter 4). Following this, we also performed a qualitative analysis of the effects of multinational design variables and of the impact of balancing market integration, and an agent-based analysis for the case of Northern Europe (chapter 5). This led to overall insights in the value of balancing market design and balancing market internationalization, as well as general design recommendations and recommendations for Northern Europe (chapter 6). Finally, a decision-making process design for decision making on balancing market internationalization has been presented (chapter 7).

In this chapter, we shortly summarize conclusions and recommendations from the research on balancing market design, balancing market harmonization, balancing market integration, balancing market internationalization, and the case study of Northern Europe (section 8.1). After that, we shortly answer the main research question (section 8.2). Last, we reflect on the setup, scope and results of the research (section 8.3), and give some suggestions for further research (section 8.4).

8.1 Conclusions and recommendations

On balancing market design

- In liberalized electricity markets in Europe, the balancing market is an intricate institutional arrangement required to maintain the balance between electricity demand and supply in a market-based and economically efficient way.
- The topic of balancing market design is multi-faceted: it involves three different pillars, three main actors, and different balancing services. The composed balancing market design framework includes an extensive list of terms and definitions, a design space with 35 design variables, and eleven performance criteria.
- Two fundamental balancing market criteria are operational security of supply and economic efficiency. The first can be translated into the criteria of availability of balancing resources, balance planning accuracy, and balancing quality. The last can be translated into the criteria of cost allocation efficiency, utilization efficiency, price efficiency, and operational efficiency. Two relevant high-level EU-based criteria are transparency and non-discrimination. In a multinational context, internationalization costs and social welfare of cross-border exchanges are two more relevant performance criteria.
- The analyses in this research have shown that both national balancing market design and multinational balancing market design have a large impact on balancing market performance. The direction and magnitude of the specific effects depend on the specific changes in design variable values.
- On an aggregate level, the criterion of availability of balancing resources is affected most by balancing market design, followed by price efficiency, utilization efficiency, and balance quality.
- The design pillar of balancing service provision has a larger impact on balancing market performance than the design pillars of balance planning and balance settlement together.
- The dependency of the impact of balancing market design on contextual power system and market factors is high. The largest influence has the contextual factor of the generation portfolio (which includes the generation aspects of the generation technologies, reserve margin, predictability, marginal costs, and flexibility).

On balancing market harmonization

- The impact of harmonization depends on the particular harmonization design and the initial national designs. Considering all theoretical options, the net effect of harmonization can range from very small to very large and from very negative to very positive. However, considering that it is relatively simple to formulate a performance-improving harmonization design for a specific internationalization case, in practice the impact of harmonization will be highly positive.

- Barriers to harmonization include legal barriers, technical barriers, economic barriers, barriers linked to context-dependencies, barriers linked to adverse effects on stakeholders, and barriers linked to disagreement between decision makers.

- An important driver to harmonization could be balancing market integration, because integrated balancing markets will benefit from the level-playing field for market parties that harmonization contributes to. A more general driver could be the integration of day-ahead and intra-day markets.

On balancing market integration

- The key design variable in the multinational balancing market design concerning balancing market integration is the cross-border balancing arrangements. The four main arrangements are system imbalance netting, BSP-SO trading, an additional voluntary pool, and a common merit order list. They represent different degrees of integration.

- The impact of balancing market integration depends on the availability of balancing resources in the region, available interconnection capacity, and differences in national balancing service price levels, but the choice of a cross-border balancing arrangement has also been found to have a large impact.

- The general potential impact of balancing market integration is highly positive. System imbalance netting will cause a significant reduction of balancing costs without much effort. A common merit order list can be expected to reduce balancing energy costs and imbalance costs by more than 30%, but requires some harmonization, and balancing prices might increase in some areas. The effects of BSP-SO trading and an additional voluntary pool strongly depend on the detailed design of these arrangements.

- Technical barriers to integration may be substantial. They do not only involve different national balancing resource capabilities, but also different control systems, the availability of interconnection capacity, control of HVDC cables, the sending of border-crossing control signals and the coordination of information exchange. In addition, legal barriers may arise from the embedding of cross-border balancing rules in the national codes and/or in a regional code.

- Harmonization prerequisites are first and foremost a barrier for the common merit order list. For this arrangement, the following design variables should be harmonized: the final gate closure time, service classes, the Schedule Time Unit, methods of procurement, timing of markets, bid requirements, balancing service pricing mechanisms, and BSP accreditation requirements.

- Drivers to balancing market integration are balancing market harmonization, day-ahead and intra-day market integration, and an increasing penetration of wind power in European power systems.

On balancing market internationalization

- Balancing market harmonization can improve balancing market performance by adopting design variable values resulting in more appropriate incentives to Balance Responsible Parties and Balancing Service Providers. Balancing market integration can improve performance by means of cross-border balancing, principally improving the utilization efficiency and price efficiency of balancing service markets. These two balancing market internationalization developments are intertwined; they can facilitate each other. Therefore, decision makers should study both developments simultaneously.

- Balancing market harmonization has been found to have a higher potential to improve balancing market performance than balancing market integration. This is caused by the higher number of national design variables, and by the higher context-dependent limitations relevant to integration (available interconnection capacity, available excess resources, etc.).

- It may prove difficult for decision makers (System Operators, national regulatory authorities, and legislators) to agree on a single multinational balancing market design, considering the different interests and design preferences they may have, considering uncertainties on effects, and considering different effects among areas and stakeholders. A structured and deliberate approach to decision making on balancing market internationalization will help to create an efficient and effective decision-making process.

- A more fragmented transition process incurs more switching costs, but may improve the flexibility and speed of the balancing market internationalization process.

On balancing market internationalization in Northern Europe

- In a short harmonization analysis exercise, a promising harmonization design formulated for Northern Europe includes a Schedule Time Unit of 15 minutes, separate reserve capacity and balancing energy markets, a weekly reserve capacity market, responsibility for renewable generation with BRPs, a final gate closure time of 45 minutes before real-time, a net position for BRPs (both production and consumption in one portfolio), marginal pricing of balancing energy, and single pricing of BRP imbalances. This design was estimated to significantly improve balancing market performance in all three areas.

- For Northern Europe, system imbalance netting can be recommended as a beneficial first step for Northern Europe, and a common merit order list as a very beneficial final step. BSP-SO trading or the additional voluntary pool might be useful as intermediate steps, especially if a common merit order list cannot be realized quickly.

8.2 Answer to research question

Coming back to the research question, we conclude that the development of multinational balancing markets in Europe has the potential to highly improve both the economic efficiency and the security of supply of all involved national balancing markets. However, the magnitude and direction of effects depend not only on the exact multinational balancing market design, but also on the particular case, i.e. the initial national balancing market designs and the contextual power systems and markets in the balancing region. Due to this context dependence, and due to the myriad of design options, possible goals and various uncertainties about effects of multinational balancing markets, a structured and deliberate approach to design and decision making is required to maximize the chance of successful decision making on balancing market internationalization.

8.3 Reflection

Analysis approach The qualitative multi-criteria analysis, which has been applied as the main analysis tool in this research, has been useful to perform a high-level comprehensive assessment of the impact of balancing market design and internationalization. The effects of balancing market design variables have not been quantified by means of computational models incorporating all important balancing market system factors and interrelations, but it is hardly possible to incorporate all the social and technical complexity present in balancing markets. Still, a quantitative modelling approach might have generated new insights in the dynamic interaction between design variables, system factors and indicators. On the other hand, such an approach would have required a lot of (modelling) assumptions, limiting the value of the results. The qualitative analysis in this research has enabled the consideration of all relevant performance criteria and design variables, creating a completer picture of the value of balancing market design and integration.

The outcomes of the multi-criteria analysis are of course subject to the formulated list of performance criteria, as well as to the chosen weights. However, the selection of the criteria has been based on an extensive explorative research on balancing markets, the criteria and weights have been subject to expert validation, and the analysis has confirmed their relevance. The estimation of the effects of the balancing market design variables on the performance criteria has been based on our accumulated knowledge on balancing markets, notably from the balancing market system analysis in section 4.1. These estimations are more debatable. However, as we do not arrive at strong conclusions built upon the detailed effect estimations, this does not affect the credibility of our conclusions and recommendations.

To support the multi-criteria analysis, agent-based simulations of the effects the imbalance pricing mechanism and of alternative cross-border balancing arrangements have been carried out. In these simulations, we have not considered the effects on the behaviour of Balancing Service Providers, which reduces the validity of the results somewhat. Furthermore, the dimensioning of the simulation models to the North-European markets could limit the generalizability of the simulation results. However, the confrontation of the simulation results with the gained insights in balancing market functioning still enables the drawing of general conclusions on the relative value of different imbalance pricing options and cross-border arrangements. Next, the validity of the results also depends on a correct representation of BRP decision-making, which could deviate from actual behaviour. It is certain, however, Balance Responsible Parties aim to minimize their imbalance costs under uncertainty of future imbalance prices, and this has been logically represented in the decision-making algorithm.

Finally, the inclusion of a single case study in the agent-based analysis of cross-border arrangements reduces the generalizability of the results. Here, however, the combination of the simulation results with the multi-criteria analysis of the effects of alternative design options and contextual factors enables us to derive to what extent the effects can be expected to deviate from the case study of Northern Europe. This is confirmed by a Nordic high price scenario in the simulation study, the results of which matched the expectations (see section 5.4).

Research scope The relevance of the research results is restricted by the research scope. First of all, we have focused on the balancing market, i.e. on the interactions within balancing markets, and not so much on the interactions between balancing markets and day-ahead and intra-day markets. However, these interactions have been considered throughout the research, by linking imbalance costs to the day-ahead price and by considering the short-term market design and liquidity as contextual factors, among other things.

Second, an institutional perspective has been taken, which means that the technical aspects related to balancing market integration have not been studied in detail. However, the literature study has not revealed large technical obstacles to integration.

Third, the interrelations between balance management and other power system operation services have not been explicitly considered. The occurrence of congestions within a control area reduces the availability of balancing resources, while the use of flesible resources by System Operators for the purpose of congestion management affects this availability as well.

Fourth, the geographical scope has been limited to Europe, because of the particular electricity market design in many European countries (a voluntary power exchange and freedom of dispatch for generation companies), in combination with the existence of many different balancing market designs and the European aim of electricity market integration. However, a large part of the balancing market design space should be relevant to centralized power pools as well, if considering that ancillary services for frequency control still need to be obtained from the market, and that energy production and consumption still need to be scheduled and settled. Nevertheless, the different power market designs will result in different effects of (even) similar design options.

Positioning in electricity sector developments As a final reflection, the research findings can be looked at in the light of developments in the European electricity sector.

Regarding electricity market integration in general, day-ahead markets and intraday markets in Europe become increasingly international. Although it may be still a long way to a pan-European day-ahead and intraday market, the most important obstacle appears to be the lack of unbundling and liberalization in some European markets. The aim of a pan-European balancing market appears less self-explanatory and more problematic. Due to the multiplying coordination and compatibility problems that wider applicable cross-border balancing arrangements appear to create, the added value of a pan-European arrangement compared to different regional arrangements could be small. Furthermore, harmonization of the balancing market rules may face institutional and technical barriers (see chapter 6), or face resistance by decision makers, e.g. for the reason of contextual incompatibility. On the other hand, given the interactions between balancing markets and short-term power markets, lacking balancing market integration may lead to market distortions.

A particularly relevant European development is that of increasing wind and solar power integration. The expected increasing intermittent renewable generation share will cause system imbalances to become larger and more unpredictable and volatile, while the availability of flexible and controllable generation resources deteriorates at the same time. Balancing market integration has the potential to reduce the balance management costs immensely, both by the geographic smoothing of wind power imbalances (surplus energy exchange) and by the import of cheaper balancing resources. Intermittent power integration can thus be greatly facilitated by balancing market integration. In fact, wind and solar integration might become the most important driver to balancing market integration. In addition, wind and solar power integration would also be facilitated by national balancing market designs that are attuned to this development. Importantly, the market (BRPs) should be balance responsible for intermittent generation, but imbalance costs should not lead to a negative business case for generation companies.

Finally, it is interesting to discuss the findings on balancing market integration in the light of two ‘development trends’ in the electricity sector: internationalization vs. decentralization. Balancing market integration, electricity market integration and wind power integration are clearly examples of the ‘internationalization trend’. The ‘decentralization trend’ concerns topics as distributed generation, demand-side management, smart grids, and micro-grids. Where internationalization aims to improve economic efficiency and security by means of international competition and exchange, decentralization aims more at self-sufficiency and energy efficiency by local production and consumption matching. Decentralization is still mainly in the research & development stage, however, and the electricity sector is still considering in what way the new opportunities enabled by smart grids can be exploited. Regarding balance management, it appears quite inefficient to start balancing the power system on a local level, which could be looked upon as a development opposite to system imbalance netting. Looking at the balancing market design space, severe congestion problems creating isolated distribution systems could be tackled by requiring BRPs to submit different energy schedules for different distribution systems (‘zonal balancing’) combined with dual imbalance pricing, which would incentivize BRPs to balance their portfolio on the distribution system level. A more rigorous step transcending the balancing market is the introduction of price areas, where local market and balancing prices in cases of congestion will create even stronger incentives. In these cases, Distribution System Operators might take over some balancing market tasks, but this requires a good coordination with those of the Transmission System Operator.

8.4 Future work

Suggestions for further research follow from the reflections above. The effect estimations in the multi-criteria analysis could be improved by additional detailed analyses of the interaction between design variables, system factors, contextual factors and performance indicators, the results of which could then be incorporated in the multi-criteria analysis. The effects of different types of design variables could be studied more closely by means different analysis methods. Variables related to the physical network, such as the geographical distribution of reserves, reservation of interconnection capacity for balancing and zonal vs. nodal responsibility, could be studied by means of network modelling and power flow analysis. System dynamics modelling could be useful to analyse variables that influences individual and system behaviour on a minute-by-minute basis, such as the Schedule Time Unit, the publication of national information, and the activation strategy. Furthermore, in view of the complexity of the balancing market and the dependency on market behaviour, agent-based modelling is a suitable method to analyse the effects of many design variables affecting the market opportunities and financial incentives of BRPs and BSPs, such as the timing of markets, the balancing service pricing mechanisms, ex-post trading, and cross-border balancing arrangements.

The agent-based analyses of the imbalance pricing mechanism and cross-border balancing arrangements in the research could be improved by including the bidding behaviour of Balancing Service Providers in the models, by adding more case studies, and by performing sensitivity analyses regarding the model assumptions, parameters and input data. Finally, a useful extension would involve the investigation of the decision-making algorithms applied to simulate the behaviour of balancing market parties. There are three directions in which such investigation could be heading. First of all, actual market participants could be interviewed to learn more about actual considerations and calculations used in deciding on market strategies. Second, these participants could also be invited into a so-called 'serious game', taking the shape of a balancing market game supported by an agent-based model[1]. Third and last, different decision-making algorithms used in the agent-based models could be examined, which may lead to improved algorithms, or enriched results on the different effects that different market strategies could have on performance.

In the light of the electricity sector developments mentioned in section 8.3, the further analysis of the interaction between balancing markets and short-term electricity markets is an interesting topic for further research in the context of electricity market integration. A relevant question here is to what extent short-term market integration requires balancing market internationalization. Regarding wind power integration, research on the compatibility of electricity market designs, balancing market designs and support mechanisms, and on the impact on wind power investment, is an intriguing topic. Regarding decentralization and smart grids, the potential and feasibility of the contribution of distributed generation and demand resources to balance management is an interesting topic.

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[1] This agent-based model could be the same as used for agent-based simulation, but with the decision-making not resulting from algorithms but from human decisions in the game.

Appendices

A Acronyms

ABM: Agent-Based Modelling

AC: Alternating Current

ACE: Area Control Error

ACER: Agency for the Cooperation of Energy Regulators

AIC: Actual Imbalance Costs

DC: Direct Current

EC: European Commission

ENTSO-E: the European Network of Transmission System Operators for Electricity

ERGEG: European Regulators Group for Electricity and Gas

EU: European Union

FCR: Frequency Containment Reserves

FRR: Frequency Regulation Reserves

Hz: Hertz

LFC: Load-Frequency Control

MCA: multi-criteria analysis

m.u.: monetary unit

MW: megawatt

MWh: megawatthour

ONRV: Optimierten Netzregelverbund (Optimized Grid Control Cooperation)

PCR: Primary Control Reserves

PTU: Program Time Unit

RR: Replacement Reserves

SC: Secondary Control

SCR: Secondary Control Reserves

SO: System Operator

STU: Schedule Time Unit

TCR: Tertiary Control Reserves

TSO: Transmission System Operator

UCTE: Union for the Coordination of Transmission of Electricity

ZNR: Zentrale Leistungs-Frequenz-Regelung (Central Load-Frequency Control)

B Balancing market definitions

- *Additional voluntary pool*: A main cross-border balancing arrangement. The arrangement can vary from bilateral exchange of balancing service bids to an additional, regional balancing service market on which System Operators of adjacent control areas can share balancing services on a voluntary basis. Form of SO-SO trading of balancing services.
- *Ancillary services*: Power system operation services acquired and utilized by the System Operator to maintain security of supply.
- *Area Control Error (ACE)*: The instantaneous difference between the actual and the scheduled value of the power interchange of a control area with the rest of the synchronous zone, taking into account the effect of primary control.
- *Balance management*: The power system operation service that involves the continuous, real-time balancing of power demand and supply in a power system. System Operators maintain the system balance by controlling the system frequency.
- *Balance planning*: Balancing market design pillar, concerning the scheduling of generation, consumption and trade by Balance Responsible Parties, making them financially accountable for energy schedule deviations.
- *Balance responsibility*: Financial accountability of Balance Responsible Parties for deviations from energy schedules over Schedule Time Units.
- *Balance Responsible Party (BRP)*: A market party who is responsible for the planning of generation, consumption and/or trade, by means of the obligation to submit energy schedules to the System Operator, and to settle the schedule deviations with the System Operator with an imbalance price.
- *Balance settlement*: Balancing market design pillar, concerning the settlement of procured and activated balancing services and the settlement of energy schedule deviations.
- *Balancing energy*: One of two fundamental balancing service types. Involves the real-time adjustment of balancing resources to maintain the system balance. Balancing energy is dispatched through the activation of balancing energy bids from Balancing Service Providers by the System Operator.

- *Balancing market*: The institutional arrangement that establishes market-based balance management in a liberalized electricity market, consisting of the three design pillars of balance planning, balancing service provision, and balance settlement. Also called the national balancing market in the context of this thesis.
- *Balancing market harmonization*: Specific form of balancing market internationalization, concerning the equalization of national balancing market rules.
- *Balancing market integration*: Specific form of balancing market internationalization, concerning the integration of balancing service markets. Different degrees of integration are represented by alternative cross-border balancing arrangements.
- *Balancing market internationalization*: The development of multinational balancing markets. Two different but related forms of balancing market internationalization are balancing market harmonization and balancing market integration.
- *Balancing region*: A group of multiple adjacent control areas that has implemented (or is considering) some form of balancing market internationalization.
- *Balancing resources*: Generation and load resources with which balancing services can be delivered.
- *Balancing service exchange*: The exchange (trade) of balancing services between control areas.
- *Balancing Service Provider (BSP)*: A market party who provides balancing services to the System Operator, in the form of balancing service bids.
- *Balancing service provision*: Balancing market design pillar, concerning the offering of balancing services by Balancing Service Providers in the form of bids, and the selection of bids by the System Operator within the scope of balance management.
- *Balancing services*: Ancillary services for balance management. Are offered by Balancing Service Providers to the System Operator. Distinctions can be made between types (reserve capacity and balancing energy), directions (upward regulation and downward regulation), and classes (Frequency Containment Reserves, Frequency Restoration Reserves, and Replacement Reserves).
- *Bid ladder*: The offered balancing service bids in a balancing service market (most commonly the balancing energy market), ranked in price order. Synonym for merit order list.
- *BSP-SO trading*: A main cross-border balancing arrangement. Involves the facilitation of cross-border trade of balancing services between Balancing Service Providers and the System Operators of adjacent control areas in the balancing region, often by means of harmonization of basic balancing market rules.
- *Common merit order list*: A main cross-border balancing arrangement. Involves a regional balancing service market, which is created by the combination of the bid ladders of national balancing service markets. A regional System Operator is responsible for maintaining the regional system balance. Form of SO-SO trading of balancing services.

- *Control area*: A power system area for which a separate system balance is maintained, by means of Load-Frequency Control.

- *Cross-border balancing*: The exchange of capacity and energy between control areas for the purpose of balance management. Two forms of cross-border balancing are surplus energy exchange and balancing service exchange.

- *Cross-border balancing arrangement*: Market arrangement establishing cross-border balancing between control areas. This arrangement forms the core of balancing market integration. Different arrangements represent different degrees of integration.

- *Cross-border capacity*: Synonym for interconnection capacity.

- *Downward regulation*: The real-time negative adjustment (decrease) of generation or the positive adjustment (increase) of demand within the scope of balance management, providing (negative) balancing energy.

- *Energy schedule*: A schedule that is submitted by the Balance Responsible Party to the System Operator within the scope of balance responsibility, indicating the net energy that is planned to be fed into/out of the grid over all Schedule Time Units (separately) in a day.

- *Energy schedule deviation*: The difference between planned and actual net energy exchange over a Schedule Time Unit, determined by comparison of the energy schedule with measurement values.

- *Exchange program*: Represents the total scheduled interchange between two control areas.

- *Final gate closure time*: The time when the System Operator is given the sole responsibility for controlling individual levels of production and consumption, and energy schedules of Balance Responsible Parties become definitive (unless ex-post trading is applied).

- *Frequency Containment Reserves (FCR)*: Balancing service class, and an alternative term for primary control. A decentralized automatic service that is activated in a matter of seconds. Its function is to contain the frequency deviation after a disturbance.

- *Frequency Restoration Reserves (FRR)*: Balancing service class, and an alternative term for secondary control. A centralized and often automatic service that is activated in a matter of minutes. Its function is to restore the system frequency, and to remove the Area Control Error. It replaces Frequency Containment Reserves, so that these become available again for balancing.

- *Imbalance costs*: The costs borne by Balance Responsible Parties resulting from imbalance settlement.

- *Imbalance price*: The price (in m.u./MWh) with which energy schedule deviations (individual imbalances) of Balance Responsible Parties are settled. The imbalance price is usually based upon the marginal or average bid price of the activated balancing energy bids, and determined on a Schedule Time Unit basis. One can distinguish between the imbalance price for shortages and surpluses, i.e. the short and long imbalance price.
- *Imbalance settlement*: The financial settlement of energy schedule deviations. Deviations are settled between the System Operator and Balance Responsible Parties with an imbalance price.
- *Individual imbalance*: The energy schedule deviation of a Balance Responsible Party. A synonym is 'BRP imbalance'. The sum of the individual imbalances in a control area equals the system imbalance.
- *Interconnection capacity*: The power transmission capacity between control areas.
- *Internal balancing*: The real-time adjustment of generation and consumption by Balance Responsible Parties to balance their portfolios. This is a form of portfolio balancing.
- *Load-Frequency Control (LFC)*: The central, automatic control system used by a System Operator to activate Frequency Restoration Reserves (secondary control) in order to remove the Area Control Error, and through this, to restore the system frequency.
- *Long imbalance price*: Imbalance price with which positive imbalances of Balance Responsible Parties (BRP surpluses) are settled. BRPs receive this price from the System Operator per MWh of surplus.
- *Multinational balancing market*: The total set of balancing market rules within the boundaries of a balancing region (in case this region spans multiple countries).
- *National balancing market*: The balancing market within a country.
- *Net settlement sum*: The cash value that remains after imbalance settlement and the settlement of dispatched balancing energy.
- *Passive balancing*: The intentional creation of schedule deviations by Balance Responsible Parties by means of internal balancing, in order to make money from imbalance settlement.
- *Portfolio balancing*: The BRP activity of balancing the energy portfolio in order to minimize imbalance costs. Three forms of portfolio balancing are forecasting generation and load, trading in short-term markets, and internal balancing.
- *Primary control reserves (PCR)*: Alternative term for Frequency Containment Reserves.
- *Regional System Operator*: The System Operator who is responsible for maintaining the regional system balance in the scope of the common merit order list.

- *Regulation price*: A single balancing energy price (in m.u./MWh) with which all activated balancing energy bids within a Schedule Time Unit are settled, typically the highest bid price among activated bids. Determined on a Schedule Time Unit basis.

- *Regulatory authority*: 'Regulator' in short. An independent authority within a country who regulates the planning and operation activities of the grid operators in a national power system. Regarding the balancing market, the regulatory authority approves of the balancing market rules proposed by the System Operator in the national code(s).

- *Replacement Reserves (RR)*: Balancing service class, and an alternative term for tertiary control. A centralized and manual service that is activated within minutes up to hours. Its function is to return operation back to schedule. In addition, it replaces Frequency Restoration Reserves, so that these become available again for balancing.

- *Reserve capacity*: One of two fundamental balancing service types. Involves the reservation (contracting) of balancing resources from Balancing Service Providers by the System Operator, in order to obtain the option to dispatch balancing energy during the reservation period. Reserve capacity is procured through the selection of reserve capacity bids.

- *Schedule Time Unit (STU)*: The basic time unit in the balancing market. Balancing service bids and energy schedules are specified for different STUs, and regulation prices and imbalance prices are determined per STU.

- *Secondary control reserves (SCR)*: Alternative term for Frequency Restoration Reserves.

- *Short imbalance price*: Imbalance price with which negative individual imbalances of Balance Responsible Parties (BRP shortages) are settled. BRPs pay this price to the System Operator per MWh of shortage.

- *Surplus energy exchange*: The export of surplus energy of a control area with a positive system imbalance to an adjacent control area with a negative system imbalance as a result of system imbalance netting.

- *Synchronous zone*: An interconnected power system consisting of one or more control areas, in which a single system frequency is maintained.

- *System frequency*: The electric frequency in a synchronous zone.

- *System imbalance*: The real-time power imbalance in a power system, which is the system-level result of the real-time dispatch of generators and consumption of consumers, resulting in a deviation from nominal system frequency. In the context of imbalance settlement, and in this research, the system imbalance refers to the net energy imbalance of a control area over a Schedule Time Unit.

- *System imbalance netting*: A main cross-border balancing arrangement. Involves the 'netting' of positive and negative system imbalances in adjacent control areas, resulting in a surplus energy flow from the surplus area to the deficit area, which prevents opposing balancing energy dispatch in those control areas. Within synchronous zones, system imbalance netting involves the combination and redistribution of Area Control Errors.
- *System Operator (SO)*: The operator of the transmission grid in a control area. Is responsible for maintaining security of supply, and as a part of this, for maintaining the system balance.
- *Tertiary control reserves (TCR)*: Alternative term for Replacement Reserves.
- *Unintentional deviation*: The instantaneous difference between the actual and scheduled value of power interchange for a control area with respect to the rest of the synchronous zone.
- *Upward regulation*: The real-time positive adjustment (increase) of generation or the negative adjustment (decrease) of demand within the scope of balance management, providing (positive) balancing energy.

C Balancing market design and performance in Northern Europe

Table C.1 – Current balancing market design in Northern Europe

	Nordic region	**Germany**	**Netherlands**
Schedule Time Unit	60 minutes	15 minutes	15 minutes
Service classes	FCNOR, FCDR and FADR	Pr., sec. and tert. control	Pr., sec. and tert. control
Zonal vs. nodal responsibility	Zonal balancing	Control area balancing	Control area balancing
Reserve requirements	within System Operation Agreement	based on common probabilistic method	based on square-root formula of UCTE OH
Methods of procurement	RC: none, market, bilateral BE: market	combined market for RC & BE Sep. markets for up/down and peak/off-peak Self-delivery after one hour	RC: bilateral BE: market Generators >60 MW: Obligation to offer available resources
Timing of markets	RC: weekly (Norway) BE: hourly	PC & SC: monthly TC: daily	RC: yearly BE: quarter-hourly
Allocation of reserve capacity costs	through fees to BRPs	through tariff	through tariff
Allocation of balancing energy costs	through imb. set.	through imb. set.	through imb. set.
Publication of national information	prices, activated volumes	offered and activated volumes and prices	activated volumes and prices, offered volumes, few ladder price indices, real-time dispatch price
Responsibility for renewable generation	BRPs, SO	SOs	BRPs
Final gate closure time	45 minutes before RT	45 minutes before RT	one hour before RT
Net vs. separate positions	separate positions	net position	net position
Activation strategy	pro-active, price order	pro-active, price order	re-active, price order
Balancing service pricing mechanisms	RC: pay-as-bid BE: marginal	RC: pay-as-bid BE: pay-as-bid	RC: pay-as-bid BE: marginal
Control systems	manual control	LFC	LFC
Bid requirements	max. act. time = 15 minutes min. price = spot price max. price = 5,000 €/MWh min. bid size = 10 MW max. bid size = 50 MW (DK) duration capabil. = 1 hour	No information found	reg. speed SC >= 7%/min. min. price = -100,000 €/MWh max. price = 100,000 €/MWh min. bid size = 4 MW max. bid size = 100 MW
Imbalance pricing mechanism	prod.: two-price set. cons.: single pricing	Net reg. costs divided by net act. volume	Dual pricing (based on reg. state)
Ex-post trading	none	Up to 4:00 p.m. D+1	none
BRP accreditation requirements	No information found	No information found	No information found
Initial gate closure time	7:00 p.m. D-1 (NW), 4:00 p.m. D-1 (SE), 4:30 p.m. D-1 (FI), 3:00 p.m. (DK)	2:30 p.m. D-1	2:00 p.m. D-1
BSP accreditation requirements	No information found	No information found	No information found
Allocation of net settlement sum	in tariff	in imbalance price	in tariff
Timing of settlement	Weekly (NW), Bi-monthly (SE) Monthly (DK&FI)	Monthly	Weekly

Table C.2 – Current balancing market performance in Northern Europe

	Nordic region	**Germany**	**Netherlands**
Offered reserve capacity (MW)	600 MW FCNOR 1,160 MW FCDR 4,680 MW FADR	2,500 MW pos. off-peak SC 3,000 MW pos. peak SC 2,150 MW neg. SC	No data found
Procured reserve capacity (MW)	500 MW in winter period (Norway) 1,000-1,500 MW weekly (NW), unknown amount bilaterally	623 MW pr. control 2,400 MW pos. off-peak SC 2,500 MW pos. peak SC 2,050 MW neg. SC >2,000 MW tertiary control	300 MW sec. control 300 MW emergency power
Offered balancing energy (MW)	No data found	Same as offered capacity	506 MW pos. SC 107 MW pos. TC -564 MW neg. SC -160 MW neg. TC
Dispatched balancing energy (MW)	223 MW up 284 MW down	497 MW SC up 44 MW TC up -535 MW SC down -102 MW TC down	37.4 MW SC up 0.4 MW TC up -53.7 MW SC down -0.1 MW TC down
System load (MW)	44,292	39,760	11,752
Market imbalance (MWh)	No data found	No data found	3.43 (52.6 sale & -49.2 purchase)
System imbalance direction (%)	No data found	No data found	56/54% (2009/2010)
Net transfer capacity with other two areas	500 MW to NL (rated 700) 2,050 MW to DE	2,300 MW to NL (rated ...) 1,700 MW to NO	500 MW to NO (rated 700) 2,290 MW to DE (rated ...)
Cross-border flows	200 MW to NL 250 MW to DE	650 MW to NL 600 MW to NO	0 MW to NO 160 MW to DE
Day-ahead market price (€/MWh)	35.02/53.06 (2009/2010)	38.85/44.49 (2009/2010)	39.16/45.37 (2009/2010)
Reserve capacity price (€/MW/h)	No data found	4.9 (pos. SC) 15 (neg. off-peak SC) 1 (neg. peak SC)	ca. 20 (not published)
Reserve capacity costs (€/year)	No data found	No data found	52.6 M€SC 15 M€emergency power
Regulation price (€/MWh)	56.73/47.19 (up/down)	Not applicable	65.3/23.9 (up/down)
Total regulation costs (€)	No data found	No data found	21.9 M€
Imbalance price (€/MWh)	61.25 (prod. – purchase) 53.35 (prod. – sale) 58.96 (cons. – purchase) 58.96 (cons. – sale)	42.07 (Amprion data)	43.2 / 41.2 (short/long)
Total imbalance costs (€/year)	No data found	No data found	41.1/33.6 M€(2009/2010)
Total AIC (€/year)	No data found	No data found	45.5/35.6 M€(2009/2010)

D Overview of criteria and variables

Table D.1 – Balancing market performance criterion definitions and underlying indicators

Criterion	**Definition**	**Indicators**
Transparency	Information availability, symmetry and clarity on balancing market design and performance	– Number of rules – Consistency of rules – Accessibility of information – Completeness of data
Non-discrimination	The equality of balancing market rules and conditions for different market parties and control areas	– Number of discriminating rules – Strictness of requirements
Availability of balancing resources	Availability of resources for meeting reserve requirements and resolving system imbalances	– Procured reserve capacity/ maximum system load – Procured / offered reserve capacity – Dispatched / offered balancing energy
Balance planning accuracy	The accuracy with which energy schedules reflect actual energy exchanges	– Market imbalance / system load – Power imbalances
Balance quality	The effectiveness of maintaining the control area balance	– Frequency deviations – Area Control Error (ACE) – System imbalance direction
Cost allocation efficiency	The efficiency with which the balancing service costs are allocated to the market	– Imbalance price / balancing energy price – Net settlement sum
Utilization efficiency	The economic efficiency of the utilization of available balancing resources	– Actual / possible minimum balancing service costs – Opportunity costs of unutilized reserve capacity – Degree of BRP portfolio balancing
Price efficiency	The cost-reflectivity of balancing service prices	– Difference balancing energy price and day-ahead price – Opportunity costs of procurement – Procured / offered balancing services – Market concentration indices
Operational efficiency	Economic efficiency of handling the transactions related to the administrative processes in the balancing market	– Transaction costs / minimum transaction costs in reference case – # Transactions / hour – Complexity of transactions
Internationalization costs	Costs of balancing market harmonization and/or integration	– # Changed design variables in the different control areas – Changes in number and scope of markets – Changes in the message amounts, contents and formats – Changes in ICT systems
Social welfare of cross-border exchanges	The total economic value generated by conventional cross-border trade and cross-border balancing	– Amount of cross-border trade – Day-ahead price difference – Amount of balancing service exchange – Balancing service price difference

Table D.2 – Definitions and values of national general and balance planning variables

Design variable	**Short definition**	**Values**
National general variables		
Service classes	The main classes of balancing services, which have different functions and technical characteristics	– Frequency Containment Reserves – Frequency Restoration Reserves – Replacement Reserves
Schedule Time Unit	The main time unit, divides balance responsibility between SO and market, used for energy schedules and balancing service bids	– 15 minutes – 60 minutes – ...
Publication of national information	Decision regarding which information is spread to the market, distinction between design information and results (data)	– Publication of prices – Publication of bid information – Publication of system balance state – Publication of rules
National balance planning variables		
Zonal vs. nodal responsibility	Aggregation level at which BRPs must submit energy schedules	– Nodal balancing – Zonal balancing – Control area balancing
Responsibility for renewable generation	The distribution of balance responsibility for renewable generation between the market and the SO (society)	– Full responsibility for BRPs – Full responsibility for SO – Separate / partial responsibility for BRPs
Net vs. separate positions	The definition of possible BRP balances (positions)	– Net position – Separate positions for production and consumption
Final gate closure time	The time at which the energy schedules of BRPs become final	– Two hours before delivery – One hour before delivery – ...
Initial gate closure time	The time at which BRPs must submit an initial energy schedule	– 12:00h on the day before delivery – 14:00h on the day before delivery – ...
BRP accreditation requirements	Requirements a market party must meet to become authorized by the SO as a BRP	– Financial security requirement – Information exchange requirement

Table D.3 – Definitions and values of national balancing service provision and balance settlement variables

Design variable	**Short definition**	**Values**
National balancing service provision variables		
Reserve requirements	Control area requirements for procurement of reserve capacity	– ... MW FCR – ... MW FRR – ... MW RR
Control system	The control system used for activation of balancing energy	– Manual vs. automatic activation – Possibility to activate both manual and automatic bids
Methods of procurement	The main methods of procurement used to procure balancing services	– Bilateral contracting vs. tender – Compulsory vs. voluntary bidding – (No) resources owned by SO – Different tenders for different balancing services
Timing of markets	The timing of bidding procedures (time horizon of markets), and the timing of market clearance (frequency and coordination with other markets)	– Frequency of bidding – Frequency of market clearance – Gate opening and closure times of balancing service markets
Activation strategy	Order of activation of balancing service bids, time of activation of bids	– Only price order vs. consideration other bid specs – Choice between markets – Option of partial bid activation – Proactive vs. reactive activation
Bid requirements	Requirements for balancing service bids	– (No) bid price requirement – (No) bid volume requirement – (No) location requirement – (No) regulation speed / activation time requirement
Balancing service pricing mechanisms	The pricing mechanisms used for balancing service markets	– Pay-as-bid pricing – Marginal pricing – Regulated pricing
BSP accreditation requirements	Requir. a market party must meet to become an authorized BSP	– Information exchange requirement – Resource pre-qualification requirements
National balance settlement variables		
Allocation of reserve capacity costs	The method used to allocate the reserve capacity costs	– Through system tariff – Into imbalance price – Through reserve obligation for BRPs – Through fees for BRPs
Allocation of bal. energy costs	The method used to allocate the balancing energy costs	– Through imbalance pricing – Through system tariff
Imbalance pricing mechanism	Pricing mechanism used to determine the short and long imbalance prices	– Single pricing; – Dual pricing – Position-based pricing – System state-dependent pricing – Use of additive component / price cap – Costs-based imbalance pricing
Ex-post trading	The possibility for BRPs to 'trade away' imbalances with each other after real-time	– No ex-post trading – Ex-post trading up to 12:00h D+1 – ...
Penalty for non-delivery	Penalty for BSPs for not delivering balancing energy	– No penalty for non-delivery – A penalty for non-delivery
Allocation of net settlement sum	Allocation of net income or expenditure from balance settlement	– In system tariff – In imbalance price – To BRPs through separate fees – Kept by System Operator
Timing of settlement	The time and frequency of settlement of balancing services and BRP imbalances	– Monthly settlement – Weekly settlement – ...

Table D.4 – Definitions and values of multinational balancing market variables

Design variable	Short definition	Values
Multinational general variables		
Balancing region boundaries	Group of control areas that has implemented some form of balancing market internationalization	– Incorporated control areas in the balancing region
Organization SOs and regulators	The division of roles and responsibilities between different SOs and regulators in the balancing region	– Specific tasks of different SOs – Existence of regional SO / regulator
National vs. regional legislation	The division of balance management legislation between the control area level and the balancing regional level	– Merely national vs. merely regional legislation – Level of detail of legislation – Level of overlap of legislation – Level of hierarchy in legislation
Publication of regional information	The spreading of information about regional market design and regional market results	– Publication of regional market design – Publication of regional market data – Compatibility between national information and regional information
Multinational balancing service provision variables		
Control area boundaries	Definition of the boundaries of the control areas, for which a separate system balance is maintained	– The geographical boundaries of control areas within the balancing region
Geographical distribution of reserves	Relative and total size of reserve capacity volumes in the control areas	– Relative size of FCR – Relative size of FRR – Relative size of RR
Cross-border balancing arrangements	Market arrangements establishing cross-border balancing between control areas	– System imbalance netting – BSP-SO trading – Additional voluntary pool – Common merit order list
Reservation of interconnection capacity for balancing	The amount of interconnection capacity reserved for the purpose of cross-border balancing	– No reservation – ... MW reservation
Regional service provision rules	Market rules for balancing service provision on the regional level (in case of advanced balancing market integration)	– Regional bid requirements – Timing of regional market – Regional balancing service pricing – Regional BSP accreditation requirements – Regional activation strategy
Multinational balance settlement variables		
Redistribution of balancing costs	Additional settlement between SOs	– (No) settlement of surplus energy – Settlement of exchanged bids (SO-SO trading)
Settlement of area imbalances	Settlement of unintentional deviations	– No compensation – Physical compensation – Financial compensation

E Expert validation of performance criteria

With the primary goal to formulate a set of plausible weights for the balancing market performance criteria, a short survey has been conducted. This survey also forms an expert validation of the set of performance criteria that we have created and introduced in the balancing market design framework in chapter 3.

A short questionnaire, consisting of six questions has been sent by e-mail to various 'balancing market experts', notably the participants of the research project Balance Management in Multinational Power Markets. In September 2011, 26 experts have filled in the questionnaire. Details on affiliation and country of residence are present in Table E.1. As can be seen, 42% of the respondents work in a university, research institute or consultancy company, 31% is affiliated with a Transmission System Operator, 19% works in the electricity industry, and 7.7% (2 respondents) works for an energy regulator or government. Regarding the country of residence, 38% of the respondents lives and works in Norway, and 27% in the Netherlands. Most of these are (former) participants of the research project (which involved mostly Dutch and Norwegian organizations), but it should be noted that the vast majority of this group has little to no prior knowledge of our research on balancing market design. Remaining respondents are from Finland (2), Sweden, Denmark, Belgium, Switzerland, Slovenia, and Spain (1 each). One respondent works for an European-wide research company.

In the beginning of the questionnaire, the research topic has been introduced shortly, as well as the research itself. A short definition of the electricity balancing market has been given, followed by a general indication of the content and effects of balancing market integration. Next to that, short explanations have been given for the eleven balancing market performance criteria.

Question on importance of criteria

The most important question in the questionnaire is the first: **1. Please indicate how *important* you think each performance criterion is**. The possible answers to each of the eleven criteria were 'very unimportant', 'unimportant', 'neutral', 'important', 'very important', and 'don't know'. The main results are depicted in Figure E.1. It can be observed that instead of the terms 'cost allocation efficiency', 'price efficiency', 'operational efficiency' and 'internationalization costs', the terms 'balancing costs allocation efficiency',

Table E.1 – Details of respondents in the performance criteria questionnaire

Affiliation	Amount	Country	Amount
Regulators	2	Norway	10
TSOs	8	Netherlands	7
Industry	5	Finland	2
Researchers	11	Sweden	1
		Denmark	1
		Belgium	1
		Switzerland	1
		Slovenia	1
		Spain	1
		Europe	1

'balancing service price efficiency', 'transaction costs' and 'integration costs' have been used. This has been done to be as clear as possible on what the criteria are about. To visualize the results, the range of answers has been transformed to a numerical scale; 'very important' is converted into '5', 'very unimportant into '1', and 'don't know' into '0'.

As can be observed, all performance criteria but one are on average evaluated above neutral (value '3'). The exception is 'internationalization costs', which got an average score slightly below neutral. Rounding all average values off to integers, eight out of eleven criteria are evaluated as important, 'internationalization costs' and 'operational efficiency' as neutral, and 'availability of balancing resources' as very important. These main results validate our set of balancing market performance criteria, as the respondents generally consider the criteria to be relevant.

Based on this expert validation, we choose to weigh the eleven balancing market performance criteria all equally, which in fact means that we will not use weights in the qualitative effect estimations. The most important reason for this choice is that the validation indicates that all criteria are important. Furthermore, both the evaluation by the respondents and the assignment of weights are quite subjective. After all, the performance criteria are incommensurables, e.g. one cannot objectively, quantitatively compare the value of the two criteria of non-discrimination and utilization efficiency. Also, respondents may have based their evaluations on the *actual* importance of these criteria, based on their knowledge on balancing market performance. For example, respondents may believe that transaction costs are low compared to balancing costs, but this does not mean that the criterion 'operational efficiency' is less important than 'price efficiency'. In addition, the assignment of weights is also ambiguous: It is open to debate which weights best reflect the differences between 'very important', 'important' and 'neutral'. For example, these three evaluations could be represented by '5', '4' and '3' as weights, by '5', '4' and '2', or by '3', '2' and '1'. Finally, the estimation of the effects in the performed multi-criteria analyses are also subjective and uncertain, as a result of which the inclusion of weights would only complicate the analysis while not improving the accuracy of the results.

The selection of weights is typically an activity that should be carried out by the decision-makers, who probably value some criteria more important than others. And although the expert validation does point towards the availability of balancing resources being more important and internationalization costs and operational efficiency being less important than the other criteria, we have chosen to produce and use the 'clean' results of effects estimations in which all criteria are equally important. These results, including conclusions that will be based on these, can serve as a reference outcome for decision-makers on balancing market internationalization.

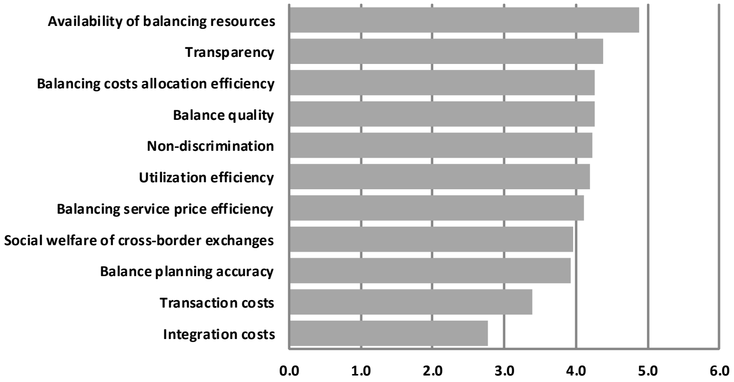

Figure E.1 – Expert judgement on the importance of the set of eleven balancing market performance criteria

Other questions

The next question in the questionnaire is an open question: **2. In your opinion, which factors have a large effect on balancing market performance?**. The intention of this question was to get an idea of the knowledge of the respondents about the topic of balancing markets, and of their viewpoints on important design variables and contextual factors. However, the word 'factors', has been misinterpreted by multiple respondents, specifying criteria instead of factors.

In Table E.2, the full range of answers that the respondents have given to question 2 is presented. The range of answers will not be discussed in detail. The important thing to note is that all mentioned factors have been incorporated in the multi-criteria analyses either as balancing market design variable(s) or as contextual factor(s) (cf. Figure 3.6). Apart from these answers, *incentives* have also been mentioned several times, but these are not design variables by themselves. In general it can be argued that all balancing market design variables influence incentives to BRPs and BSPs, as these variables make up the rules of the game for these balancing market players. Important variables directly influencing the prices that incentivize BSPs and BRPs are the balancing service pricing mechanisms, the imbalance pricing mechanism, and the penalty for non-delivery. Two other mentioned factors were 'forecasts of BRPs' and 'TSO willingness to cooperate'. More accurate forecasts of BRPs will improve balance planning accuracy; this is a system variable that can be influenced among others by the design variables of the Schedule Time Unit and the final gate closure time. The willingness of Transmission System Operators to cooperate with each other is a very important factor for the realization of balancing market internationalization, but this factor cannot be influenced easily. One might consider legislation that stimulates or obliges TSOs to cooperate to be of influence, however, which corresponds with the design variable 'national vs. regional legislation'.

Table E.2 – Relevant factors mentioned by respondents in questionnaire

Design variables	**Contextual factors**
Cost-reflective settlement procedure	Availability of flexible resources
Product definition	Sufficient grid capacity
IT-systems for balancing service provision	Availability of demand-side resources
Market entry constraints	Price level balancing energy compared to other markets
Rules for contracted balancing capacity	Number of BSPs
Allowance of passive balancing	Liquid and integrated intra-day markets
Imbalance settlement period	Pricing mechanism in day-ahead market
Balancing resource price	Power plant types in country
Integration of balancing markets	
Balance responsibility of RES generators	
Regulation pricing mechanism	
Time of contracting tertiary reserves	
Final gate closure time	
Pricing/payment rules	
Rules on balancing market participation	
Contracting of balancing services	

The third question is about the relevance of balancing market design: 3. **How important do you consider the balancing market design to be within the context of the overall electricity market design?**. The possible answers were 'very unimportant', 'unimportant', 'neutral', 'important', 'very important', and 'don't know'. On average, the respondents consider the balancing market design to be **important**. This is in line with the results of our multi-criteria analyses, which show that the balancing market design choices have a large impact on balancing market performance. Also, it is in line with the outcomes for question 1. Alternatively, the evaluation indicates the respondents' belief that the functioning of the balancing market influences that of the overall electricity market, which is a topic that has not been covered by our research.

The fourth question in the questionnaire read: 4. **What is your opinion on the importance of balancing market integration?**. The possible answers were the same as for question 3. The average evaluation of the respondents is that balancing market integration is **important**. Thus, the respondents generally consider integration to have a large impact on performance, which is in confirmation with our analyses on the impact of alternative cross-border balancing arrangements.

Related to this is the next question: 5. **What do you think will be the overall impact of balancing market integration?**. Here, the possible answers were 'very negative', 'negative', 'neutral', 'positive', 'very positive', and 'don't know'. The average answer of the respondents was that the overall impact of integration is **positive**. This answer is in line with the beliefs and expectations of the electricity sector (see chapter 2), and also with our analysis results, although we found that some cross-border balancing arrangements could have a negative impact, for some of the control areas or even for the entire balancing region (see chapter 5).

The sixth question was **6. Do you feel that one or more performance criteria are missing?**. This was another open question. Six relevant suggestions from respondents have been given. First, harmonization of national balancing market rules has been mentioned. This is not a criterion, but a general goal that is achieved by adapting design variable values. Second, ' flexibility for integration of renewable energy' has been mentioned. This suggests a criterion on the availability of balancing resources that is dedicated to a sufficient availability of balancing resources to enable the large-scale integration of renewable generation. This is an instance of the criterion 'availability of balancing resources'. Third, micro-generation and renewable generation, which one respondent missed in the performance criteria set, do not call for new performance criteria for balancing markets either. In our view, it is no intrinsic objective of the balancing market design to facilitate the integration of renewable generation, distributed generation, or demand-side resources. This does not mean that decision-makers cannot have such an objective, or that the balancing market design does not influence the attractiveness of investment in renewables, as becomes clear from the design variable 'responsibility for renewable generation'. Fourth, the total balancing energy dispatch costs were mentioned. We have classified this as a system factor (see Figure 4.1), and it can be found back as an indicator of utilization efficiency (see Figure 4.5). Fifth, 'delivery accuracy' was suggested by a respondent, which is probably about the accuracy with which BSPs actually deliver the balancing services requested by the SO. This issue has a direct effect on balance quality, and can therefore be considered part of this performance criterion. Sixth and last, one respondent suggested a further elaboration of social welfare, making a distinction between different countries / control areas in the performance criteria set. However, this distinction is only relevant in the context of balancing market integration, while making this explicit would also cause overlaps of criteria and/or large increases in the number of criteria. Therefore, this distinction is not made within the criteria, but in the analysis of the effects of balancing market integration, which can be considered for the balancing region as a whole vis-à-vis the individual control areas.

Finally, the respondents were asked if they had any further comments. Most remarks that were made related to a perceived lack of clarity in the questionnaire or were specific balancing market design issues or recommendations. One remark of a different sort is worth mentioning here. A respondent raised the question how balancing market integration will affect the composition of international production portfolios on the long term. This relates to two branches of effects that have not been included in the balancing market design framework: the impact on the performance of the electricity market/system in general, and the long-term effects of balancing market design. Both have been specified in chapter 1 as being out of the research scope. It should be noted, however, that the defined balancing market performance criteria can be considered time-independent; they are important in present as well as in future balancing markets.

Wrapping up on the findings from the questionnaire-based expert judgment, we can conclude that balancing market expert views support the relevance of the balancing market design framework presented in chapter 3. In particular the relevance of the performance criteria set has been validated.

F Details of imbalance pricing mechanism analysis

This appendix contains additional information about the agent-based analysis of the imbalance pricing mechanism design variable covered in subsection 4.4.3.

Input parameter values The input parameter values that are specified as fixed assumptions throughout the simulation are listed in Table F.1. It is assumed there are ten BRPs with varying portfolio sizes. The total portfolio size of the modelled balancing market is 25,000 MW, which is similar to the sum of average generation and load in the Netherlands. The standard deviation of the forecast error that is used for the unintentional imbalance calculation is set at 0.015 for all BRPs, which is close to the found standard deviation of 0.013 of the system imbalance-to-load ratio in the Netherlands in 2010 (TenneT, 2011). The initial values of the expected AIC for different intentional imbalance options and for different BRPs are all set at the arbitrary value of 50 euro.

There are seven intentional imbalance options, shortly ‘options’, between which the BRPs can choose each round. These are represented by percentages. Options 1 to 3 correspond with a negative intentional imbalance of varying size (under-contracting), option 4 with no intentional imbalance (no over/under-contracting), and options 5 to 7 with a positive intentional imbalance of varying size (over-contracting). The combination of possible intentional imbalances, which range from 0 to 2% of the portfolio size, and the probability distribution function of the unintentional imbalance is such that BRPs have a large influence on the BRP imbalance size and direction, and are able to hedge against imbalance risks (when profitable).

Fixed bid ladders are assumed for upward and downward regulation, see Figure F.1. Upward and downward regulation prices and volumes are based on typical bid prices in the Netherlands in 2009. The shape of the upward regulation curve is exponential, and very steep in the end. The shape of the downward regulation case is more linear, and much more gradual. The sum of the bid volumes is about 480 MW for both directions, which is proportional to the volumes in the Dutch balancing energy market. The volumes range from 5 to 20 MW.

In the model, it is assumed that the required upward and downward regulation equals 25% of resp. the market shortage and market surplus (in MWh), which resembles the

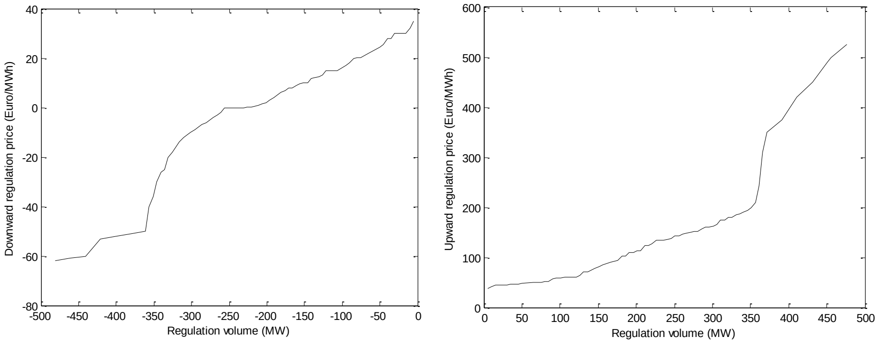

Figure F.1 – The downward (left) and upward (right) bid ladder in the agent-based analysis

found values for the Netherlands in 2009[1]. This is represented by the up- and down-regulation rate parameters. Finally, it is assumed that 2 MWh of bid volume needs to be activated to deliver 1 MWh of actual balancing energy, which reflects the fact that the full MWh equivalent of a regulation bid cannot be delivered, as the balancing resources have a limited response and regulation speed. This is represented by the delivery rate parameter. Finally, if the required regulation in one direction is smaller than 0.75 of the required regulation in the other direction, the first (regulation in the 'minor direction') is set to zero. This is represented by the single-sided regulation rate parameter. This results in an occurrence of two-sided regulation of 17%, instead of the 35% for the Netherlands in 2009. This parameter will be adapted for cases 2b and 2c (see below).

The day-ahead price has been set at 36 €/MWh, which was about the average day-ahead power exchange price for the Netherlands in 2009. This price lies on purpose below the upward regulation bid prices and above the downward regulation bid prices, a common and logical situation in balancing markets.

The simulation run length is 1,000 rounds, with each round equalling a STU of 15 minutes, as is the case in the Netherlands[2]. The recency parameter has been set to the value of 0.9, in order to weigh the results of recent rounds only slightly heavier than old rounds[3].

Different imbalance pricing mechanisms are represented in the model as alternative imbalance pricing rules that can be activated with some control parameters. In addition, there are some detailed input parameters that correspond with dual pricing (case 2) and the additive component (case 4). See Table F.2. For the dual pricing sub-cases 2b and 2c, the single-sided regulation parameter is changed in order to increase the level of activity

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[1] These were 16% for upward regulation / market shortage and 25% for downward regulation / market surplus (TenneT, 2011).

[2] The length of the STU is not relevant within the simulation, because it does not influence any model parameter. It is merely used to convert MW into MWh and vice versa. In reality, the STU length affects the imbalances of BRPs, the amount of activated balancing energy, and the amount of internal balancing by BRPs.

[3] This value has been chosen arbitrarily. However, a sensitivity analysis has shown that the simulation results are not significantly influenced by the recency parameter, which can be explained by the long simulation run length and the use of both a fixed set of options and a fixed decision-making algorithm.

Table F.1 – Input value assumptions in the agent-based analysis

Parameters	Values	Parameters	Values
BRP parameters		*Intentional imbalance percentages*	
BRP size 1 (MW)	8,000	Option 1 (%)	-2
BRP size 2 (MW)	6,000	Option 2 (%)	-1
BRP size 3 (MW)	4,000	Option 3 (%)	-0.5
BRP size 4 (MW)	3,000	Option 4 (%)	0
BRP size 5 (MW)	1,000	Option 5 (%)	0.5
BRP size 6 (MW)	900	Option 6 (%)	1
BRP size 7 (MW)	800	Option 7 (%)	2
BRP size 8 (MW)	600		
BRP size 9 (MW)	500	*Regulation parameters*	
BRP size 10 (MW)	200	Delivery rate	2
Stand. dev. forecast error	0.015	Up-regulation rate	0.25
Initial expected AIC (€)	50	Down-regulation rate	0.25
		Upward bid ladder	*Fixed list of 72 bids*
Simulation settings		Downward bid ladder	*Fixed list of 72 bids*
Number of rounds	1,000	Single-sided reg. rate	0.75
Recency parameter	0.9		
		Market parameters	
		Day-ahead market price (€/MWh)	36

Table F.2 – Parameter settings for different cases in the agent-based analysis

Parameters	Case 2a	Case 2b	Case 2c	Case 4a	Case 4b	Case 4c	Case 4d
Single sided reg. rate	0.75	0.5	0.25				
Imbalance price mark-up				2.5	2.5	5	5
System imbalance threshold				75	50	75	50

of dual pricing. The values have been set such that the activity rates differ substantially between the sub-cases. For the different sub-cases of the additive component, there is a parameter for the size of the component (the imbalance price mark-up parameter) and a parameter related to the activation criterion (the system imbalance threshold parameter). The used activation criterion is the size of the system imbalance: If the system imbalance is larger than the system imbalance threshold parameter, the imbalance price mark-up is added to/subtracted from the short/long imbalance price (see subsection 4.4.3). In the four sub-cases, two different component values and two different activation criterion values are used.

Model validation The significance of the difference between cases is indicated by the standard deviations of the total AIC values over the 50 runs, which are small compared to the differences in total AIC between cases (see Table F.4).

It is noted that a system surplus always occurs more often than a system shortage (so > 50%), but is always below 60%. This is in line with the Netherlands in 2009, where a system surplus occurred in 55.7% of the STUs. Also, the system imbalance volume is relatively small[4], thanks to the BRPs who limit their imbalance and due to the fact that BRP imbalances even out partially. The total AIC for the different cases is in the order of two million euro, which comes down to 2,000 euro per round, and to 200 euro per BRP per round on average. In comparison, the total AIC for the Netherlands in 2009 are, based on the market imbalance values, 1,300 euro per round (TenneT, 2011). This is 35% lower, so the height of the AIC is overestimated.

The capacity equivalents of the average activated regulation volumes in the simulation results are in the order of ± 100 MW, which is higher than the averages of 58 MW upward regulation and -72 MW downward regulation that were found for the Netherlands in 2009. Also, the average system shortage and surplus in the simulation results are -39 MWh and 45 MWh, compared to -24 MWh and 27 MWh for the Netherlands in 2009 (TenneT, 2011). Thus, system imbalances are about 40% smaller in reality, which appears to be the main and logical cause of the 35% lower total AIC mentioned above. An important reason for the lower system imbalances in reality is the execution of internal balancing by BRPs in the Netherlands, as is confirmed by further comparison of the model results with Dutch market outcomes[5]. Another reason is that the simulated decision-making algorithm differs from, and is less effective than, the actual BRP strategies[6].

Furthermore, we observe that the average penalties for BRP shortage and BRP surplus for case 2a, in which the activity rate of dual pricing approaches that of the Netherlands in 2009 (17% compared to 10%), are similar to the values for the Netherlands in 2009: 5.85 €/MWh for BRP shortage and 0.96 €/MWh for BRP surplus in case 2a, compared to 3.8 and 0.8 €/MWh for the Netherlands in 2009.

In summary, the comparison of the simulation results with Dutch balancing market data shows that BRP imbalance and system imbalance levels are overestimated in the model, which appears to explain the overestimation of the Actual Imbalance Costs. The absence of internal balancing in the model and the probabilistic decision-making algorithm cause this overestimation. Still, there is a relative similarity between the model results and real data, which brings us to the conclusion that the model is sufficiently valid for the purpose of this analysis.

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[4] As the aggregate portfolio is 25,000 MW and the largest intentional imbalance is set at 2%, system imbalances of ± 500 MW are theoretically possible. The found average system imbalance of ± 40 MW is much lower than that.

[5] An indicator that shows the presence and impact of internal balancing is the net-to-gross market imbalance ratio, which should be lower if internal balancing is applied. For the Netherlands this ratio is on average 29% in 2009, against 44% in the analysis results. This suggests that the absence of internal balancing in the simulation causes the large overestimation of the system imbalance volumes and the Actual Imbalance Costs that we have found.

[6] Indeed, BRPs can be expected to go for the option with minimum expected AIC rather than choose an option inversely proportional to expected AIC values, which would likely result in lower AIC.

Results tables

Table F.3 – Agent-based analysis of imbalance pricing mechanism: Main results (part 1)

Case	Average system surplus (MWh)	Average system shortage (MWh)	Occurrence system surplus (%)	Occurrence system shortage (%)
Case 1	45.2	-37.8	57.6	42.4
Case 2a	45.1	-38.2	57.4	42.6
Case 2b	44.7	-38.6	56.6	43.4
Case 2c	44.6	-38.5	56.3	43.7
Case 3	44.6	-38.7	55.9	44.1
Case 4a	45.2	-38.3	57.6	42.4
Case 4b	45.1	-38.4	57.4	42.6
Case 4c	44.8	-38.5	57.3	42.7
Case 4d	45.2	-37.9	57.3	42.7
Case 5	43.9	-39.2	54.8	45.2
Case 6	42.2	-41.0	51.4	48.6

Table F.4 – Agent-based analysis of imbalance pricing mechanism: Main results (part 2)

Case	Total AIC (€)	Standard deviation total AIC	Average penalty for BRP surplus (€/MWh)	Average penalty for BRP shortage (€/MWh)	Difference penalty 'shortage-surplus' (€)	Imbalance costs uncertainty indicator (€)
Case 1	1,687,493	89,354	-2.26	2.26	4.52	64
Case 2a	2,013,551	90,923	0.96	5.85	4.89	57
Case 2b	2,389,977	77,543	4.97	10.97	6.01	48
Case 2c	2,723,010	74,525	11.22	16.97	5.75	35
Case 3	2,500,785	82,491	13.77	17.37	3.60	32
Case 4a	1,752,731	89,265	-2.02	2.81	4.83	64
Case 4b	1,799,690	90,027	-1.67	3.40	5.07	64
Case 4c	1,800,303	88,977	-1.85	3.42	5.27	64
Case 4d	1,882,002	87,121	-0.76	4.20	4.96	64
Case 5	1,893,241	82,773	0.71	-0.71	-1.41	73
Case 6	2,104,003	93,514	4.77	-4.77	-9.54	88

G Details of cross-border balancing arrangement analysis

Model input The input of the agent-based model used to analyse the impact of alternative cross-border balancing arrangements for Northern Europe (see section 5.4) is described below. The parameter values are listed in Table G.1.

Table G.1 – Input values for model of cross-border arrangements in agent-based analysis

Parameters	**Areas**		
	Netherlands	**Germany**	**Nordic region**
Intentional imbalance options (%)	-2.0 / -1.0 / -0.5 / 0.0 / 0.5 / 1.0 / 2.0		
Schedule Time Unit (minutes)	15		
Delivery rate (-)	2		
Total portfolio size (MW)	25,000	120,000	82,500
$\sigma_{\text{forecast error}}$	0.015	0.0175	0.015
Regulation rate (-)	0.15	0.25	0.2
Day-ahead market price (€/MWh)	39	38.5	35
Regulation pricing mechanism	marginal	pay-as-bid	marginal
Imbalance pricing mechanism	dual	average	single
Initial expected AIC (€)	close to zero (draw from uniform distribution with range [0,1])		
Number of rounds	1,000		
Recency parameter	0.9		
Up/down-regulation bid ladder	fixed set of bids for each of the areas		
Average offered up-regulation (MW)	600	4,000	12,000
Average offered down-regulation (MW)	-700	-4,000	-10,000
Transfer cap. NL-DE (MW)	2,300		
Transfer cap. DE-NO (MW)	1,700		
Transfer cap. NO-NL (MW)	700		
Cross-border flows (MW)	fixed series of flows for three lines		

The input parameter values that are used in the simulation model are presented in Table G.1. First of all, there are seven intentional imbalance options, represented by percentages of the portfolio size, namely. Furthermore, each round equals a Schedule Time Unit (STU) of 15 minutes, as is the case in the Netherlands and Germany. The Nordic region actually has a STU of 60 minutes, but an identical STU is at least required for a common merit order list, which is why this input value has been chosen. The STU is not a model input that has any effect on the model parameters, whereas in reality it affects the BRP strategies. Another general input value is the delivery rate of 2, which means that each 2 MW of activated regulation power yields only 1 MWh of balancing energy per hour, because of the limited ramping rate.

The first area-specific input parameter is the standard deviation of the forecast error, which is set to a value that matches the area imbalance volume relative to system size, which is larger for Germany (cf. van der Veen, Abbasy and Hakvoort (2010a)). Next, the activated up and down-regulation volumes in the model are proportional to resp. the market shortage (sum of BRP shortages) and the market surplus (sum of BRP surpluses), which enables the modelling of two-sided regulation, i.e. both upward and downward regulation within the same STU. This is determined by the regulation rate. The day-ahead market prices are based on the average exchange prices in 2009. Next, the areas have different regulation and imbalance pricing mechanisms, see subsection 2.1.1. These are applied in the model (except for the common merit order list, see below). In the Netherlands, dual pricing is applied when a certain regulation state occurs. In the model, dual pricing is applied when both up- and down-regulation are activated, which depends on the absolute and relative size of the market surplus and the market shortage. Detailed parameter settings have been calibrated such that the activated balancing energy volumes resembled actual data.

The initial expected Actual Imbalance Costs for different options are set close to zero. They are drawn from a continuous uniform distribution between 0 and 1, so that BRPs will not all choose the same option at the start of the model run. One model run is 1,000 rounds long, which comes down to at least ten full days.

Furthermore, the fixed bid ladders are based on regulation (bid) data from 2009. It must be noted that not a lot of detailed bid data could be obtained, which means that the accuracy of the bid ladders is not very high. The first parts of the up- and down-regulation bid ladders for the three areas are shown in Figure G.1. It can be noticed that the Dutch ladder is steepest, whereas the Nordic ladder is the flattest. In addition, the Nordic region has a very large over-supply of bids.

Finally, there are fixed cross-border capacity and cross-border flow values for the three interconnections between the areas, which are based on ENTSO-E data. The fixed cross-border capacities are derived from D-1 NTC values, whereas the cross-border flow data series are directly taken from a period in 2010 (ENTSO-E, 2010).

Results table The results are listed in Table G.2.

Sensitivity analysis A sensitivity analysis has also been conducted. It turns out that the model results are not very sensitive to the reduction of available cross-border capacity for cross-border balancing, even though an increase in congestions has been observed. This is probably caused by the fact that balancing energy can always be exchanged in the direction opposite to the momentary cross-border flow, in combination with a simultaneous

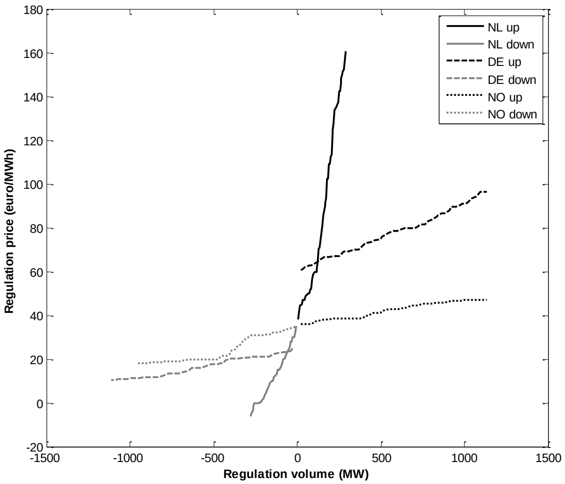

Figure G.1 – Up/down-regulation bid ladders of the three areas in Northern Europe in the agent-based analysis

demand for both up- and down-regulation within the same areas for most STUs. Furthermore, small bid ladder changes do not significantly affect the results, but obviously, large changes do, which is a main reason why the impact of integration is case-dependent.

Table G.2 – Agent-based analysis of cross-border balancing arrangements: Main results

Results	**Area**	**Separate markets**	**ACE netting**	**BSP-SO trading**	**Voluntary pool**	**Balancing energy trading**	**Common merit order list**
Average system surplus (MWh)	*Netherlands*	41	28	43	41	25	28
	Germany	147	107	119	136	90	98
	Nordic region	79	63	71	77	56	70
Average system shortage (MWh)	*Netherlands*	-41	-28	-41	-42	-33	-31
	Germany	-120	-100	-152	-134	-117	-113
	Nordic region	-97	-67	-111	-96	-74	-66
Occurrence system surplus (%)	*Netherlands*	49	40	54	48	36	37
	Germany	58	54	40	50	41	40
	Nordic region	41	36	30	41	37	51
Occurrence system shortage (%)	*Netherlands*	51	44	46	52	49	49
	Germany	42	39	60	50	52	53
	Nordic region	59	51	70	59	51	38
Total AIC (€)	*Netherlands*	1,382,903	1,003,223	634,710	1,296,135	534,793	309,028
	Germany	4,108,876	3,827,085	2,118,310	3,112,452	1,890,939	1,748,199
	Nordic region	564,642	441,463	1,980,975	551,943	439,041	797,913
Average penalty for BRP surplus (€/MWh)	*Netherlands*	6.53	6.40	0.87	6.32	3.45	2.39
	Germany	-3.54	-3.77	2.79	-0.01	1.20	1.89
	Nordic region	0.63	0.46	6.79	0.56	0.34	-1.61
Average penalty for BRP shortage (€/MWh)	*Netherlands*	3.80	4.02	2.53	3.80	1.92	-2.31
	Germany	3.54	3.77	-2.79	0.01	-1.20	-1.81
	Nordic region	-0.63	-0.46	-6.79	-0.56	-0.34	1.69
Total activated balancing energy (MWh)	*Netherlands*	12,279	10,136	14,048	13,167	12,143	11,982
	Germany	122,361	113,103	126,081	125,450	116,341	116,675
	Nordic region	60,239	54,043	65,947	62,975	57,268	57,673
Average up-regulation price (€/MWh)	*Netherlands*	49	48	44	49	43	48
	Germany	73	73	60	81	48	48
	Nordic region	39	38	43	39	38	48
Average down-regulation price (€/MWh)	*Netherlands*	26	27	34	27	32	22
	Germany	17	18	19	18	22	22
	Nordic region	30	30	4	30	31	22
Short imbalance price (€/MWh)	*Netherlands*	43	43	42	43	41	37
	Germany	42	42	36	39	37	37
	Nordic region	34	35	28	34	35	37
Long imbalance price (€/MWh)	*Netherlands*	32	33	38	33	36	37
	Germany	42	42	36	39	37	37
	Nordic region	34	35	28	34	35	37
Total imbalance costs (€)	*Netherlands*	1,399,079	1,112,862	459,143	1,371,953	806,902	541,392
	Germany	2,780,583	2,461,319	3,845,383	3,119,038	2,736,344	2,973,343
	Nordic region	1,416,867	1,344,003	3,946,787	1,438,266	1,088,390	752
Total regulation costs (€)	*Netherlands*	242,237	168,479	86,475	252,302	143,491	141,121
	Germany	2,573,532	2,475,257	1,737,598	2,371,638	1,837,765	1,845,221
	Nordic region	487,638	331,250	1,751,658	519,656	388,490	212,306
Total net settlement sum (€)	*Netherlands*	1,156,842	944,383	372,668	1,119,650	663,411	400,271
	Germany	207,051	-13,939	2,107,785	-5,842,578	898,579	1,128,122
	Nordic region	929,229	1,012,753	2,195,129	918,611	699,901	-211,555

H Effect estimation of national design variables

In this appendix, the full qualitative evaluation of the effects of the national balancing market design variables on the performance criteria is given, the results of which are presented in section 4.6. The effect estimations are summarized in Table H.1, Table H.2 and Table H.3. The variables are ordered by the order of magnitude of importance found in section 4.2.

The estimation consists of the following three points: 1) Estimation of the impact level of individual design variables, 2) Estimation of the influence of the contextual factors on the impact of each design variable, and 3) Consideration of the existence of a 'best' variable value. These three points are consecutively treated in the evaluation, and summarized in separate columns in the tables.

National design variables with a high impact

Schedule Time Unit : The Schedule Time Unit (STU) length divides balance responsibility between the System Operator (SO) and the Balance Responsible Parties (BRPs). Smaller STU lengths will give stronger incentives to BRPs to balance their energy portfolio, as power fluctuations during the STU will even out to a lower extent. As a result, power imbalances on the system level will fluctuate less, which leads to a lower activation of balancing energy bids. The extent to which BRP imbalances will be actually reduced, depends on the increase in imbalance costs due to the smaller STU under the same BRP balancing strategies compared to the costs of intensified portfolio balancing. Generally speaking, the STU length has a very large impact on balance planning accuracy. 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 balancing energy and decrease the supply, it is not clear what will be the effect on availability of balancing resources and price efficiency. However, as the BRP portfolio balancing replaces more efficient centralized active balancing by the SO, a smaller STU can be expected to reduce the utilization efficiency. Next, a change in the STU will have a large effect on transaction costs, as it determines the frequency with which energy schedules and balancing energy bids are submitted by BRPs/BSPs, and checked and processed by the SO. Finally, there may be some switching costs attached to changing this variable, when procedures and communication protocols need to be adapted. Switching costs can be considered internationalization costs; they are the costs of harmonizing design variable to the same value.

With regard to context dependence of the effects, the short-term day-ahead and intra-day market design influence the possibilities to improve balance planning accuracy when a smaller STU creates the incentive for this. As a result, reducing the STU will have a smaller effect when short-term markets do not offer much opportunity for portfolio balancing. Next, a generation mix that creates a lot of unpredictable minute-to-minute power fluctuations (notably wind power) will be affected much more by a decrease in the STU length, as the schedule deviations over the shorter time periods will be relatively higher[1]. Also, a power system with a low share of balancing resources will have a low amount of balancing resources available near real-time after the required reserve capacity procurement. This will reduce the possibilities for BRPs to engage in 'internal balancing', and

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[1] This of course only holds for the BRPs that have wind power in their portfolio.

probably the ability to balance their portfolio by means of trading in the intra-day market as well. Thus, in this case, the effect of a STU length reduction will be smaller. Furthermore, relatively high minute-to-minute unpredictable consumption fluctuations, a high short-term market liquidity and small BRP portfolios will cause an STU length reduction to have a larger effect.

It is not clear which STU length is the best in a certain power system. Viewing adopted STU lengths in Europe, the STU should be not lower than 15 minutes and not higher than 60 minutes. Which value works better depends on the design of short-term markets, and on the generation portfolio. A STU length that is similar to the time unit used in short-term markets may bring lower imbalance costs. Moreover, an increasing wind power share in the system (or, more generally, a system imbalance pattern with frequent and sharp power spikes) may require a smaller STU, so that the market is incentivized more strongly to minimize power fluctuations, and perhaps even to provide better investment signals: To dampen the investment in wind power, and to trigger investment in flexible generation units and adjustable wind power.

Service classes : The definition of different balancing service classes provides the fundaments of balancing service procurement in general. It determines how much balancing resources are needed of each service class, how many balancing service markets are there, what control systems are needed, and what the balancing service bid requirements are in each of those markets. Therefore, this design variable indirectly has a very large impact on the availability of balancing resources: As it determines the amount of required reserves and the capability to offer balancing services, it significantly affects both the demand for and the supply of balancing services. Furthermore, the activation method and regulation speed of the service classes also directly influence the effectiveness of removing Area Control Errors (ACEs), and therewith substantially impact on the balance quality. Utilization efficiency is also somewhat affected, because a high regulation speed of balancing resources will improve the efficiency with which balancing energy services are activated for real-time system balancing, and because the use of more classes and markets may reduce the effectiveness of selection of the cheapest bids. Price efficiency will be indirectly affected by the change in demand and supply of balancing services. Moreover, transparency and operational efficiency are indirectly reduced if more service classes and corresponding markets are introduced, because of more transactions and more market rules and data. Assuming that the distinction between service classes is functional, this cannot be considered a form of discrimination, leaving the criterion of non-discrimination unaffected. Finally, the harmonization of balancing service classes could have large indirect effects on internationalization costs, when balancing service markets need to change, and when new control systems are needed. In the short term, harmonization may not be possible when there are not enough balancing resources in one or more of the involved power systems to meet the new bid requirements.

The effects of balancing service classes depend first and foremost on the generation portfolio in the power system. The presence of flexible generation units in the system, the technical capabilities of these units and the predictability of generation are most relevant here. The definition of service classes that result in strict bid requirements that cannot be met by present generation resources will have a large constraining effect on the availability of balancing resources. Especially when flexible units are scarce, bid requirements should not be too strict. If a lot of unpredictable generation is present in the system, the need for quick balancing resources becomes higher, increasing the value of a corresponding balancing service class. With regard the consumption portfolio in the system, the same arguments can be given. However, noticing that load resources do not (yet) contribute a lot to real-time system balancing, the impact of predictability of consumption on the need for balancing resources and the impact of the volatility of consumption patterns on the need for quick resources are most relevant. The set of Balancing Service Providers also has an impact on the effects of balancing service classes, because stricter bid requirements will increase the market power of BSPs, which may have a varying effect on balancing service prices given the original level of market power (determined by the number of BSPs). This also depends on the strategy of BSPs, as this determines the inclination with which BSPs abuse market power.

With regard to the best choice of a set of service classes, the distinction between Frequency Containment Reserves (FCR), Frequency Restoration Reserves (FRR) and Replacement Reserves (RR) is definitely useful, because of their specific functions in frequency regulation: FCR contain the system frequency disturbance, FRR restore the system frequency, and RR replace the FRR going back to scheduled production and consumption (ETSO, 2007; UCTE, 2009a). Regarding the control methodology, FCR has to be automatic and decentralized in order to respond within seconds. FRR and RR must be centralized to be under the control of the System Operator. Whether or not FRR should be automatic depends on the pattern of system frequency deviations. With increasing frequency stability problems, caused e.g. by an increasing share of wind and solar generation in the system, an automatic Load-Frequency Control (LFC) system becomes more and more necessary, as is indicated by the introduction of LFC in the Nordic region (Svenska Kraftnät and Statnett, 2010). Replacement

Reserves do not need to be activated automatically, which makes manual (non-automatic) activation the cheapest option, as no Automatic Generation Control system needs to be used by the BSP. More than three service classes does not appear to have added value, as too many different balancing service markets reduce utilization and price efficiency, whereas it sufficient from a security perspective for System Operators to distinguish on the basis of the three different frequency regulation functions.

Zonal vs. nodal responsibility : The fundamental design variable of zonal vs. nodal balance responsibility has a major effect on the process of energy schedule submission, and thereby on portfolio balancing as well. If energy schedules must be drawn up on a nodal basis, incentives to Balance Responsible Parties to balance their portfolio are much stronger and specific than if energy schedules are submitted on a zonal basis. After all, each MWh of deviation from the scheduled energy exchange for each single node is settled with the relevant imbalance price, whereas a large share of these deviations would cancel out within a zonal portfolio. The same story can be told with regard to the differences between zonal balancing and control area balancing, where one control area can be divided up into multiple zones (which is usually on the basis of existing transmission bottlenecks). This variable has a huge impact not only on BRP imbalance volumes, but also on imbalance prices, if different balancing energy prices and imbalance prices are defined for the different zones[2]. As a result, balancing planning accuracy will be affected to a very large extent. Operational efficiency is significantly affected due to the change in the number of energy schedules submitted to the System Operator per Schedule Time Unit. Transparency decreases somewhat if multiple price zones are applied. There may be internationalization costs involved if the change in the number of energy schedules requires a new administration system[3]. Furthermore, non-discrimination could be argued to be affected if zonal or nodal balancing is applied, but this would be a purposeful discrimination. The purpose would be to give locational incentives to BRPs and BSPs (in case of zonal balancing). This would indirectly result in an increase in availability of balancing resources and utilization efficiency for power systems with congestion problems, as resources are located better and less resources need to be used for redispatch. Thereby, price efficiency would improve as well. Considering nodal balancing, incentives on BRPs could be so strong that they would balance internally using flexible resources, which may substantially reduce utilization efficiency. However, it must be noted that when marginal regulation pricing is applied, market parties are generally better off offering flexible resources as balancing energy services to the System Operator than keeping it for 'internal balancing'[4].

The context dependence of the effects of zonal vs. nodal responsibility relates mostly to the location of generation and consumption in the power system, and the availability of transmission capacity. If the combination of these factors create a lot of congestion problems, zonal balancing may improve balancing market performance a lot by giving locational incentives to BRPs and BSPs. In congested systems, a frequent balancing energy market splitting into zonal markets could reduce balancing energy costs, because zones that export balancing energy up to congestion will be faced with a lower regulation price. The effect of this on price efficiency is unclear: As a result of lower imbalance prices imbalances might increase[5], and BSPs might ask for higher balancing energy prices to offset lower profits, but not necessarily. Regarding short-term market design and liquidity, the same arguments on dependency of the effects can be given for nodal vs. zonal responsibility as for the STU length. Especially in case of nodal balancing, favourable short-term market design and liquid markets are important.

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[2] In case of nodal balancing, the determination of nodal balancing energy prices appears hard and inappropriate, because balancing energy dispatch cannot be linked to imbalances in specific nodes. Therefore, nodal imbalance prices do not appear to be an option either.

[3] Additional costs for setting up energy measurement systems are probably costs for the Distribution System Operators or energy supply companies, so are not part of the internationalization costs (remember that balancing market performance is considered from a system perspective).

[4] This is because imbalance prices will be based on the (marginal) regulation prices. If market parties offer their resources to the SO at marginal costs, selection will always reward them with the regulation price, whereas internal balancing only prevents paying (an equally high) imbalance price in cases of individual imbalance. The effect in such cases is the same. However, there is also a risk of wrongly estimating what the imbalance price is going to be. If the imbalance price turns out to be lower than the marginal costs of the resource, the internal balancing has been more costly than leaving an imbalance would have been.

[5] It cannot be said that lower imbalance prices will cause higher imbalances. BRPs will balance their portfolio with the objective to minimize costs. These costs consist of imbalance costs, but also of portfolio balancing costs, i.e. the money spent to prevent imbalances by forecasting, short-term trading, and internal balancing. It may be the case that, with the lower imbalance prices, it becomes cheaper to leave some imbalance instead of preventing it by means of portfolio balancing.

Finally, note that the size of BRPs is directly restricted by this design variable[6].

What form of balance responsibility is most suitable depends on the level of congestions in the transmission network; if there are a lot of transmission bottlenecks the use of zonal balancing will provide locational incentives to BRPs and BSPs, which will probably improve performance. And as a system with zonal balancing will work just like control area balancing in STUs without congestions on the borders of the zones, zonal balancing appears to have no disadvantage compared to control area balancing even for uncongested power systems. Nodal balancing leads to unnecessarily high imbalance costs.

Reserve requirements : Reserve requirements are determined by the System Operator, but follow from the agreements between SOs of the synchronous zone on frequency quality standards, service class definitions, resulting control systems to be used, control area boundaries, and the resulting geographical distribution of reserves. This is true first and foremost for the Frequency Containment Reserve (FCR) requirements, because this service class is delivered instantaneously to contain frequency disturbances affecting all control areas in the synchronous zone. In the UCTE, the total primary control reserve is dimensioned to the size of the 'reference incident' of 3,000 MW, which is divided among control areas based on load size (UCTE, 2009a). With regard to Frequency Restoration Reserves (FRR) and Replacement Reserves (RR), SOs have more freedom to determine national reserve requirements. Although it is the aim to remove Area Control Errors within 15 minutes, this is of lower importance for frequency stability. In any case, countries have the sovereignty to determine national reserve requirements themselves. System Operators can use different calculation methods to determine the reserve requirements. In the UCTE Operation Handbook, four methodologies for the sizing of secondary and tertiary control reserves are mentioned: 1) Empiric Noise Management Sizing Approach, 2) Probabilistic Risk Management Sizing Approach, 3) Largest Generation Unit of Power Infeed, and 4) Extra-ordinary Sizing of Reserves. Methodology 1 calculates a minimal amount required to control load and generation variations, Methodology 2 calculates an amount required to control the ACE in e.g. 99.9% of the year, methodology 3 dimensions the requirement equal to the largest possible generation incident, while methodology 4 takes into account other influential criteria like the capability to control large changes in total exchange programs and topology of the control area (UCTE, 2009a). We cannot say to what extent the methodologies lead to different contracted reserve capacity amounts, but consider here that SOs are free to vary these amounts a lot. The choice for specific reserve requirements (for FRR and RR) has a large impact on the amount of contracted reserve capacity, but also impacts on the amount of offered balancing energy. More procurement may therefore increase market power in the reserve capacity market, but decrease market power in the balancing energy market, which makes the effect on price efficiency unclear. Without a doubt, however, more reservation will substantially increase the availability of resources for real-time system balancing. Utilization efficiency might be improved if increased reservation enables the SO to use the cheapest resources better. Because the SO can choose to reserve ample and quick resources for effective ACE removal, balance quality is significantly affected. Transparency could be slightly reduced if the SO would not use a clear dimensioning methodology.

Obviously, a larger power system must have a higher reserve requirement, although the relative share of reserve can be lower thanks to the evening out of imbalances and the fact that the largest unit makes up a smaller share of the total capacity. Having said that, different power systems could have a different goodness of fit with methodologies. For example, a large risk of the failure of the largest unit makes the reservation of an equal amount of reserve capacity the logical calculation method. But also installed generation capacity compared to system load, generation and consumption volatility, network topology, and the risk of failure of transmission lines can affect the suitability of reserve capacity calculation methods and the need for a certain amount of reserve capacity. Thereby, the generation and consumption portfolio and the transmission capacity have a large impact on the reserve requirements, and thus on the effect of a specific reserve requirement. Interconnection capacity also has an impact, because a high degree of interconnectivity increases the possibility to rely on frequency control support from FCR. This may reduce the need for large amounts of quick balancing resources, although in the end the control area must remove its ACE itself. If the control area is not synchronously connected, however, all FCR must be procured within the control area[7], and being part of a larger synchronous zone reduces the control area FCR requirement.

A 'best' absolute size of the national reserve requirements obviously does not exist. The share of required balancing capacity, and the suitability of different calculation methods, depends on the technical contextual

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[6] That is, with regard to the size of energy portfolio(s) that can be scheduled by means of one energy schedule, within which energy imbalance can even out.

[7] Whether this is true, actually depends on the ability to procure FCR from asynchronously connected systems. According to Grande et al. (2008), this is possible, although technical challenges are fundamental.

factors. The most concrete broadly important method appears to be the reservation of at least the amount of (upward) reserve capacity equal to the largest generation unit, in order to replace this unit if it fails. The required size to cover certain power system imbalances and ACEs is much harder to determine. Besides, it is debatable what percentage of what imbalance/ACE values should always be resolved, and what values and occurrences are still acceptable.

Methods of procurement : Balancing services can be procured by the System Operator through either bilateral contracting or tendering in a balancing service market, they can originate from resources that are owned by the SO, or they can be obtained by means of some obligation to market parties to provide balancing services. These methods of procurement are very different in nature, and can therefore be expected to lead to large differences in offered quantities of balancing services, as well as submitted bid prices and the quality (technical capability) of the services. Compared to tendering, bilateral contracting by the SO is likely to reduce competition significantly, especially if the SO has no financial interest in contracting the cheapest services and if the contracting procedure is untransparent. Balancing resources owned by the System Operator may result in low-priced balancing service bids, but also in unfair favouring of the own bids, whether to make money, to improve controllability, or for the sake of simplicity. In Germany, the former vertically integrated power company E.ON favoured its own generation assets in the procurement of balancing services, which led the European Commission to adopt the decision that E.ON should divest its transmission system business (European Commission, 2009d), which became reality when the Dutch TSO TenneT bought Transpower (the former E.ON Netz) (Energy Business Review, 2010). This shows that the SO should not have a financial interest if it is to own balancing resources. Also, the SO ownership could significantly reduce competition in the balancing service market, in case it is not profit-driven and delivers large volumes at marginal costs. Moreover, such ownership likely reduces the general efficiency of use of the generation units (unless they are old and expensive units that would not have been dispatched by producers). Obligations could significantly increase the amount of available balancing services, or guarantee a desired minimum amount, but at the same time the quality of services could significantly decrease, as BSPs have no incentive to provide high-quality services. Thus, it follows that this design variable has a large impact on the availability of balancing resources, price efficiency, and balance quality. Furthermore, if market parties must all procure a share of the required reserve capacity, like is the case in PJM, the utilization efficiency of reserve capacity procurement probably reduces to a large extent. The operational efficiency is affected a bit, because an obligation to submit bids will lead to higher transaction costs than SO ownership. Next, transparency is influenced, because some procurement methods (tendering) are more transparent than others (bilateral trading, SO ownership). Bilateral contracting might result in some discriminatory treatment of Balancing Service Providers. Internationalization costs will only be significantly influenced if a bid submission system is going to be introduced.

The impact of the methods of procurement is affected somewhat by the technical capabilities of flexible generation resources. If high-quality balancing resources are scarce, an obligation to provide a certain share is a less good idea. And with a high number of BSPs, the choice for tendering will have a larger positive impact on price efficiency. With a small number of large BSPs, an obligation to BSPs to procure a certain share of balancing services, will have a smaller negative effect on utilization efficiency and balance quality. Also, if BSPs have market power and are inclined to abuse market power (which is a more serious threat in case of a small number of BSPs), bilateral contracting, compulsory provision with regulated or no remuneration and SO ownership might be better options than tendering. Finally, a lack of flexible resources in the system might call for an obligation, Considering availability in the short term, this is probably better tackled by a sufficiently high reserve requirement. However, an obligation could also give a long-term incentive or enforcement to invest in new balancing resources that is much stronger than the one given by high balancing service prices, which could make sure that no (temporary) shortages of balancing resources will arise.

Generally most beneficial is the tendering of balancing services, because it incentivizes market parties to offer cheap and high-quality[8] balancing services at prices close to the marginal costs. Obligations appear not to be vital to assure the availability of balancing resources: Reserve capacity procurement tackles this, and market parties will generally offer uncommitted resources in the balancing service market, as this is the last chance to make some money with these resources. However, the obligation for new generation units to include the technical equipment needed to deliver balancing energy services appears a useful option, especially in case the ratio between balancing energy demand and supply increases to a level that endangers the availability of balancing resources. This becomes reality if the wind and solar energy share are increasing to a high level. If an obligation is needed to ensure security of supply, it is probably still better to retain a competition of balancing

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[8] That is, if the SO takes the quality of balancing services into account in the activation strategy.

service bids, in order to improve utilization efficiency (by selecting the cheapest bids) and balance quality (by stimulating the provision of high-quality services).

Timing of markets : The timing of markets, i.e. the timing of balancing service bidding procedures and balancing service market clearances, has a large impact on the bidding behaviour of Balancing Service Providers. If reserve capacity markets are cleared yearly, only BSPs with balancing resources that are available across one whole year can bid balancing resources, which is a large entry barrier for small market participants and significantly reduces the offering of reserve capacity, i.e. the utilization efficiency. As a result the price efficiency will be low, but this is substantially aggravated because BSPs must predict the opportunity costs of reserve capacity procurement for up to one year in advance (see subsection 4.4.2). The advantage of long-term procurement is a higher certainty on the availability of balancing resources. Of course, the same arguments hold for monthly clearing compared to weekly clearing, and weekly clearing compared to daily clearing. In case of a daily reserve capacity market, the coordination of timing of the reserve capacity market clearance with the day-ahead market clearance becomes an issue. It was found in Abbasy et al. (2010a) that a reserve capacity market clearance after the day-ahead market clearing will lead to the lowest prices in both markets and highest reserve capacity volumes, although this could result in a lower balancing resource availability. The frequency of clearing of balancing energy markets is determined by the Schedule Time Unit. In case of marginal pricing, the effect of higher a higher clearing frequency will result in lower balancing energy prices, which could lead to a lower price efficiency as a result of BSPs leaving the market or increasing their bid prices in order to compensate for the lower regulation prices. Furthermore, the time of offering balancing service bids compared to market clearing is also important: A bidding deadline that is well before the clearing time will increase the uncertainties on profits, compared to profits that could have been made in other markets (i.e. opportunity costs). As a consequence, bid prices will increase. A good example is given by the former monthly secondary control reserves market in Germany with combined balancing service bids: As the secondary control energy bid ladder was fixed for the whole month, monthly average bid prices of activated secondary control energy bids were 2-6 times higher than the monthly average intraday prices in 2009 (Abbasy et al., 2010b). For more information on the abovementioned research we refer to subsection 4.4.2. Finally, the timing of markets also influences the availability of resources: a larger reserve contracting period and bid submission deadlines well before the market clearing will increase this. These effects are estimated to be smaller than those on BSP behaviour, because the presence of balancing resources in the system stays the same. Nevertheless, we denote that there is a trade-off between availability of balancing resources and price efficiency. To wrap up, this design variable has a large impact on availability of balancing resources and utilization efficiency, and a very large impact on price efficiency. Operational efficiency is slightly affected due to the effect on the number of bids. Internationalization costs might include the extension of the administrative system for handling balancing service bid submissions and remuneration, in case some countries shift to markets with a higher bidding and clearing frequency.

Regarding context dependence, the presence of flexible generation units in the power system influences the effects of different frequencies of reserve capacity market clearing (contracting periods). The reduction in the submission of reserve capacity bids due to a larger contracting period could have larger negative consequences for resource availability and price efficiency in power markets with a low flexible generation share. Furthermore, as mentioned above, the coordination of the day-ahead market clearing time with the clearing time of a daily reserve capacity market has an impact on reserve capacity volumes and prices. Finally, if BSPs are more inclined to behave strategically, a short contracting period is more favourable.

Generally, a short contracting period for reserve capacity appears preferable for efficiency reasons. If it does not jeopardize the availability of balancing resources, a daily reserve capacity market with a clearance after the day-ahead market clearance appears the best option. The period of bid submission should end as close to the balancing service market clearing as possible, to enable BSPs to bid with as much certainty on availability and prices as possible.

Allocation of reserve capacity costs : There are four main options to allocate the reserve capacity costs to power system users: 1) By adaptation of the system services tariff (common in Europe), 2) by assignment of reserve obligations to Balance Responsible Parties (applied in PJM), 3) by adaptation of imbalance prices (proposed by Catholic University of Leuven and Tractebel Engineering (2009) and Vandezande (2011)), and 4) Separate fees for BRPs. These are very different options. In the first option, the reserve capacity costs are allocated to the system users (this can be only the consumers, or also the producers, depending on who pay the tariff); in the other three options the BRPs pay for these costs. Moreover, the second option implies the use of a reserve capacity procurement obligation for BRPs, while the third option means a sophistication of the imbalance pricing mechanism. Thus, the second option is entangled with the design variable of methods of procurement, and the third option with the design variable of the imbalance pricing mechanism. The first option is not connected to other design variables. With regard to feasibility, the first option can be applied very easily. The second option is not difficult either; the total reserve requirement is allocated to BRPs proportional to their size. The third option is quite cumbersome, though: The reserve capacity costs must be allocated by the increase of the imbalance price with some additive component, which will be too high or too low if determined before real-time, or create a lot of financial uncertainty in case it is determined after real-time. In option 4, separate, additional fees are charged to the BRPs, which can proportional to the BRP size, fixed, or proportional to imbalances. The Nordic region applies a combination of all those. It thus has chosen option 4, which has to do with the fact that financing by means of the grid tariff is not allowed (NordREG, 2008). Because the system services tariff is paid by end-consumers (and is evenly distributed among them), the first option does not really affect the behaviour of balancing market parties. In the second option, however, it is the BRPs instead of the System Operator who procure reserve capacity. As mentioned under 'methods of procurement', this may create a much lower utilization efficiency and price efficiency, due to the decentralized decisions on the purchase or self-procurement to fulfil the obligations. In addition, the BRPs have no incentive to procure high-quality resources, which may have a negative impact on balancing quality. Subsequently, the third option will have a large impact on the incentives of BRPs to balance their portfolio. Considering that the total reserve capacity costs are at least a significant share of the total balancing service costs[9], the additive component will significantly increase the imbalance prices. This may not only create overly large incentives to balance BRP portfolios, but also give an incentive to BSPs to keep balancing resources for internal balancing[10]. Moreover, the higher uncertainty on the level of the imbalance prices will further over-dimension the incentive to prevent BRP imbalances. Although this may substantially increase balance planning accuracy, the cost allocation efficiency is reduced much more: The settled imbalance costs are much higher than the settled real-time balancing costs. In addition, the utilization efficiency may reduce to a very large extent, because the shift to internal balancing is far less efficient than the centralized activation by the System Operator. This shift also causes a reduction in availability of resources, price efficiency and possibly balance quality, because the SO has less (quick) balancing energy bids to call upon. This reduction is not severe, however, because the system imbalance volumes reduce as well due to the intensified BRP portfolio balancing. The transparency of imbalance pricing will reduce a lot if reserve capacity costs are recovered through imbalance settlement. This option might also be considered discriminatory towards (frequently unbalanced) BRPs, if it can be argued that the reserve capacity procurement is necessary irrespective of BRP imbalance volumes. The option of tariff adaptation could be considered discriminatory towards consumers, in case producers do not pay a system services tariff. The internationalization costs are small. Harmonization requires the adapting of the process of tariff determination, embedding of processes of reserve obligation calculation, monitoring and control and adapted settlement, or adapting the process of imbalance price calculation.

Regarding context dependence, a relatively large need for reserve capacity will cause option 3 (recovery through imbalance settlement) to have larger negative effects on incentives for BRPs and BSPs. Depending on the reasons to procure reserve capacity, option 3 may also be more or less discriminatory. The reasons are mainly influenced by the generation portfolio. If there is a large number of small BRPs, option 2 (reserve capacity obligations to BRPs) has a higher negative effect on the utilization efficiency and balancing service price efficiency, and the negative effects of option 3 on cost allocation efficiency and utilization efficiency may be even higher due to relatively large imbalance volumes. Finally, if BRPs are risk-averse, they will put more effort into preventing BRP imbalances, which causes larger negative effects in option 3.

Viewing the mentioned disadvantages of option 2 (reserve obligations for BRPs) and option 3 (additive component in imbalance price), option 1 (system tariff) appears the best allocation method for the reserve capacity costs. Since we believe that all system users equally benefit from reserve capacity procurement and the security of supply that it safeguards, the reserve capacity costs should be equally distributed to system users. It can be noted that we adopt a different view than Catholic University of Leuven and Tractebel Engineering (2009) and Vandezande (2011), who argue that the reserve capacity costs are needed due to BRP imbalances, and should thus be paid by BRPs. Irrespective of the adopted view, however, an additive component will damage the incentives to BRPs and BSPs too much, and create overly high costs and uncertainties for BRPs.

Allocation of balancing energy costs : Usually, imbalance settlement serves to allocate balancing energy costs to the Balance Responsible Parties. Alternatively, balancing energy costs could be (partly) recovered

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[9] This is in accordance with (Jaehnert and Doorman, 2010b; TenneT et al., 2011), and also with a data analysis of procured German secondary control bids from 2010, where the total reserve capacity costs have been found to be ~40% of the total balancing energy costs (Amprion et al., 2011).

[10] This is because imbalance prices are higher than balancing energy prices, which makes the prevention of imbalances more valuable than the provision of balancing energy.

through a system services tariff, which means that real-time balancing costs are socialized. As mentioned before, this variable is a fundamental design variable: Without an allocation to BRPs, there is no imbalance settlement, and market parties will not have an incentive to balance their own portfolios, because the balancing costs they create are socialized. First of all, it should be noted that, actually, imbalances must always be settled, in order to prevent giving an adverse incentive to produce less energy or consume more energy than scheduled. However, imbalance could be settled with just the day-ahead price, which would still require an (additional) allocation method to recover balancing energy costs. Recovery through a tariff significantly damages cost allocation efficiency, in the sense that the costs are not allocated to the 'costs-causing' parties. Furthermore, the balance planning accuracy could decrease to a very large extent. Since this would significantly increase the procurement and dispatch of balancing services, the availability of balancing resources and price efficiency could significantly reduce. Transparency will improve thanks to the termination of imbalance settlement (that is, the settlement with uncertain settlement prices based on balancing energy prices). In the unlikely event that a country applies recovery through the tariff, the internationalization costs are the costs of setting up an imbalance settlement system, which are estimated to be low.

If the generation and consumption portfolio of the power system are very unpredictable, socializing the balancing energy costs will have worse effects (compared to allocation via imbalance settlement) than in a predictable power system. Furthermore, the presence of liquid short-term markets and short-term market designs that give a lot of opportunities to BRPs to balance their portfolio will create a larger gap in system imbalance volumes between both forms of balancing energy allocation. Finally, if there is a large number of small BRPs, the difference in performance could also be larger, because small BRPs may be stimulated more to balance their portfolio in case of allocation through imbalance settlement[11].

It is as clear as crystal that the balancing energy costs should be allocated to Balance Responsible Parties by means of imbalance settlement, in order to give incentives to market parties to plan accurately, and stick to their energy schedules.

National design variables with a medium impact

Publication of national information : The publication of national information is about the publication of both balancing market rules and balancing market data. Both obviously affect transparency. If the market rules are published in a more transparent way, entry barriers to taking up the role of Balance Responsible Party or Balancing Service Provider are lower. Regarding BSPs, this can mean more competition in balancing service markets, which improves the availability of balancing resources, enlarges price efficiency, and increases utilization efficiency if more cheap available balancing resources can be dispatched as an effect. More relevant is the publication of market data. First of all, the choice which market data to publish can have large effects on market behaviour. If Balancing Service Providers receive too much information on bid ladders, they may distract the bidding behaviour of competitors, and behave strategically using that information. This could result in a lower price efficiency. Still, giving some more information on bid ladders could help BSPs to bid more effectively, and thereby attract more bidders, which would improve price efficiency. Second, the time of data provision is important. If BSPs receive real-time information on the interim bid ladder, it may attract more bidders. With regard to BRPs, real-time information on bid prices of activated balancing energy bids and the system state forms a good basis for imbalance price prediction, which could trigger BRPs to 'passively balance', i.e. create an intentional imbalance by real-time adjustment of generation or consumption (internal balancing) that helps to reduce the system imbalance. This requires the application of 'single pricing' as the imbalance pricing mechanism, however. The occurrence of 'passive balancing' may significantly reduce the balance planning accuracy, but at the same time significantly increase the availability of balancing resources, price efficiency and utilization efficiency, as the 'internal' balancing resources are in competition with the balancing resources that were offered to the SO for (centralized) system balancing. An advantage for market parties with both the BRP and BSP role is that 'passive balancing' enables them to make money with their balancing resources after the final gate closure time, by which the balancing energy bid ladder usually becomes definitive. A disadvantage for the system is that it could significantly reduce the balance quality, as the SO has less control over the real-time balancing. Finally, a quick publication of regulation and imbalance prices helps market parties to optimize their strategies, which (in case of appropriate incentive mechanisms) could help to improve balance planning accuracy, availability of balancing resources and price efficiency. Considering the switching costs for this design variable, the internationalization costs will be low. Some data storage centers and a data publication website may need to be invested in.

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[11] This depends on the imbalance pricing mechanism. See the estimation for that variable.

Regarding context dependence, there is one contextual factor that has a clear influence on the impact of the publication of national information. In case of a small number of BSPs, high transparency of market rules and data is important to attract new bidders, but too much bid ladder information will create higher risks of market power abuse.

The best way of publishing information on the balancing market is probably by means of a national website on which all information and data is put together. The provision of real-time information for Balance Responsible Parties appears to be better, because it increase the possibilities for providing balancing energy services, which leads in an indirect way to more competition between these services. We view this effect is more important than the reduction in balance quality, because the latter is a less important performance criterion (see section 4.3). Information on bid ladder data should only be given if it will not create opportunities for gaming. Last, a quick publication of prices will enable market parties to make better decisions on the short term.

Responsibility for renewable generation : The two main options in this variable are balance responsibility for renewable generation for renewable power producers and balance responsibility for the SO. In the first case, renewable generation has to be taken up in BRP portfolios, which gives the Balance Responsible Parties incentives to accurately predict renewable production, to 'trade away' imbalances in the day-ahead and intraday time frame, and to 'internally balance' the renewable production. All of this could significantly reduce the contribution of renewable generation to the system imbalance, compared to SO responsibility. After all, SO responsibility means that the market does not pay for imbalances caused by renewable generation, and therefore have no incentive to balance it. However, the SO could take up this task, as occurs in Germany, where TSOs forecast and schedule wind and solar power, and proactively balance this power by means of trading on the power exchange (Biermann, 2009; Klessmann et al., 2008; LBD-Beratungsgesellschaft, 2007). But in that case, the SO has no incentive to forecast accurately or minimize the costs of any proactive balancing, because the costs are recovered through the system services tariff, as mentioned by Klessmann et al. (2008). Also, the SO may have less experience and detailed information to forecast accurately, but on the other hand the centralized forecasting could also enable a higher accuracy (Klessmann et al., 2008). Therefore, it is not clear to what extent SO responsibility leads to different balancing costs than BRP responsibility. It is likely, however, that BRPs will put more effort into wind and solar power balancing, thereby reducing the system imbalance volumes and imbalance prices. This will increase the balance planning accuracy. Moreover, on the long term, investment in renewable energy may be dampened as imbalance costs skyrocket, keeping balance planning accuracy and availability of resources within acceptable limits. However, this decentralized balancing by BRPs could very well create large inefficiencies in balancing, and thus go along with a much lower utilization efficiency. In addition, it could create more and large frequency disturbances, which means a lower balance quality. An intermediate design option is the use of a separate balance responsibility and imbalance settlement design for renewable generation. An example is Belgium, where the BRP is partially responsible for off-shore wind power generation imbalance outside a certain tolerance margin (de Vos and Driesen, 2009). The main advantage of such a hybrid option appears to be that BRPs do have incentives to balance renewable energy, but are not faced with excessive imbalances. On the downside, it appears to prohibit the evening out of renewable energy imbalances with conventional energy imbalances. Thus, partial responsibility appears to give more limited incentives and options to balance the portfolio, compared to full BRP responsibility. In general, this design variable affects not only balance planning accuracy, utilization efficiency and balance quality, but also the availability of balancing resources, because BRP responsibility incentivizes BRPs to invest in and use flexible resources to balance their portfolio, but also because it stimulates BRPs to reduce imbalances by better forecasting and trading, reducing the need for balancing resources. In case of SO responsibility, a very large negative effect on cost allocation efficiency can be observed, because the money that the SO spends on renewable energy balancing is distributed to all system users, whereas the investors in renewable generation have caused these costs. Furthermore, transparency and operational efficiency are somewhat affected by especially separate (partial) BRP responsibility, which is the most complex design option and requires separate energy schedules and settlement for renewable generation. Finally, the exemption of renewable energy producers from balance responsibility and imbalance settlement (or separate arrangements for these) are definitely a form of discrimination. Internationalization costs could be substantial if SOs need to install a renewable and forecasting business unit.

The generation portfolio obviously has a very large influence on the impact of the responsibility for renewable generation, because a high renewable share in the generation mix of a power system means that a change of this design variable has much larger effects on market behaviour and performance. Furthermore, the day-ahead and intraday market design and liquidity are very important contextual factors regarding the ability of BRPs to balance renewable portfolios in order to maintain imbalance costs within acceptable limits. Also, large BRPs will have higher capabilities to balance, and imbalances will even out more for them.

From the perspective of non-discrimination, full BRP responsibility for renewable generation is definitely the best option. This option gives appropriate incentives to BRPs to balance their portfolio, and could even put a natural brake on the investment in renewable generation in case the system balance is affected too much. Furthermore, higher imbalance prices would also provide an incentive to market parties to offer more balancing services, and invest in balancing resources, including more controllable wind turbines. If operating costs end up to be too high for market parties to invest in renewable generation, it is better to subsidize by some other measure (e.g. a higher feed-in tariff) than shifting balance responsibility to the SO and thus to society, so that the incentive compatibility of the balancing market is not distorted. We note that the Council of European Energy Regulators (CEER) has, in a report on regulatory aspects of the integration of wind power in Europe, also concluded that wind generators should be responsible for their imbalances for similar reasons as stated here (CEER, 2010a). Only if the regulatory regime cannot be changed on short notice, and BRPs will not be able to prevent unacceptably high imbalance costs, a current SO responsibility for renewable generation could be maintained. But in that case, partial BRP responsibility (or separate responsibility with a more favourable imbalance pricing mechanism) is preferable, and a useful transitory option towards full BRP responsibility. A 'subtractive component' to the imbalance price for renewable portfolios appears to be better than a tolerance margin, as it provides an incentive to minimize imbalances, rather than staying within the margin.

Final gate closure time : The final gate closure time is the time at which the energy schedules become final (unless ex-post trading is applied, see the description of that design variable below). This time determines until which Balance Responsible Parties (market parties) can trade with one another, and adapt the energy schedules accordingly. It is therefore and important design variable for BRPs: After the final gate closure time, 'internal balancing' is the only BRP balancing activity with which the BRP imbalance costs can still be influenced. The closer this time is to the Schedule Time Unit of delivery, i.e. real-time, the more certainty BRPs will have about actual production and consumption. After all, the forecast accuracy of intermittent generation and consumption increases the closer one gets to real-time, while unforeseen events such as generation unit failure can also still be taken into account. In addition, BRPs will be better able to predict imbalance prices, which enables them to optimize their strategies even further. Next, the final gate closure time is also usually the time at which balancing energy bids become final. Here, the closer final gate closure time lies to real-time, the more time BSPs have to consider their bidding strategy. It should be noted, however, that if BSPs are incentivized to bid at marginal costs (as marginal pricing does, see below), and to offer balancing services rather than keep it for internal balancing (which marginal pricing in combination with imbalance pricing without penalties does, see below), the bidding strategy will not depend a lot on the final gate closure time. Viewing the above, the only performance criterion that is clearly affected is the balance planning accuracy. If there is no intraday market, the final gate closure time could already be on the day before delivery (cf. CEER (2010b)). This may cause much higher system imbalances, but on the other hand flexible resources could not have been committed in the intra-day market, so the supply of balancing energy bids could be equally large. However, a high wind power share would, in case of a final gate closure time on the day before delivery, not only lead to a very low balance planning accuracy (if the market is responsible for wind power), but also to much higher system imbalances. After all, the BRPs are not able to 'trade away' imbalances, and have limited internal balancing capabilities. This would lead to a much larger use of balancing energy services, and thus a significantly reduced availability of resources and price efficiency. Moreover, the 'internal balancing' by BRPs would reduce the utilization efficiency. In case of SO responsibility for wind power balancing, the final gate closure time would not have effects like these, however.

Following from the above, a final gate closure time close to real-time is much more useful in case of a high wind power share. The same holds for a power system with a consumption portfolio that becomes much more predictable as the time of delivery approaches. The closure of the last short-term market determines the earliest possible point in time for final gate closure (it could also be set at a later time, which would enable more bilateral trade between BRPs). Therefore the short-term market design constrains this design variable. Also, small BRPs will be affected more by a change in the final gate closure time, because their imbalance volumes are relatively high.

A final gate closure time as close as possible is the best setting, because forecast accuracies for intermittent generation and consumption increase closer to the time of delivery. Of course, BRPs should have the ability to trade up to gate closure in order to benefit from a later gate closure time. The increased portfolio balancing by BRPs will reduce the burden on flexible generation and load resources for real-time balancing. The period between the final gate closure time and the time of delivery must be large enough for the System Operator to process all final schedules and bids, and to anticipate on the task of maintaining the system balance. According to CEER (2010a), the final gate closure time in different Member States of the European Union differs varies between 24 hours ahead and 30 minutes ahead. Thus, at least a 30 minute ahead final gate closure time is achievable.

Net vs. separate positions : The main difference between applying one net scheduled position and separate positions for production and consumption is that the latter does not allow the netting of production imbalances with consumption imbalances, which increases the schedule deviations of Balance Responsible Parties while the system imbalance is the same. This will create higher imbalance costs for BRPs, and thereby a larger incentive to balance the separate portfolios. This leads to a schedule deviation reduction again. Therefore, the reduction in balance planning accuracy will be limited. The effect on balance planning accuracy depends also on the used imbalance pricing mechanisms. In the Nordic region, 'two-price settlement' is used for the production balance and 'one-price settlement' (single pricing) for the consumption balance (see subsection 2.1.1). This arrangement 'maximizes the amount of regulation power (balancing energy services) given to the market' (NordREG, 2008), and gives strong incentives to producers to keep their balances (Nordel, 2006b). The one-price settlement for consumption reduces the entry barriers for retailers, because imbalance costs are lower, and there is a smaller advantage of pooling (i.e. becoming part of a large BRP portfolio). Moreover, it encourages 'passive balancing' by consumers such as big industries, and also the provision of balancing services to the SO by such consumers (NordREG, 2006). On the downside, it gives less incentive to the BRPs to compose reliable consumption schedules (Nordel, 2006b). Furthermore, NordREG (2008) states that two separate balances and the resulting inability to cancel production imbalances with consumption imbalances means that suppliers without production capacity are not discriminated. Also, it mentions substantial changes in IT-systems as an effect of a change in the number of scheduled positions (balances). Furthermore, according to a 2009 note from Energinet.dk, Sweden changed in the end of the nineties from a net position to separate positions (while two-price settlement was retained) to cope with the problems that it had with 'self-regulation against the system', i.e. internal balancing (Energinet.dk, 2009). Thus, separate balancing could also be argued to reduce the degree of internal balancing by BRPs, which would increase utilization efficiency, given that BRPs regulate in the direction opposite to the main regulation direction (enlarging the system imbalance) half of the time (Energinet.dk, 2009)[12]. This only holds if the regulation and imbalance pricing mechanisms give incentives to keep balancing resources for internal balancing, however (see below). We can conclude from the above that this design variable has a moderate impact on balance planning accuracy, utilization efficiency, and non-discrimination, and a small effect on availability of balancing resources, balance quality and price efficiency. Also, separate positions for production and consumption increases transparency for the System Operator, but reduces the operational efficiency as a result of more schedule and settlement transactions. The internationalization costs associated with changes in IT-systems are estimated to be small.

Regarding context dependence, the presence of internal congestions in the power system makes it more important for the System Operator to receive accurate and detailed information on production schedules. Thus, separate balances for production and consumption are much more important here. Subsequently, liquid and favourable short-term market designs improve the ability of BRPs to intensify their portfolio balancing efforts in a system with separate positions and the larger imbalance costs that this effectuates. Also, the impact of separate balances is lower for large BRPs[13]. Finally, in small power systems, there may be less point in adopting separate positions for reasons of non-discrimination or transparency. However, internal balancing may have a larger adverse effect in small power systems, which could make separate positions more useful.

For this design variable, it is hard to come up with a general 'best value'. What can be said is that separate positions for production and consumption are more suitable in case more accurate production and consumption schedules are required for system operation, non-discriminatory conditions for small market participants are strived for, and/or internal balancing is problematic. In the absence of such reasons, we tend to value a net position higher, because the evening out of production and consumption imbalances bring about lower imbalance volumes. Besides, it is not unthinkable that the lower balancing incentives actually reduce the degree of internal balancing. Apart from that, we mention again that internal balancing can be made unattractive by specific pricing regimes (see below).

Activation strategy : Two aspects of the strategy applied by the System Operator in the activation of balancing services bids are the order of activation and the time of activation. With regard to the order of activation

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[12] Actually, adverse BRP regulation will occur in less than half of the cases, because the majority of BRP imbalances will have contributed to the system imbalance being in a certain direction.

[13] If large BRPs have both a lot of production and consumption in their portfolio, the introduction of separate positions has a smaller effect.

of reserve capacity bids, bids are principally selected on the basis of the stated capacity bid price, but grid location, technical capabilities (notably the regulation speed) and energy price (in case this is specified), can also be selection criteria. After all, procured reserve capacity that is in an often-congested area or is slow is less useful to the System Operator. It is desirable to procure reserves from different parts of the power system to improve availability. Also, the procurement of quick resources may reduce the amount of both procured reserve capacity and dispatched balancing energy. Furthermore, if energy prices are indicated in the capacity bids, the selection of reserves that have a very low energy price but are out of merit order (i.e., price order) in the reserve capacity bid ladder could lead to the lowest overall balancing service costs. Therefore, there can be both economic and technical reasons to deviate from merit order in the reserve capacity market. However, it depends on the degrees of freedom of the System Operator what activation strategies he can adopt. With regard to the balancing energy market, activation of balancing energy bids that do not correspond with resources behind a congested border is a necessity. The activation of quick resources might be required in case of sharp and large frequency disturbances, or to maintain balance quality. With regard to the time of activation, a proactive balancing strategy of the SO, in which the SO proactively activates energy bids to anticipate on expected system imbalance fluctuations, could lead to lower activated balancing energy volumes and the use of slower but cheaper balancing resources (Replacement Reserves). On the other hand, a reactive strategy in which the SO activates as a response to the actual system imbalance could turn out to lead to a much lower activation of balancing energy services without a large drop in balance quality. The effects on activated volumes depend among others on the variability of production and consumption in the power system, and on the exact algorithm applied by the System Operator to calculate the control signal used in the LFC system based on the Area Control Error[14]. Considering all these aspects of the activation strategy, this variable is estimated to have a very large effect on the availability of balancing resources and on balance quality. The more the SO deviates from activation in merit order, the lower the utilization efficiency will be (unless congestions make this unavoidable), so this performance criterion may also be significantly affected. Also, the activation strategy may increase the ability of some Balancing Service Providers with quick or well-located resources to exercise market power. Therefore, an effect on price efficiency could materialize. Furthermore, the deviation from merit order activation will reduce transparency of balancing service procurement and dispatch, and could perhaps be regarded as discrimination on the basis of regulation speed or grid location.

The availability of balancing resources and the balance quality in a power system with unpredictable generation and consumption could be improved by the procurement of quicker balancing resources, and by prioritized activation of quicker resources in real-time. A proactive activation of balancing energy would probably have a larger effect, in case the System Operator has sufficiently reliable forecasts of power imbalances. In addition, if the amount of flexible resources is scarce, it is relatively more important for the SO to secure their availability for system balancing by contracting these resources. Subsequently, if the Balance Responsible Parties have more opportunities to balance their portfolio, the availability of resources will be less jeopardized, reducing the need for a prioritization of quick balancing resources. Thus, short-term market designs, short-term market liquidity and the size of BRPs influence the effects. Finally, the availability of transmission capacity in the system has a very large effect on the need to select balancing services on the basis of grid location.

Clearly, the selection of the reserve capacity and balancing energy bids with the lowest bid prices is best from an economic point of view, but depending on the need for quick or well-located balancing resources called for by the technical state of the power system, large deviations from merit order activation could be needed to maintain security of supply. In case the System Operator is balance responsible for intermittent generation, or if separate positions for production and consumption are applied, there is an absence of portfolio balancing that may force the SO to adopt a proactive balancing strategy.

Balancing service pricing mechanisms : The choice for a balancing service pricing mechanism to remunerate selected reserve capacity and balancing energy bids in markets for Frequency Containment Reserves, Frequency Restoration Reserves and Replacement Reserves has an impact on the bidding behaviour of Balancing Service Providers that is difficult to extract. Especially the difference in impact between the two main options of marginal pricing (also called uniform pricing) and pay-as-bid pricing (also called discriminatory pricing) is relevant to consider here. In a survey of agent-based simulation studies of electricity markets, Weidlich and Veit (2008) find that marginal and pay-as-bid pricing have been compared in several studies, with generally the same outcome: Market parties submit higher bid prices under pay-as-bid pricing, but the overall prices are (somewhat) higher under marginal pricing. This outcome can be explained by the fact that under pay-as-bid pricing market parties try to bid near the price of the last selected bid, while the payment of submitted bid prices creates a lower average market price than the price of the last selected bid under marginal pricing. Cramton and Stoft (2007) tell

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[14] This control signal represents the instantaneous activation of balancing energy services in Megawatts.

a different story: They write that the theoretical answer to which pricing mechanism is better depends on the particulars of the model used, but that in the simplest cases the effects on prices are the same. Moreover, they note that empirical evidence confirms these findings, and show that the differences are 'typically small and often insignificant' (Cramton and Stoft, 2007). Also, the fact that marginal pricing and pay-as-bid pricing are used in European countries about equally frequently in secondary and tertiary control energy markets (ENTSO-E, 2011a), indicates that there is at least no clear generally superior pricing mechanism. It is hard to evaluate (without analysis) to what extent the typical market phenomena of the balancing energy market, namely a small but very volatile and unpredictable demand from a single buyer that will pay any price (unless there is a price limit) and limited supply and a steep supply curve, would change the difference in performance of these two pricing mechanisms. In our view, the high price level and uncertainty, in combination with the balancing energy market being the last market to earn some money with, create a good chance that marginal pricing leads to lower balancing energy costs. Of course, the specific volumes and costs of offered balancing services and the system imbalance pattern will have a large impact. Indeed, considering that empirical observations mentioned by (Cramton and Stoft, 2007) show an insignificant difference, the question which pricing mechanism leads to the lowest balancing energy prices could very well depend on the context. However, there are some considerations of effects on performance criteria, which are in favour of marginal pricing. First of all, marginal pricing gives a better incentive to BSPs to bid at marginal costs, which will improve price efficiency. Second, because with pay-as-bid pricing BSPs are incentivized to bid close to the regulation price, which in case of the balancing energy market is particularly difficult, the bids with the lowest bid prices may not correspond with the balancing resources with the lowest operating costs, creating dispatch inefficiencies (Cramton and Stoft, 2007). This will reduce the utilization efficiency. Third, pay-as-bid pricing favours large market parties, which have an information advantage on prices thanks to the ability to submit multiple bids, and a higher budget for price forecasting (Bower and Bunn, 2000; Cramton and Stoft, 2007). Thus, there is discrimination against small players for pay-as-bid pricing. Fourth, marginal pricing will create a higher transparency of prices and money involved in the balancing energy market. A last important reason specific for the balancing energy market is that the use of pay-as-bid pricing results in balancing energy rewards that always differ from imbalance penalties. Typically, as the imbalance price will become the weighted average of the bid prices of selected bids, half of the paid bid prices will be lower than the imbalance price, and half will be higher. This has two negative effects on balancing market performance. Most importantly, market parties that are both BRP and BSP may get incentives to not deliver requested balancing energy (in case the imbalance price is lower than their bid price, and activation is automatically rewarded), and incentives to keep flexible resources for internal balancing (in case the imbalance price is higher than their bid price). This may have large effects on availability of balancing resources and utilization efficiency. The other effect is that the balancing energy costs are less efficiently allocated to Balance Responsible Parties, resulting in larger and more volatile net settlement sums, reducing the cost allocation efficiency. The above consideration was directed to the balancing energy market. The reserve capacity market has a very different nature. Importantly, the demand is larger, fixed for longer periods and there is no close interaction with imbalance settlement. The special feature of reserve capacity is that the costs are not operational, but are the opportunity costs of not being able to trade in the electricity market. Again, it is hard to evaluate qualitatively whether these particular features and conditions favour marginal or pay-as-bid pricing. Fact is that a large majority of European countries has adopted pay-as-bid pricing for reserve capacity markets (ENTSO-E, 2011a), which suggests it does result in lower reserve capacity costs. Also the consideration above appears to apply to a lesser degree to reserve capacity. Subsequently, regulated pricing is a third option, but this one will substantially distort the incentives to BSPs and (indirectly) BRPs in the balancing market. It can cause a large reduction in the offered amounts of balancing services, and significantly reduce cost allocation efficiency and balance planning accuracy, because BSPs may not recover their costs, while BRPs do not receive incentives proportional to the actual balancing costs. What is more, these effects could deteriorate in case regulated pricing is combined with a bid obligation (as covered by the design variable of methods of procurement).

As discussed above, it is hard to tell what the impact is of the amount and technical characteristics of flexible resources in the power system on the difference in effect between pay-as-bid pricing and marginal pricing in balancing service markets. It has at least the potential to have a large impact on this difference. If balancing resources are scarce, however, applying marginal pricing in the balancing market may be very useful in order to prevent internal balancing and non-delivery[15]. Limited transmission capacity could necessitate marginal pricing for the same reason, if it poses balancing resource availability problems. If there are large Balancing Service Providers in the market, the competitive advantage of these parties under the pay-as-bid pricing regime is higher, which makes the adoption of marginal pricing more desirable from the perspective of non-discrimination.

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[15] If the BSP can foresee that the imbalance price will be lower than its operating costs, and the BSP automatically receives the regulation price upon activation, he can profit from not delivering the balancing energy.

Viewing the discussion above of using marginal pricing or pay-as-bid pricing in balancing service markets, marginal pricing appears to be the best pricing regime for balancing energy markets. For reserve capacity markets, above considerations are less applicable, which leads us to conclude here that the best pricing regime for these markets depends on the specific market conditions.

Control system : The control system that is used to activate Frequency Restoration Reserves (FRR) and Replacement Reserves (RR) is a design variable that is closely linked to the design variables of service classes. After all, as FRR is defined in Europe as a centralized automatic service that is activated to remove the Area Control Error (ACE) within 15 minutes (replacing FCR), the System Operator requires a central Load-Frequency Control (LFC) system to automatically activate FRR energy bids. RR energy is typically activated manually, although in coordination with FRR activation. The main balancing market design choice is here between manual FRR and automatic FRR[16]. The Nordic region is an example of a system that has until today not made use of automatic FRR and therefore has not developed and used a LFC system for activation of balancing energy. However, this is under development right now (Svenska Kraftnät and Statnett, 2010). Besides this, it might be considered to introduce different control systems for different zones in the power system, in order to better deal with frequent congestions between zones. However, that would actually mean a splitting up of the balancing market into multiple ones, and the splitting up into multiple control areas, which will be covered by the design variable of control area boundaries. Noticing that the choice between automatic or manual FRR is already covered by the design variable of service classes, we should consider here what the impact is of not using a LFC system while being supplied with automatic FRR, or vice versa. In the first case, the replacement of control signals sent by a LFC system with phone calls to activate automatic FRR causes a delay in their activation, which has a very large effect on balance quality. In the second case, the LFC system is useless, and will only have caused significant implementation costs.

Depending on the need for fast balancing energy dispatch, thus on the presence of a high share of unpredictable and volatile loads and generation units, the severity of the absence of a LFC system that can activate FRR energy automatically will vary. Of course, the presence of generation and load resources supplied with controllers that can receive and react on signals from a LFC system is very important for the impact of the introduction of a LFC system on balance quality.

An LFC system is generally is generally best for balance quality in power systems with significant and volatile frequency deviations. With the on-going trade of a growing wind power share in power systems, a LFC system can even become indispensable. In systems with few and low frequency disturbances, A LFC system could still be preferable to maximize balance quality. In any case, the choice is dependent on the used service class definitions.

Bid requirements : The balancing service bid requirements may include specifications about bid price, volume, grid location, regulating speed, response speed, activation time, activation duration, method of activation (automatic or manual), divisibility of the bids, relevant BRP, and possibly more. Each of these has a different effect on the bidding behaviour of Balancing Service Providers, and thereby on balancing market performance. First, price limits could reduce the amount of resources that can be profitably offered in the balancing service market. Second, bid volume limitations could limit the amount of offered balancing resources (in case of a lower limit), but a positive effect could be the increase in competition, enlarging the price efficiency. Another effect could take place on balance quality, if the activation of many small bids reduces the effectiveness of frequency control, compared to a few large bids. Third, the requirement to specify the grid location is necessary for the SO to know what balancing services are available in case of congestions, which may increase the balance quality and utilization efficiency thanks to more efficient activation[17]. Fourth, the requirement to specify the regulating and response speed enable the SO to select quicker balancing service if technically necessary, improving balance quality at the expense of utilization efficiency. If there are lower limits to these speeds for balancing services, the availability of resources could decrease to a very large extent, and in turn price efficiency too. Fifth, the activation time, i.e. the time at which the balancing energy bid should be fully activated, is actually known when response speed and regulating speed (in % per minute) are known, and thus it has the same effects as those specifications. Sixth, the activation duration, i.e. the minimum time the balancing energy bid must be able

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[16] Some references consider the absence of automatic centralized balancing services as an absence of FRR, which is due to the service class definitions they have formulated. Our definitions are based on function rather than activation method (see subsection 3.1.1).

[17] The procurement of reserve capacity from different power system zones is an issue that falls under the design variable of reserve requirements.

to operate, will improve the balance quality at the expense at the availability of resources. Seventh, the specification of the method of activation and the relevant BRP are just needed information for the SO to properly activate balancing energy services, and adapt the energy schedule and/or penalize non-delivery after activation. Eighth, the requirement that balancing energy bids are divisible may reduce the offering of bids, but improve the balance quality and utilization efficiency because of more precise activation of balancing energy according to the needs. Finally, a general effect of restrictive bid requirements is the introduction of discrimination between BSPs/resources based on specifications. Operational efficiency and transparency are not noticeably influenced by changes in bid requirements.

The effects of bid requirements are influenced by the technical capabilities of flexible generation units and loads in the power system, because these determine to what extent specific bid requirements limit the possibilities for Balancing Service Providers to offer balancing services to the System Operator. Furthermore, the existence of a lot of transmission capacity bottlenecks makes it more important to know about the (exact) grid location. Also, the presence of a small number of BSPs will improve the value of relieving the bid requirements to attract new providers.

From the perspective of non-discrimination and the availability of balancing resources, as few restrictive bid requirements as possible is most beneficial. However, due to large frequency stability problems specifications on response speed, regulating speed, activation time, and activation duration may be necessary. Bid price limits distort the incentive compatibility apart from the other negative effects mentioned above, and should be foregone unless to prevent serious market power abuse. A lower volume limit is advantageous from a security of supply perspective, and a higher volume limit from an economic efficiency perspective. The divisibility of bids should be made possible, but not compulsory to BSPs in case this reduces the possibilities to offer.

Imbalance pricing mechanism : The impact of the imbalance pricing mechanism has been analysed by means of an agent-based-simulation, as described in subsection 4.4.3. Included in the analysis were the most important options, i.e. single pricing, dual pricing, two-price settlement, and additive component, and pricing based on the total regulation costs. It was concluded that the imbalance pricing mechanism has a larger impact on the actual imbalance costs paid by Balance Responsible Parties than on their intentional imbalance strategies, because the different mechanisms all give the general incentive to be 'long', and to have as small imbalance. Here, the general incentive to be 'long' was caused by the up-regulation bid prices having a higher mark-up (compared to the day-ahead market price) than the down-regulation prices. A detailed look at the different imbalance pricing mechanisms reveals some further differences effects on balancing market performance criteria. First, single pricing has led to the lowest actual imbalance costs, reflecting that this mechanism results in the highest cost allocation efficiency. This mechanism is the only one in which BRPs can make a profit from being in the right direction. A concern could be that the low balance planning accuracy caused by weak incentives to balance result in higher real-time system imbalances, reducing the availability of balancing resources. Providing real-time information to the BRPs will enable them to balance passively, which could contribute significantly to real-time system balancing (TenneT et al., 2011), and would form a sort of competition with balancing energy services offered to the SO [18]. This has the potential to improve balance planning accuracy, price efficiency and utilization efficiency. The latter could be improved as a consequence of a reduced BRP portfolio balancing in the direction opposite to the main regulation direction. However, we may wonder to which level BRPs are both capable and willing to balance passively, also given that the offering of balancing energy services will generate the same profits (if marginal pricing is used as the regulation pricing mechanism) without any risk of wrong forecasting of the imbalance price. Another effect of single pricing 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 (Energinet.dk, 2009), which happens more often for small BRPs. Furthermore, if pay-as-bid pricing is used as the regulation pricing mechanism, the single imbalance price can be based on only the costs of regulation in the main direction, or total regulation costs. This could create unpredictable imbalance prices and inappropriate balancing incentives, however. Second, dual pricing (short imbalance price is the up-regulation price, and vice versa) always generates a cost for BRP imbalances in both directions. This will cause high incentives to balance BRP portfolios, improving balance planning accuracy. This is probably at the expense of utilization efficiency, because BRPs will also spend money to remove imbalances that would have helped to balance the system. As discussed before, the effects on availability of balancing resources is not that clear, because the portfolio balancing by BRPs is likely to commit balancing resources, while the demand for balancing energy is reduced at the same time. Finally, the net settlement sum becomes very high, significantly reducing cost allocation efficiency. Third, two-price settlement (imbalance price for direction helping the system is equal to the day-ahead price)

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[18] F. A. Nobel (TenneT), personal communication, July 2011.

only gives an incentive to prevent BRP imbalances that add to the system imbalance. The result is lower imbalance costs compared to dual pricing, but still a large incentive to balance, without the stimulation of passive balancing of single pricing. Therefore, effects are sort-of in-between single and dual pricing. Fourth, additive components will, depending on the size of the component, result in a weak form of dual pricing. If the additive component is not fixed and hard to predict, it will cause additional uncertainties for BRPs, which might lead to a degree of BRP portfolio balancing that approaches dual pricing. Fifth, imbalance price caps and regulated imbalance prices will distort the incentives for BRPs to balance their portfolio, which may have negative effects on balance planning accuracy, availability of balancing resources and utilization efficiency. This holds especially for regulated imbalance pricing, if this results in imbalance prices that deviate significantly from regulation prices. On the other hand, price caps could reduce the financial risks for BRPs, reducing excessive portfolio balancing and thus improving utilization efficiency. Sixth, different imbalance prices can be applied to production and consumption, if separate positions for production and consumption are applied (see the design variable of net vs. separate positions). This is used in the Nordic region, where two-price settlement is applied to production, and single pricing to consumption. The idea behind this regime is that production is incentivized to stick to their generation schedules, which is important in the Nordic region for effective congestion management, while reducing the imbalance costs and entry barriers for market parties representing consumption. Seventh, different imbalance pricing mechanisms can be applied to different ‘regulation states’ (balancing energy dispatch patterns) or security definitions (e.g. activation of emergency power). This can be useful in order to give stronger incentives in periods where the effectiveness of real-time system balancing is jeopardized. On overall, we find that there are numerous imbalance pricing mechanisms which have significant effects on balancing market performance. Different mechanisms bring about different incentive intensities, resulting in different results of the general trade-off between balance planning accuracy and utilization efficiency. Finally, it is found that imbalance prices higher than regulation prices stimulate market parties to keep balancing resources for internal balancing, whereas imbalance prices lower than regulation prices may stimulate BRPs to not deliver the balancing energy called by the SO[19]. Therefore, imbalance prices should be equal to regulation prices (balancing energy bid price of last activated bid in main/both direction(s)).

The impact of the imbalance pricing mechanism is influenced by the predictability and volatility of generation and consumption in the power system, because this determines the frequency control problems in the power systems. If these problems are higher, it is more important to incentivize BRPs to balance their portfolio. An imbalance pricing mechanism that gives strong incentives is more useful in this case, because balance planning accuracy (security of supply) will have become more relevant compared to utilization efficiency. As with earlier variables related to balance planning and settlement, the short-term market design, short-term market liquidity and the size of BRPs influence the abilities of BRPs to balance their portfolio, and thereby the actual impact of applying an imbalance pricing mechanism that gives stronger incentives. As mentioned above, single pricing favours small BRPs, and is therefore more advantageous if there are small BRPs next to large ones.

In the agent-based simulation of the imbalance pricing mechanism described above, single pricing came out as the pricing regime leading to the lowest actual imbalance costs for Balance Responsible Parties. For the reason of cost allocation efficiency, this regime could be best, on the condition that balance planning accuracy is not affected too much. This does not need to be a concern, because BRPs will still benefit from portfolio balancing: It creates lower imbalance cost cash flows and corresponding financial uncertainty, and especially large BRPs will more often have an imbalance in the wrong direction than in the right one. Apart from this, single pricing will also lead to the highest utilization efficiency and non-discrimination. However, high system imbalance problems (or congestion management problems) might put forward the need for a mechanism that provides stronger incentives to BRPs. Depending on the size of the problems, different mechanisms could be applied. Moreover, different mechanisms could be combined to optimize incentives given the state of security of supply. The principle should be here: The incentives should be as weak as possible to safeguard operational security of supply. This is in order to keep internal balancing within limits, and reduce utilization efficiency not more than necessary. The first mechanism to consider here appears to be the use of a small additive component for Schedule Time Units with high security threats, as in other STUs single pricing could still be applied.

Ex-post trading : Ex-post trading, i.e. the trading of ‘imbalance energy’ between BRPs after real-time in order to mutually reduce their imbalance volumes, will generally reduce the imbalance costs and the financial

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[19] Actually, this is the case when imbalance prices are lower than the operating costs of the balancing resource, but this cannot be the case when imbalance prices are equal to regulation prices. If imbalance prices are lower than regulation prices, it is possible that imbalance prices are below the operating costs of (some of) activated balancing energy services.

risks of imbalance settlement for Balance Responsible Parties. Because BRPs can make long-term arrangements to 'net imbalance energy' between each other at a predetermined price, the financial risks can be reduced to a large extent. In case of imbalance pricing mechanisms that result in high imbalance prices, such as dual pricing, the possibility of ex-post trading will have a large positive effect on cost allocation efficiency. With regard to the balance management activities of the System Operator, this arrangement probably causes the submission of more adapted energy schedules, but not any new administrative tasks. The BRPs will have an additional activity of trading imbalances, but this will reduce their imbalance costs. A negative effect of ex-post trading may be the reduction in balance planning accuracy caused by the lower imbalance costs. However, not all BRP imbalances can be 'traded away' (otherwise there would not have been a system imbalance), and long-term contractual arrangements and bilateral ex-post trading will only be partly effective. After all, if BRPs want to remove their imbalance volume, they need to find a counterparty with an opposite imbalance of the same size, which could prove to be quite hard.

The effect of ex-post trading on the imbalance costs of BRPs will be higher when these costs are on a higher level, which may be caused by unpredictable generation and consumption, a bad short-term market design, illiquid short-term markets, or an electricity market with small BRPs.

Ex-post trading appears to be a no-regret design option that will be especially useful if BRPs are faced with high imbalance costs. However, one should be aware that it will reduce the incentives for portfolio balancing, and could thereby weaken the effect of a 'strong' imbalance pricing mechanism that was intended to reduce the operational security problems.

Penalty for non-delivery : In balancing markets, the automatic rewarding of activated balancing energy, combined with an adaptation of the corresponding energy schedules, is a simple arrangement. It works well in balancing markets where imbalance prices are equal to regulation prices, because imbalance prices (the costs of not delivering) will then be higher than the operating costs (the prevented costs by not delivering). After all, because all BSPs bid higher than their operating costs, the regulation price must be higher than the operating costs of all selected balancing resources, and thus the imbalance price must be higher than the operating costs too. However, if imbalance prices often become lower than the operating costs of balancing energy dispatch, BSPs have an incentive to not deliver the activated balancing energy. This could be the case for BSPs on the right side of the selected part of the balancing energy bid ladder in a pay-as-bid pricing regime. In addition, it may occur with BSPs involved in cross-border balancing, particularly when excess bids are traded cross-border. This is because the operating costs of balancing energy bids 'out of national merit order' could very well be higher than the national imbalance price paid in case of non-delivery. These problems could be dealt with by the introduction of a penalty for non-delivery. However, this requires the real-time measurement and monitoring of the output of activated balancing resources, in order to check whether activated balancing energy is really dispatched. The monitoring of actual dispatch may not only be technically challenging, but also forms an additional balance management expenditure for the System Operator (cf. Lampropoulos et al. (2012)). In case of the exchange of some specific balancing resources, however, the monitoring could be limited to these resources. Furthermore, the penalty itself could take different forms. It could be a huge discouraging penalty, or set as the difference between operating costs and imbalance price in order to take away the incentive to not deliver. It could also be that the balancing energy payments are only made after actual delivery has been checked, which would mean a high penalty equal to the regulation price. In any case, the use of a penalty for non-delivery also requires an extension of the settlement process, adding further to the implementation costs. Also, the monitoring and settlement processes mean a reduction of operational efficiency. Still, if large non-delivery problems are solved by this design option, balance quality, availability of balancing resources, balance planning accuracy and cost allocation efficiency could be improved significantly.

Power system and electricity market-related contextual factors have no clear influence on the usefulness of a penalty for non-delivery; this is first and foremost determined by the applied pricing mechanisms and cross-border balancing arrangements. The only contextual factor that comes to mind here is the number and size of BSPs: If there are many small BSPs, the market power of BSPs and the ability to predict imbalance prices will be lower, which may limit the ability to exploit a profit-making potential of non-delivery.

Considering the high implementation costs, the prevention of adverse non-delivery incentives by careful design regulation pricing mechanisms, imbalance pricing mechanisms and pricing of exchanged balancing energy bids appears much better than the cure of a monitoring system and a penalty for non-delivery.

National design variables with a low impact

BRP accreditation requirements : The BRP accreditation requirements could concern a certain financial security (to have some certainty that the party is able to pay imbalance costs in time), and the technical capability to exchange information with the SO in the right data format and in a timely fashion. If the requirements are too strict, it is an barrier for small parties to enter the electricity market as a Balance Responsible Party. Of course, he can shift the balance responsibility to a registered BRP, but that would mean it cannot trade in the electricity market independently. If the accreditation requirements are too loose, BRPs may fail to submit schedules, or fail to pay imbalance costs. The first could lead to incomplete information on planned power injections and withdrawals, which could threaten the effectiveness of the SO to manage congestions and the system balance. The second failure could result in money lending by the SO to pay BSPs, and in case of permanent failure to pay the socialization of the involved imbalance costs. Thus, non-discrimination could be affected if the BRP accreditation requirements are too strict, and balance planning accuracy and cost allocation efficiency could be affected if they are too loose.

The presence of a lot of unpredictable generation and consumption resources in the system makes it more important to receive energy schedules in time, so strict requirements regarding energy schedule submission is more useful here. The same holds for limited transmission capacity and the frequent occurrence of congestions. If there are a lot of large BRPs, it may be more useful to reduce the market entry barriers by relaxing the BRP accreditation requirements.

The BRP accreditation requirements should be strict enough to be certain that Balance Responsible Parties are able to submit energy schedules and pay imbalance costs in time, but not stricter than that, in order to minimize the barriers to enter the electricity market.

Initial gate closure time : The time at which BRPs should submit an initial energy schedule to the SO can serve two goals. First, it may provide the System Operator with information on scheduled energy injections and withdrawals on the day before delivery, so that it can effectively manage congestions and plan for a system balance. Second, it ensures that balancing costs can be allocated to BRPs, giving them at the same time the incentive to follow up their schedules. The first goal is by far most important. The importance depends on the relevance of the schedule information for congestion and balance management in the period from the day-before delivery up to final gate closure time. In the Netherlands, energy schedules do not contain information regarding transport flows; these are notified by means of separate 'transport prognoses'. This is corresponds with the existence of a meshed and redundant national power grid in which congestions do not often occur. The opposite situation exists in Norway. There, production schedules provide crucial information to the SO to manage congestions in a network divided up into several zones between which transmission bottlenecks exist[20]. Thus, the use of an initial gate closure time on the day before delivery can be crucial. Regarding the impact on performance criteria, this means that the availability of balancing resources can be significantly affected. This is because inefficient congestion management will require the use of more balancing resources for redispatch, and reduce the availability of balancing resources in frequently congested zones. As a result, price efficiency can be affected as well. The use of an initial gate closure in addition to a final gate closure might reduce the operational efficiency, but not in a power system where a day-ahead notification of transport flows is indispensable.

As follows from the above, the transmission capacity is an important contextual factor influencing the impact of this design variable, although the energy schedules do not need to be the means of communication of transmission flows. The gate closure time of the day-ahead market has an impact, because the most logical time for initial gate closure (for energy schedules) is right after the closure of the day-ahead market: Concluded trade transactions on that market will have a large impact on the infeeds and offtakes planned by BRPs. Other contextual factors do not appear to have a significant impact.

An initial gate closure time on the day before delivery looks like another no-regret option, which may reduce the concerns of BRPs not meeting up to their tasks (which might enable a reduction in the strictness of BRP accreditation requirements), and could be valuable as a means to inform the System Operator about energy injections and withdrawals on the day before delivery. As said above, the most logical time is right after the closure of the day-ahead market.

BSP accreditation requirements : The BSP accreditation requirements will not so much relate to the final security situation of BSPs (as with BRP accreditation requirements), because BSPs are the parties that receive money, and because the balancing energy payments may be made via the corresponding Balance Responsible

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[20] This is also enabled by the need to submit schedules for individual power plants, a form of nodal balancing. This gives much more detailed information about the power flows to be expected, as production companies have much less degrees of freedom in dispatch.

Party. The capability to submit sound balancing service bids in time is a more relevant requirement. This requirement will not pose a large challenge for small players, and certainty with regard to the availability of balancing energy bids is already obtained through reserve capacity procurement. Most important, however, are the pre-qualification of balancing resources. Balancing Service Providers usually need to get their balancing resource(s) pre-qualified by the System Operator, so that he can be sure that the obtained balancing services meet the bid requirements, and therewith have the desired technical capabilities for frequency control. Needless to say that these pre-qualification requirements are important for ensuring the availability of balancing resources and balance quality. Furthermore, too high accreditation requirements may unnecessarily prohibit small parties to become a BSP, affecting non-discrimination.

The use of prequalification requirements is relatively more important in power systems with high frequency stability problems due to unpredictable and volatile generation and/or consumption. In case there are large BSPs in the market, relaxing the BSP accreditation requirements will probably have a higher impact on non-discrimination, competition in balancing service markets, and resulting price efficiency. It could also improve utilization efficiency, if the newly entered bidders own balancing resources that were previously not or only internally utilized.

The use of pre-qualification requirements appears a necessary design choice to ensure operational security of supply. However, BSPs will usually not submit balancing service bids if they cannot deliver the desired services (as stipulated in the bid requirements). Furthermore, if there is a high margin between offered and demanded balancing services, such requirements may not be necessary.

Allocation of net settlement sum : Ideally, the net settlement sum, i.e. the net sum remaining after both balancing energy settlement and imbalance settlement is zero. There are various reason why this is not the case. Especially if imbalance prices deviate from regulation prices, high net settlement sums may emerge. Typically, the net settlement sum is a positive sum, because the total imbalance costs are higher than the total balancing energy payments. This is particularly true when dual pricing or additive components are used in the imbalance pricing mechanism, as opposite BRP imbalances that do not require balancing energy dispatch will still result in a net imbalance costs cash flow from BRPs to the SO. The main cost allocation methods are through the system services tariff, through imbalance prices, through a separate fee to BRPs, or the redistribution to other SO tasks. First and foremost, the allocation method has an impact on the efficiency of allocation of imbalance and balancing energy costs, and therefore on cost allocation efficiency. From this perspective, redistribution to other SO tasks is the worst option, because money will then probably flow out of the balancing market. The adaptation of imbalance prices will redistribute imbalance costs back to BRPs, but incentive compatibility is affected by this, reducing the economic efficiency of portfolio balancing by BRPs and real-time system balancing. The fairest option appears to be a separate fee to BRPs, so that the surplus costs paid by BRPs are given back the BRPs. There are different distribution methods, but a redistribution proportional to BRP imbalance volume looks like the fairest option. A redistribution based on BRP size may also give good results, while much easier to execute. The allocation method of the adaptation of the system services tariff is the simplest method, with the lowest administrative costs, but redistributes the net settlement sum to grid users instead of Balance Responsible Parties. If only consumers pay the system tariff, the consequence is that especially BRPs representing production will be financially damaged. The transparency of this last method is higher than e.g. a complicated fee structure.

The use of an allocation method with a high cost allocation efficiency is more important when net settlement sums are higher. As said, the level of the net settlement sum is significantly influenced by the imbalance pricing mechanism, but there is no obvious reason why it would be affected by one of the contextual factors.

To maximize cost allocation efficiency a separate fee structure where the net settlement is redistributed periodically proportional to imbalance volumes appears the best design choice. It requires that the imbalance volumes of all BRPs are stored for the length of the redistribution period, and then the calculation of individual fees to BRPs. The lower operational efficiency and transparency of this method compared to the adaptation of the system services tariff is estimated to be of lower weight than the higher cost allocation efficiency.

Timing of settlement : The frequency of imbalance settlement, i.e. the actual financial transaction between BRP and SO, has an impact on the dynamic development of the cash balance of Balance Responsible Parties. However, the net imbalance costs payments should in the end be the same. There is no obvious reason why the frequency of settlement would have a noticeable impact on financial risks of BRPs. A high frequency means small payment values, while a low frequency results in more stable values. Therefore, this design variable appears to have no clear impact on BRP behaviour. However, if the settlement would take place separately for each Schedule Time Unit, this would create significant additional transaction costs, compared to e.g. a weekly settlement. Furthermore, a too high frequency could be considered to reduce cost allocation efficiency, because costs not allocated efficiently in terms of speed, which might cause some cash problems for both the SO and market parties. On the other hand if the frequency is on the high side, BRPs and BSPs will 'feel' the effects of their behaviour less, and with a larger time delay. In that sense, a high frequency of settlement might help to improve the incentive compatibility of both BRPs and BSPs, possibly improving utilization efficiency.

In power systems with small BRPs and BSPs, the application of a too high frequency of settlement may cause high transaction costs and financial risks for them, increasing the barriers to entry. But a too low frequency of settlement could also be relatively more harmful for small balancing market parties, because they do not have the liquidity to deal with delays in payments or to pay large sums.

In view of the above, the frequency of settlement should be lower than on a STU basis but higher than on a yearly basis. For the reason of cost allocation efficiency and utilization efficiency, daily settlement might be considered 'best', but it is unclear if benefits actually exist compared to weekly or even monthly settlement, which generate lower administrative costs. A daily settlement might be impractical if invoices are sent by postal mail, though. Also, if BRPs have a term of several days to pay, the actual money flows might end up to be the same as in the weekly settlement arrangement.

Table H.1 – Multi-criteria analysis results: Estimated effects of national balancing market design variables with a high impact

	Range of effects of different variable values on performance criteria	**Influence of contextual factors**	**'Best' variable value**
Schedule Time Unit	*Avail. of bal. res.*: unclear *Bal. plan. acc.*: very large *Price efficiency*: unclear *Utilization eff.*: large *Operational eff.*: large *Int. costs*: small	*Generation portfolio*: large *Consumption portfolio*: large *Short-term market design*: large *BRP size*: small	In range 15-60 minutes; optimum depends on system imbalance patterns and short-term market design.
Service classes	*Avail. of bal. res.*: very large *Balance quality*: large *Price efficiency*: large *Utilization eff.*: moderate *Operational eff.*: moderate *Transparency*: moderate *Int. costs*: large	*Generation portfolio*: large *Consumption portfolio*: large *Number of BSPs*: moderate *Strategy of BSPs*: moderate	Distinction FCR, FRR and RR. Three service classes. Need for automatic FRR increases with larger frequency disturbances.
Zonal vs. nodal responsibility	*Avail. of bal. res.*: moderate *Balance plan. acc.*: very large *Price efficiency*: moderate *Utilization eff.*: moderate *Operational eff.*: large *Transparency*: moderate *Int. costs*: small	*Transmission capacity*: large *Short-term market design*: large *Short-term market liquidity*: large (*BRP size*: affected by variable)	Nodal balancing in congested systems; control area balancing or nodal balancing in uncongested systems.
Reserve requirements	*Avail. of bal. res.*: very large *Balance quality*: large *Price efficiency*: unclear *Utilization eff.*: small *Transparency*: small	*Power system size*: very large *Generation portfolio*: large *Consumption portfolio*: large *Transmission capacity*: large *Interconnection capacity*: moderate	Requirements depend on technical contextual factors. Procurement of reserve capacity at least equal to largest generation unit.
Methods of procurement	*Avail. of bal. res.*: large *Balance quality*: large *Price efficiency*: large *Utilization eff.*: moderate *Operational eff.*: small *Non-discrimination*: small *Transparency*: small *Int. costs*: small	*Generation portfolio*: large *Consumption portfolio*: small *Number and size of BSPs*: large *Strategy of BSPs*: moderate	Tendering in markets. In case of endangered security of supply: An obligation to install controllers to provide balancing energy (combined with competitive pricing).
Timing of markets	*Avail. of bal. res.*: large *Price efficiency*: very large *Utilization eff.*: large *Operational eff.*: small *Int. costs*: small	*Generation portfolio*: moderate *Day-ahead market design*: moderate *Strategy of BSPs*: moderate	High reserve capacity market clearing frequency. If it does not endanger security: daily reserve capacity market, which clears after day-ahead market. Bid submission up to clearing time.
Allocation of reserve capacity costs	*Avail. of bal. res.*: small *Balance plan. acc.*: large *Balance quality*: moderate *Price efficiency*: very large *Utilization eff.*: very large *Cost all. eff.*: very large *Non-discrimination*: moderate *Transparency*: large *Int. costs*: small	*Generation portfolio*: moderate *Number and size of BRPs*: large *Strategy of BRPs*: moderate	Allocation by adaptation of system services tariff.
Allocation of balancing energy costs	*Avail. of bal. res.*: large *Balance plan. acc.*: very large *Price efficiency*: large *Cost all. eff.*: very large *Transparency*: moderate *Int. costs*: small	*Gen. & cons. portfolio*: large *Short-term market design*: large *Short-term market liquidity*: large *Number and size of BRPs*: moderate	Allocation to BRPs through imbalance settlement.

Table H.2 – Multi-criteria analysis results: Estimated effects of national balancing market design variables with a medium impact

	Range of effects of different variable values on performance criteria	**Influence of contextual factors**	**'Best' variable value**
Publication of national information	*Avail. of bal. res.*: moderate *Balance plan. acc.*: moderate *Balance quality*: moderate *Price efficiency*: moderate *Utilization eff.*: moderate *Transparency*: very large *Int. costs*: small	*Number of BSPs*: large	National website with all information and data combined. Real-time information for BRPs. If no gaming will arise: Information on bid ladder. Quick publication of prices after real-time.
Responsibility for renewable generation	*Avail. of bal. res.*: moderate *Balance plan. acc.*: large *Balance quality*: large *Utilization eff.*: large *Cost all. eff.*: very large *Operational eff.*: small *Non-discrimination*: very large *Transparency*: small *Int. costs*: moderate	*Generation portfolio*: very large *Short-term market design*: very large *Short-term market liquidity*: very large *Size of BRPs*: large	Full BRP responsibility. In case of unacceptably high imbalance costs for BRPs: separate BRP responsibility (subtractive component on imbalance price for renewable energy portfolios).
Final gate closure time	*Avail. of bal. res.*: large *Balance plan. acc.*: very large *Price efficiency*: large *Utilization eff.*: moderate	*Generation portfolio*: very large *Consumption portfolio*: very large (*Short-term market design*: affected by variable) *Size of BRPs*: moderate	Final gate closure as close to real-time as possible. 30 minutes ahead is an achievable value.
Net vs. separate positions	*Avail. of bal. res.*: small *Balance plan. acc.*: moderate *Balance quality*: small *Price efficiency*: small *Utilization eff.*: moderate *Operational eff.*: small *Non-discrimination*: moderate *Transparency*: moderate *Int. costs*: small	*Power system size*: moderate *Short-term market design*: small *Short-term market liquidity*: small *Transmission capacity*: large	Net position. In case of need for accurate schedules, non-discriminatory market conditions for small players or internal balancing problems: separate positions for production and consumption.
Activation strategy	*Avail. of bal. res.*: very large *Balance quality*: very large *Price efficiency*: moderate *Utilization eff.*: large *Non-discrimination*: moderate *Transparency*: moderate	*Gen. & cons. portfolio*: large *Short-term market design*: moderate *Short-term market liquidity*: moderate *Size of BRPs*: moderate *Transmission capacity*: very large	Selection of bids in price order, unless safeguarding of security of supply requires deviation from this. In case of SO responsibility for renewable generation or separate positions for production and consumption: proactive balancing strategy.
Balancing service pricing mechanisms	*Avail. of bal. res.*: large *Balance plan. acc.*: large *Balance quality*: moderate *Price efficiency*: large *Utilization eff.*: large *Cost all. eff.*: large *Non-discrimination*: large *Transparency*: moderate	*Generation portfolio*: large *Transmission capacity*: moderate *Size of BSPs*: large	Marginal pricing for balancing energy markets. Pricing mechanism for reserve capacity markets depends on specific market conditions.
Control system	*Balance quality*: very large *Int. costs*: large	*Generation portfolio*: very large *Consumption portfolio*: large	Depends on service classes. A LFC system improves balance quality, and becomes more valuable when frequency problems increase.
Bid requirements	*Avail. of bal. res.*: very large *Balance quality*: large *Price efficiency*: very large *Utilization eff.*: large *Non-discrimination*: very large	*Generation portfolio*: very large *Transmission capacity*: moderate *Number of BSPs*: large	As few requirements as possible. Large frequency problems: limits on speed/time/activation. Large market power abuse: bid price limits. Lower and higher volume limit. Option to specify that bid is divisible.
Imbalance pricing mechanism	*Avail. of bal. res.*: moderate *Balance plan. acc.*: large *Balance quality*: large *Price efficiency*: moderate *Utilization eff.*: moderate *Cost all. eff.*: large *Non-discrimination*: small	*Gen. & con. portfolio*: large *Short-term market design*: moderate *Short-term market liquidity*: moderate *Size of BRPs*: moderate	Single pricing. In case of security problems: an additive component for STUs with reduced system security. In case of strong security problems: two-price settlement.
Ex-post trading	*Balance plan. acc.*: moderate *Cost all. eff.*: large	*Gen. & con. portfolio*: moderate *Short-term market design*: moderate *Short-term market liquidity*: moderate *Size of BRPs*: moderate	The use of ex-post trading. In case ex-post trading interferes with imbalance pricing mechanism that must ensure system security: no ex-post trading.
Penalty for non-delivery	*Avail. of bal. res.*: moderate *Balance plan. acc.*: moderate *Balance quality*: moderate *Cost all. eff.*: moderate *Operational eff.*: large *Int. costs*: very large	*Number and size of BSPs*: moderate	No penalty for non-delivery.

Table H.3 – Multi-criteria analysis results: Estimated effects of national balancing market design variables with a low impact

	Range of effects of different variable values on performance criteria	**Influence of contextual factors**	**'Best' variable value**
BRP accreditation requirements	*Balance plan. acc.*: moderate *Cost all. eff.*: small *Non-discrimination*: small	*Gen. & con. portfolio*: moderate *Transmission capacity*: moderate *Size of BRPs*: small	As loose as possible, but strict enough to ensure schedule submission and imbalance costs payment.
Initial gate closure time	*Avail. of bal. res.*: large *Price efficiency*: moderate *Operational eff.*: small	*Transmission capacity*: large *Day-ahead market design*: large	Use of an initial gate closure time on the day before delivery, after closure of the day-ahead market.
BSP accreditation requirements	*Avail. of bal. res.*: large *Balance quality*: large *Price efficiency*: moderate *Utilization eff.*: moderate *Non-discrimination*: moderate	*Gen. & con. portfolio*: moderate *Size of BSPs*: moderate	Use of pre-qualification requirements, unless the availability of balancing resources and balance quality are sufficiently high.
Allocation of net settlement sum	*Utilization eff.*: small *Cost all. eff.*: large *Operational eff.*: small *Transparency*: small	No influence of contextual factors.	Allocation to BRPs with separate fees proportional to imbalance volumes.
Timing of settlement	*Utilization eff.*: small *Cost all. eff.*: small *Operational eff.*: small *Non-discrimination*: small	*Size of BRPs*: small *Size of BSPs*: small	Daily/weekly/monthly settlement, but unclear which one is better.

I Effect estimation of multinational design variables

In this appendix, the full qualitative evaluation of the effects of the multinational balancing market design variables on the performance criteria is given, the results of which are presented in section 5.2. The effect estimations are summarized in Table I.1, Table I.2 and Table I.3. The variables are ordered by the order of magnitude of importance found in section 4.2.

The estimation consists of the following three points: 1) Estimation of the impact level of individual design variables, 2) Estimation of the influence of the contextual factors on the impact of each design variable, and 3) Consideration of the existence of a 'best' variable value. These three points are consecutively treated in the evaluation, and summarized in separate columns in the tables.

Multinational design variables with a high impact

Balancing region boundaries : This design variable defines the boundaries of the balancing region, that is, which control areas are included in the group of control areas that has implemented some form of balancing market internationalization. As we have found in chapter 2 that each country has its own balancing market with its own detailed set of balancing market rules, and have found in chapter 4 that the contextual power system and market has a large impact on balancing market performance, the choice of the involved control areas in balancing market internationalization will affect the impact of balancing market internationalization to a very large degree. After all, the balancing region boundaries affect the initial balancing market design variable values and contextual factor values. Therefore, all balancing market performance criteria can be affected a lot by this design variable. The social welfare of cross-border exchanges is for an important part influenced by the availability interconnection capacity in-between the control areas within the balancing region.

The impact of the choice of balancing region boundaries could be considered to be influenced by contextual factors, but it must be noted that the contextual factors themselves are actually the result of this very choice. Because this design variable determines the entire set of initial national balancing market designs, and because most defined contextual factors could have a very large influence on the effects of several national design variables, most contextual factors can be estimated to have a very large influence. The number and size of BRPs and BSPs have, according to the national effect estimation, at most a large influence, and the strategy of BRPs and BSPs have at most a moderate influence (see appendix H). The impact on the criterion 'social welfare of cross-border exchanges' is influenced to a very large degree by contextual factors of short-term market design and liquidity, generation and consumption portfolios (which determine price levels in short-term markets), and the amount of interconnection capacity.

Regarding a 'best' design variable value, there are some general principles that can be considered. First of all, the level of similarity between initial national balancing market designs is a very relevant issue. The higher the similarity, the easier it will be to harmonize and integrate the balancing markets. Considering that the integration of non-harmonized balancing markets may obstruct balancing service exchange and cause distortions in incentive compatibility (see below), the potential benefits of integration are higher for more similar balancing markets. On the other hand, the potential benefits of harmonization are lower (unless a totally different set of variable values is adopted that performs better than the original one). Second, the number, size and relative position of the participating control areas matters a lot. Generally, the higher the number of control areas in the balancing region, the harder it will be to reach agreement on a uniform set of design variable values, complicating both harmonization and integration developments. Regarding integration, an increasing number of control areas might increase the difficulties regarding the coordination of balancing energy activation and balance settlement much more, and increase the uncertainties of the effects much more. On the other hand, it will also increase the potential benefits of integration. Perhaps there is an 'optimal' number of control areas. The relative size of control areas in the balancing region is relevant for integration, because integrating small with large balancing markets will have a small impact on the large market and a large effect on the small market. In case of equally sized control areas, the impact level will be more equal too. We see no obvious reason why equally sized areas would be preferable, however. The geographical position of control areas is also relevant for integration. Triangular/meshed configurations of power networks have higher potential benefits of integration than sequential/radial configurations, but the coordination of activation and the uncertainties of effects will be higher as well.

Control area boundaries : The control area boundaries in a synchronous zone determine for which areas a separate balance is maintained, splitting up the balance market activities of planning, balancing service provision and settlement. The choice of the division of a synchronous zone into control areas thus has an impact on all three pillars of the balancing market, and is therefore likely to affect all balancing market performance criteria. The merging of control areas can be considered as an alternative to the realization of a common merit order list, with similar effects (see subsection 5.1.1). The merging of control areas will improve availability of balancing resources, utilization efficiency and price efficiency to a very large degree, in case no significant increase in congestions will materialize. It may also simplify the balance planning and settlement processes. But because the former interconnection lines have become internal transmission lines and capacity on these lines are not allocated to market parties, much more congestions could occur[1]. Such congestions would limit the possibilities for surplus energy exchange and balancing service exchange. Also, more balancing resources could be needed for congestion management. This can mean a very large decline of the availability of balancing resources, utilization efficiency, price efficiency and a large decline of balance quality, against which the small increase in transparency, operational efficiency and non-discrimination do not weigh up. Furthermore, the integration costs of merging control areas could be very large, because it means a shift in the responsibilities of the involved System Operators and an integration of all balancing market processes for System Operators. If different System Operators remain in the merged control area, coordination of tasks and exchange of information is another important task, to which significant implementation costs could be attached. All this may require investment in new ICT systems. The impact of control area merging on the social welfare of cross-border exchange is not very clear, because the borders actually change due to this variable. Conversely, control area splitting could be considered to have the opposite effects to control area merging. The splitting into multiple control areas will result in balance planning and settlement on a zonal level, and more explicit procurement of reserve capacity on a zonal basis. This could alleviate any congestion management problems, but the net impact on balancing market performance could turn out to be a large reduction in utilization efficiency due to reductions in the evening out of imbalances and separate ACE control. The exact impact depends on the relative size of these negative effects compared to the positive effects of locational incentives and a lower need of balancing resources for redispatch. Another general effect of changing the control area boundaries is on balance planning accuracy, which is the result of the change in balancing energy costs and thereby imbalance prices. Especially when congestions between low-price and high-price areas are tackled by control area splitting, balance planning accuracy in the high-price area could increase as a result of higher imbalance prices.

The power system size has an influence on the impact of changing the control area boundaries. After all, small power systems will have relatively large system imbalances. Here, control area merging will have a more positive effect on balancing costs. Furthermore, a high utilization factor of interconnection capacity will increase the likelihood that control area merging will result in a net negative effect on balancing market performance. Conversely, a high utilization factor of certain transmission lines increase the chance that control area splitting along those lines will have a positive effect.

Becaus we have found in subsection 5.1.1 that the introduction of a common merit order list will create the same benefits as control area merging, we are not sure about added value of merging control areas in addition to the introduction of a common merit order list. Conversely, control area merging requires much more balancing market integration and harmonization than does a common merit order list, and is therefore more

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[1] This may very well be prevented by the simultaneous introduction of congestion areas / price areas, with boundaries that match those of the former control areas. However, here we estimate the possible range of effects of design variables in isolation

difficult to realize. However, if merging is feasible and will reduce congestion management costs and balancing market administrative costs thanks to the integration of system operation activities, this design option can be recommended. With regard to providing higher locational incentives to tackle local congestion problems, the introduction of separate zones (and thus zonal balancing) appears better than control area splitting, because the real-time balancing benefits of one control area are maintained, while balancing energy market splitting in case of congestions will still create locational incentives to BRPs and BSPs. Norway and Sweden are examples of the introduction of zones to deal with congestions, while maintaining a regional balancing market and one big control area.

Geographical distribution of reserves : Compared to the national design variable of reserve requirements, this multinational variable is about the relative and total size of reserve capacity (contracted reserves) for Frequency Containment Reserves (FCR), Frequency Restoration Reserves (FRR), and Replacement Reserves (RR) in the balancing region. The geographical distribution of reserves is most relevant for FCR, because this is a decentralized and automatic service that is activated within seconds to keep frequency deviations in the synchronous zone within limits. Regarding FRR and RR, there may not be any direct requirements on a synchronous zone level about reserve capacity volumes in the different control areas, but the general principle that control areas should remove their Area Control Error (ACE) within fifteen minutes indirectly requires control areas to procure enough reserve capacity to be able to do that. The main design choice related to the geographical distribution of reserves is whether or not FCR and RR reserve requirements are set on a synchronous system level[2]. This design choice has a large impact on utilization efficiency; both the actual use of reserve capacity and the use of the regionally cheapest resources can be improved. On the one hand, reserve capacity could be overdimensioned as a result of less information about national needs, but on the other hand a regional assessment of the system needs could take the possibility of balancing service exchange into account, reducing the national reserve requirements. Of course, the latter is limited by technical limitations of balancing service exchange, and the need to procure enough reserves nationally to ensure the national availability of balancing resources and balance quality. Moreover, if a too large share of the national reserve requirement would be met by importing reserve capacity, not only the national security of supply would be jeopardized, but also security of supply in the synchronous zone, because all areas are synchronously connected[3]. This is why the UCTE Operation Handbook includes standards on minimum share that need to be contracted in the own control area (UCTE, 2009a) (see subsection 2.3.1). However, the regional dimensioning of reserve capacity implies a more radical development: reserve capacity sharing, rather than foreign contracting. It follows that the geographical distribution of reserves has a very large effect on the availability of balancing resources and a large effect on utilization efficiency. And if control areas cannot remove their ACEs, balancing quality will be substantially affected too. Because the choice between regional and national dimensioning of reserve capacity influences reserve capacity volumes, it also influences competition in balancing service markets, and therefore price efficiency. The change to regional dimensioning will affect transparency somewhat (at least from a national perspective), and generate some implementation costs attached to the development of a regional calculation method and enactment of national reserve requirements. Possibly, a monitoring system for checking the availability of contracted reserves may be needed too. Finally, the regional dimensioning implies reserve capacity exchange, and thus the reservation of interconnection capacity. This can have a large impact on the social welfare of cross-border exchanges.

The power system size has an influence on the impact of the design choice between regional and national reserve capacity dimensioning. Small power systems require a relatively high reserve capacity volume, and therefore have more to gain from reserve capacity sharing. The day-ahead and intra-day market designs have a large impact, because with regard to multinational balancing markets these contextual factors also deal with the presence of coupled day-ahead and intra-day markets. If these markets are coupled, less interconnection capacity will typically be available for cross-border balancing, reducing the possibilities for reserve capacity sharing. Short-term market liquidity also matters a lot, because high liquidity will lead to high cross-border trade volumes. Also, if generation and consumption portfolios in a control area are very unpredictable and balancing resources are very scarce, reserve capacity sharing could introduce enormous security of supply risks. Of course, if interconnection capacity is generally not available, reserve capacity cannot be shared.

Because the option of regional dimensioning of reserve capacity for FRR and RR with the intention to reduce the contracted volumes implies the use of the radical and risky sharing of reserve capacity, this appears a

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[2] Actual reserve capacity volumes and the use of calculation methods are covered by the national variable of reserve requirements.

[3] The European-wide blackout in the UCTE zone in 2006 is a good example of the interdependencies in security between power systems of a synchronous zone (UCTE, 2007).

very unsafe thing to do. With regard to FCR, the geographical distribution of reserves is a natural arrangement for control areas in the same synchronous zone, as there is one system frequency which is contained by all FCR dispatch in the zone, and the Transmission Reliability Margin on interconnectors allows for temporal FCR energy exchange. In fact, a zone that only applies national dimensioning of FCR could face high risks of FCR scarcity, because control area will tend to free-ride on FCR provision by other control areas.

Cross-border balancing arrangements : This is the key multinational design variable related to balancing market integration. The main design choice is here between four fundamental arrangements of system imbalance netting, BSP-SO trading, an additional voluntary pool and a common merit order list, which were introduced in subsection 3.1.2. The latter three arrangements can be considered for both reserve capacity exchange and balancing exchange. Here we give an initial estimation of the general impact of this variable; in section 5.3 a more detailed qualitative assessment is given for the different arrangements, and in section 5.4 an agent-based simulation study is presented of the impact of different arrangements on balancing market performance in Northern Europe. With regard to real-time system balancing, all four cross-border balancing arrangements have the potential to change the activated balancing energy volumes and/or the regulation prices significantly. This is likely to alter the bidding behaviour of Balancing Service Providers in balancing energy markets, which in turn affects the activated volumes and regulation prices again. Based on this, we estimate here that the availability of balancing resources can be affected to a very large degree, and also the utilization efficiency, price efficiency, and balance quality. Furthermore, the changes in regulation prices (balancing energy costs) cause changes in imbalance prices (imbalance costs), which will also affect the portfolio balancing behaviour of Balance Responsible Parties. Therefore, balance planning accuracy could be substantially affected. Because cross-border balancing can create differences between regulation prices and imbalance prices (in case of BSP-SO trading or an additional voluntary pool), cost allocation efficiency may be negatively affected. Furthermore, some detailed cross-border balancing arrangements could be quite untransparent, or involve a discriminatory treatment of different market participants. The operational efficiency will decrease, because of the additional information and money exchange between System Operators as a result of cross-border balancing. The additional transactions and coordination and control mechanisms may also bring about high implementation costs (new ICT systems, adapted procedures and protocols, etc.). The more balancing energy is exchanged cross-border, the more social welfare of cross-border exchanges will improve (assuming that no interconnection capacity is reserved for this). With regard to the cross-border exchange of reserve capacity, the availability of balancing resources could actually be damaged because of the lower availability of imported reserve capacity, although the price efficiency and utilization efficiency could be improved by such exchange. Most striking is however the impact on social welfare of cross-border exchanges, which can diminish a lot as a result of the required reservation of interconnection capacity. Transparency and operational efficiency of reserve capacity procurement are probably damaged somewhat, and non-discrimination could be as well. The costs of the development and introduction of a calculation method that co-optimizes the amount of interconnection capacity allocated to reserve capacity exchange and the amount allocated to cross-border day-ahead and intra-day trade (as suggested by ENTSO-E (2011d)) generates additional implementation costs.

The impact of cross-border balancing arrangements is influenced by power system size, because the integration of two small balancing markets will have a relatively larger impact than the integration of two large markets, while the integration of one big and one small market will have a huge impact on the small market but an insignificant impact on the large one. The generation portfolio has a large influence, because this determines the volumes and operating costs of available balancing services in the individual balancing markets. It is not immediately clear in which situation the benefits of integration are highest, in case of markets with different balancing service price levels or in case of markets with similar price levels. If price levels are very different, there is a clear high potential for balancing service exchange, but this exchange is one-directional. If price levels are similar, there will be less exchange, but competition will improve in both markets. Furthermore, the contextual factors of short-term market design and liquidity and interconnection capacity significantly influence the availability of interconnection capacity for cross-border balancing, just as mentioned under ‘geographical distribution of reserves’. Finally, the presence of market power in balancing service markets due to a small number of BSPs can be resolved to a large degree by balancing market integration (c.f. European Commission (2007)).

Which cross-border balancing arrangement is most beneficial is something that is studied in more detail in in section 5.3 and section 5.4. Noticing that a common merit order list theoretically maximizes the efficient use of balancing services for balancing the region as a whole, and that this arrangement has been mentioned as the final target model by ERGEG (2009) and considered ‘desirable’ on the longer run by ENTSO-E (2011d), we estimate that the common merit order list is a generally ‘best’ option. However, system imbalance netting is a beneficial first step, reducing activated balancing energy volumes in all control areas, without requiring changes in market design.

Reservation of interconnection capacity for balancing : The impact of this design variable depends on the design variable of cross-border balancing arrangements: Only if balancing markets are integrated, the reservation of interconnection capacity for balancing makes sense. Basically, this variable increases the level of cross-border balancing, enlarging the effects mentioned under 'cross-border balancing arrangements'. In order to make the cross-border exchange of reserve capacity possible, interconnection capacity needs to be reserved, which reduces the interconnection capacity available to conventional day-ahead and intra-day cross-border trade. The extent to which this actually reduces cross-border trade volumes in day-ahead and intraday-markets depends on the size of the interconnection capacity that remains after intra-day market closure compared to the size of the reserved interconnection capacity. If the last is smaller than the first, the reservation does not reduce trade volumes. However, in case of coupled day-ahead and intra-day markets, different market price levels and limited interconnection capacity, we can assume that trade volumes will usually be affected. It is clear that the social welfare of cross-border exchanges could reduce to a very large degree by such reservation. What is unclear, however, is to what extent the reduction in economic value of conventional cross-border trade is compensated by the increase in economic value of reserve capacity exchange. This depends not only on the difference in national day-ahead/intra-day price compared to the different in reserve capacity prices, but also on the effect of reserve capacity exchange on regulation prices. Indeed, the reserve capacity exchange might indirectly decrease imbalance costs significantly. Furthermore, a fixed reservation volume potentially has much more negative effects than allocation by means of an optimization calculation as suggested by ENTSO-E (2011d). In theory, such 'optimized variable allocation' would only reserve interconnection capacity for balancing if social welfare would be improved, although it could prove hard to forecast prices and values with sufficient accuracy. Alternatively, interconnection capacity could be specifically reserve for balancing energy exchange. The economic benefits of this for balancing energy dispatch are very uncertain, however, because the volume of balancing energy exchanges depends not only on bid prices, but also on the demand for balancing energy, which is highly volatile (in contrast to reserve capacity demand). On the other hand, balancing energy price differences between countries could be much larger than reserve capacity or short-term market price differences. After all, the limited supply and the offering of expensive resources typically results in balancing energy bid ladder curves that are very steep on the right side (higher price range), making large price differences between areas more likely. Regarding the impact on other performance criteria, the reservation of a large interconnection capacity volume could have a very large impact on the availability of balancing resources, as a lot more foreign resource can become available. The utilization efficiency can increase a lot due to the use of the regionally cheapest balancing services. Also, price efficiency could significantly increase because of much stronger competition in balancing service markets. The balance quality could increase if quicker resources become available. The reduction in regulation prices and imbalance prices could reduce the balance planning accuracy, but because BRPs on overall aim to minimize imbalance costs, this effect is estimated to be moderate. The introduction of 'optimized variable allocation' could create some implementation costs. Furthermore, the possible large reductions in imbalance prices mean a possible large rise of cost allocation efficiency. In itself, this design variable does not have a significant effect on other performance criteria.

The impact of the reservation of interconnection capacity for cross-border balancing is dependent on the economic potential of balancing service exchange, given demand for and supply of balancing services and balancing service price levels. Considering this, power system size and generation and consumption portfolio do have large impact. The relative size of interconnection capacity, compared to the potential of cross-border trade affects the impact on the social welfare of cross-border exchange, so short-term market design and liquidity and interconnection capacity are important contextual factors too. Finally, a small number of BSPs in national balancing markets increases the value of enlarging the balancing service exchange by means of reservation.

Because it is unclear to what extent the reservation of interconnection capacity maximizes social welfare of cross-border exchanges, let alone balancing market performance, and highly dependent on the context, we can only underline here the recommendation by Frontier Economics (2009) and ENTSO-E (2011d) to consider such reservation for each specific case. In case reservation turns out to be worthwhile quite frequently, an 'optimized variable allocation' looks like a good idea. Of course, this requires a reserve capacity market with a very high frequency of clearing. A daily reserve capacity market will enable a variable allocation on a daily basis, which allows for an optimization with day-ahead trading for one specific day. The allocation calculation should then be done before the clearing of both the day-ahead market and the reserve capacity market.

Regional service provision rules : Depending on the specific cross-border balancing arrangement to be introduced, some balancing service provision rules have to be defined on the regional level. For the additional voluntary pool, these rules concern the regional pool, with national rules still applying to the national balancing service markets. For the common merit order list, a set of rules for the regional balancing service market are needed, which replace the national ones. This design variable is a high-level multi-faceted one, because it deals with the procurement method, market timing, bid requirements and balancing service pricing mechanism of the regional balancing service market. This is actually only applicable to the regional common merit order list, because a regional pool is merely an intermediary for balancing service bids. That is, it is not an actual market with its own clearing and bid requirements. Only the pricing mechanism is relevant here: This relates to the pricing of exchanged balancing service bids, which may be separate for national balancing service pricing (in case the exchange is not supposed to influence national regulation prices and imbalance, and only excess services are exchanged). For the common merit order list, the regional list replaces the national markets. With that, the procurement method, market timing, balancing service pricing mechanism and bid requirements become regional design issues. The Nordic case has shown that national pricing rules and bid requirements could still be existent (Nordel, 2008b), but it is unclear to what extent this has been more than a difference in national laws and codes. Besides, the price rules were detailed ones, they did not concern the main pricing mechanism. Theoretically, different control areas cooperating in a common merit order list could still apply national bid requirements, but that would hamper the regional SO in shaping its activation strategy, and embed some level of discrimination between BSPs of different control areas. The impact of regional service provision rules on performance will thus be similar to the aggregate of the impact of the procurement methods, timing of markets, balancing service pricing mechanisms and bid requirements. This means that the impact on availability of balancing resources, price efficiency and non-discrimination can be very large, the impact on balance planning accuracy, balance quality, utilization efficiency and cost allocation efficiency can be large, the impact on transparency will be moderate, and the impact on operational efficiency and internationalization costs will be small. The social welfare of cross-border exchanges is estimated to be moderately affected; the regional balancing service market design choices could pose several barriers to the ability and attractiveness to submit balancing service bids, which would generally reduce the economic efficiency of balancing service provision, and therefore the economic value of balancing service exchange as well. An interesting question is if such barriers make balancing service exchange relatively more or less important. Indeed, it could be that more competition in national markets effectuated by removing barriers brings larger economic benefits than integration. With regard to the separate pricing option for an additional voluntary pool, some incentive compatibility problems arise. If only excess bids are exchanged (in order not to influence national prices), the received balancing energy payment should be at least the bid price of the exchanged bid, which will always be higher than the national imbalance price. As a result, the BSP could have an incentive to not deliver the requested balancing energy, damaging both economic efficiency and security of supply in the area of the connecting SO[4]. There appear to be only two ways of preventing such adverse incentive from occurring: monitoring of the actual delivery of balancing energy (see the design variable ‘penalty for non-delivery’), or no separate payment of exchanged bids.

The same contextual factors influence the impact of the regional balancing service provision rules as for the methods of procurement, timing of markets, regulation pricing mechanisms, and bid requirements. This means that the generation portfolio may have a very large influence, the number and size of BSPs may have a large influence, and the day-ahead market design, transmission capacity and the strategy of BSPs may have a moderate influence. In addition, the interconnection capacity is estimated to have a moderate influence. If more capacity is available, the removal of barriers and stimulation of bid submission will have stronger effects on balancing market performance, due to the higher balancing service exchange. Liquid cross-border day-ahead and intra-day markets may reduce the balancing service exchange, and thus have an effect as well.

In order to prevent high monitoring costs or adverse incentives, the best solution for an additional voluntary pool appears to be no separate pricing of exchanged balancing energy bids, which makes this design variable irrelevant for this cross-border balancing arrangement. For the common merit order list, the ‘best design’ resembles the ones given for methods of procurement, timing of market, balancing service pricing mechanism and bid requirements: Use of competitive markets for the common merit order list(s), a daily reserve capacity market, marginal pricing for balancing energy market, as few bid requirements as possible. However, a regional reserve capacity market only makes sense if enough interconnection capacity is available, social welfare of cross-border exchanges is not affected, and security of supply of national markets are not damaged. All in all, the realization of a common merit order list for reserve capacity appears much less likely than a common merit order list of balancing energy.

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[4] Whether this incentive is actually there, depends on the size of the imbalance price compared to the operating costs of the involved balancing resource.

Multinational design variables with a medium impact

Publication of regional information : This design variable concerns the publication of information of balancing market rules on the regional level, and the publication of regional balancing market data. Effects are of a similar nature as for the national variable 'publication of national information', but the range of the multinational variable is dedicated to cross-border balancing arrangements and cross-border exchanges of balancing services. The larger the role/share of cross-border balancing in system balancing in the balancing region, the more important this design variable becomes. Therefore, the effects of this design variable are dependent on the cross-border balancing arrangement. Considering the above, we estimate that the effects on individual performance criteria are somewhat smaller than for 'publication of national information', with the exception of transparency and non-discrimination. This is because a main issue is here that balancing market rules and data should be identical and equally accessible for market participants from different control areas. This could be a challenge for advanced and complicated cross-border balancing arrangements.

In case of a small number of BSPs, high transparency of market rules and data is important to attract new bidders, but too much bid ladder information will create higher risks of market power abuse. Furthermore, a high availability of interconnection capacity will generally result in stronger competition between BSPs in the balancing region, reducing the risks of market power abuse caused by the publication of too little or too much balancing market data. For the same reason short-term market design and short-term market liquidity have an influence.

Regarding a 'best' design option, the same can be said as for 'publication of national information'. Information on bid ladder data should only be given if it will not create opportunities for gaming, and real-time information to BRPs can help to improve the efficiency of balance management. A quick publication of prices will enable market parties to make better decisions on the short term. The best way of publishing information on the regional balancing market is probably by means of an international website on which all information and data is put together. This is most relevant for a common merit order list, but for BSP-SO trading, publishing all national data on one regional website appears a simple and robust way to guarantee equal access to market data too. In case of an additional voluntary pool, it is System Operators for whom a regional information exchange platform guarantees equal information on balancing service exchange possibilities.

Redistribution of balancing costs : The redistribution of balancing costs consists of four concrete cases of additional settlement of balancing costs between System Operators: 1) the pricing of exchanged surplus energy in case of system imbalance netting, 2) the determination of prices of exchanged balancing service paid by the receiving SO to the connecting SO in case of an additional voluntary pool, 3) the allocation of exchanged balancing energy to different System Operators and the pricing of this energy in case of a common merit order list, and 4) compensation of connecting SO by receiving SO for incurred reserve capacity costs associated with exchanged balancing energy bids. In order to assess the impact of this design variable, we need to go into the details of design options and effects for each of these cases. Regarding case 1, pricing of surplus energy in the first place is the basic design question. Because the volumes of exchanged surplus energy will even out over longer time periods, pricing is not really needed. Of course, the reduction of activated balancing energy volumes will be more valuable (reduce regulation prices more) to one control area than another, but calculation of the size of prevented balancing energy costs and a payment to level the value of surplus energy exchange appears a disproportionally large process compared to its added value. Besides, market integration, including balancing market integration will generally lead to unequal effects on costs and benefits; this is inherent to integration[5]. A simpler way of redistributing surplus energy would be to settle it with e.g. the average of regulation prices in the involved control areas. This would be a relatively simple additional settlement process with a small effect on operational efficiency. However, the settlement will require also additional allocation of the settled costs. As discussed under 'allocation of net settlement sum', this could damage the cost allocation efficiency. Regarding case 2, the price paid for exchanged bids between SOs in a voluntary pool could be equal to price paid by the connecting SO to the BSP, but it could also be a higher price, that is related to the value of the exchanged bid for the receiving SO (i.e. to the regulation price of the importing area) rather than to the actuals costs of the bid (i.e. the regulation price of the exporting area) (Frontier Economics and Consentec, 2005). If the price is based on value, the connecting SO would make a profit. In that case, the cost allocation question pops up again, but this question is covered already by the variables 'allocation of reserve capacity costs' and 'allocation of net

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[5] Solving these inequalities by redistribution would not make any sense. The idea of full integration is to create a single balancing market with a single performance level. Given the fact that initial national performance level differ, it follows that effects of integration will differ as well.

settlement sum.' And additional allocation option, however, is to pass entire value-based payment on to BSP. This appears to improve cost allocation efficiency, but it could incentivize BSPs in the exporting area to increase prices, in order to increase the chance of receiving that high price. Another configuration of the voluntary pool could be a separate auction held by the connecting SO to select exported bids, but this would reduce price and utilization efficiency in the balancing market. Regarding case 3, the allocation of exchanged balancing energy volumes to different System Operators is a second issue next to the pricing of these volumes. This is due to the centralized system balancing for a balancing region consisting of multiple control areas. Consider for example a situation with three control areas, where control area A has a system surplus of 10 MWh, and control areas B and C each have a system shortage of 10 MWh. Upward regulation is cheapest in area A, so 10 MWh of positive balancing energy is activated there. How are these last 10 MWh allocated to areas B and C? As can be seen, this relates to the redistribution of the Area Control Error. If we assume that, as discussed above, the remaining ACE is redistributed proportionally to the system imbalance volume, the 'new' ACEs (after system imbalance netting) become 0 for area A, -5 MWh for area B, and -5MWh for area C. From this, it follows that both area B and C import 5 MWh of balancing energy. Thus, the allocation of balancing energy costs depends on the redistribution of ACEs. The second issue is what prices are used to settle exchanged balancing energy. In case of a single regulation price, it is logical to use this price. But if congestions have caused different regulation prices in different areas, another price needs to be used. If the price is set equal to regulation price of the importing country, the exporting country gains; if the price is equal to the regulation price of the exporting country, the importing country gains. Perhaps the use of the average of both regulation prices, as applied in the Nordic region (Nordel, 2002) is more fair. Furthermore, matters are complicated further if pay-as-bid pricing is applied, in which case the redistribution of balancing energy costs between SOs probably needs to be based on average costs of exchanged bids. Regarding case 4, i.e. the compensation of incurred reserve capacity costs, the settlement sum is logically equal to the level of the reserve capacity costs for the specific exchanged bids, for the duration of the exchange. In case it is clear who is the receiving SO, this could be relatively straightforward. In case of a common merit order list with more than two areas, however, the allocation of costs to specific areas could be quite complex. More fundamental is the question if reserve capacity costs should be compensated for in the first place. Such compensation is more fair, but increases complexity and costs of cross-border balancing, possibly reducing the level of balancing service exchange while security of supply in the exporting area is not necessarily affected. Considering the detailed options under each of the four cases of redistribution of balancing costs, it is first and foremost the cost allocation efficiency that could be affected. After all, the redistribution takes between System Operators, changing the net settlement sums of the different control areas. Secondly, incentive compatibility could be damaged by specific pricing rules for exchanged balancing services or surplus energy, because Balancing Service Providers could receive too high prices for exchanged bids, creating incentives for undesirable behaviour such as non-delivery or general bid price increases. It is our estimate that these pricing rules could have a large effect on price efficiency; it could significantly increase in importing countries and decrease in exporting countries. Balance quality could be affected if the pricing rules give an incentive to not deliver upon activation. The transparency could reduce because of complicated pricing rules, and non-discrimination because of an unfair large profit for exported bids. Operational efficiency is reduced a little due to the additional money transactions between SOs.

In general, the choices regarding the distribution of balancing costs caused by cross-border balancing will have a larger impact if there is more cross-border balancing. Thereby interconnection capacity, short-term market design and short-term market liquidity influence the effects. The generation portfolio is influential, because it largely determines the relatively price level of balancing services in different areas. The larger the price difference, the more balancing service exchange.

Because of its simplicity and fairness (equality in benefits), no pricing of surplus energy exchange appears a generally better option. Regarding the pricing of exchanged bids in an additional voluntary pool, it is not immediately clear whether a value-based or costs-based price would make more sense. A value-based price would reduce cost allocation efficiency in the export area, but a costs-based price would not compensate enough for possible reduction in availability of resources price increasing effects in the exporting area. Perhaps an in-between price, i.e. the average of both regulation prices, can be considered generally 'better', also in case of the pricing of exchanged bids in a common merit order list. With regard to allocation of balancing energy volumes in a common merit order list, a distribution of energy proportional to system size appears most fair. A distribution proportional to system imbalances would favour areas with large imbalances, causing a lower incentive compatibility. The compensation of reserve capacity in case of exchanged balancing energy bids appears only worthwhile if the availability of balancing resources is really affected by the exporting area, considering the additional efforts and the low sums concerned.

Multinational design variables with a low impact

National vs. regional legislation : This multinational design variable deals with the embedding of balancing market rules in national and international legislation. On the regional level, legislation becomes a much more important issue, because multiple countries part of the same multinational balancing market will still have different national legislations. Next to that, in the case of Europe, there is also the European legislation. A basic distinction can be made between laws and codes. Laws are directly set up and enforced by governments, and usually contain only general rules and principles on balance management and balancing markets. Codes are usually set up by the System Operator and approved by the regulator, and usually contain the detailed balancing market rules. Codes are a form of secondary regulation, they are typically enforced through an article in the national electricity law (see e.g. Energiekamer (2010)).

On the European level, the Directive 2009/72/EC (repealing Directive 2003/54/EC, which in turn repealed Directive 96/92/EC) is an important document for electricity; it concerns the common rules for the internal market in electricity in Europe. The most important balance management provisions in this directive are that 'TSOs shall procure reserve capacity in their system according to transparent, non-discriminatory and market-based procedures' (article 12), that 'rules adopted by TSOs for balancing the electricity system shall be objective, transparent and non-discriminatory, including rules for charging system users of their networks for energy imbalance' (article 15), and that 'the regulatory authorities shall be responsible for fixing or approving sufficiently in advance of their entry into force at least the methodologies used to calculate or establish the terms and conditions for ... the provision of balancing services...' (article 37) (European Commission, 2009a). A first observation is that these provisions concern high-level goals that European balancing market designs should meet, which are covered by our balancing market performance criteria set. Secondly, these provisions do not include specific balancing market design variable values, which suggests that it is up to national governments, System Operators and regulators to decide which specific balancing market rules meet the European goals. Usually, the specific rules of a national balancing market are laid down in a national code; the national electricity or energy law usually contains similar provisions as in Directive 2009/72/EC.

Another legal document on the European level is the UCTE Operation Handbook, of which Policy 1 provides standards regarding the geographical distribution of primary control in the UCTE network, and also regarding secondary and tertiary control (in the form of the stipulation that 66% of secondary control and 50% of the sum of secondary and tertiary control reserves must be kept inside the control area) (UCTE, 2009a). In addition, secondary control is defined as a reserve that is under automatic control, and an important standard is that secondary should be used to return the Area Control Error (ACE) to zero within fifteen minutes. The legal status of this document is not very clear; it is not mentioned in the directive. This makes sense, because the UCTE Operation Handbook applies to countries within the synchronous zone of continental Europe, not to EU Member States (The same holds for the Nordel System Operation Agreement, which just applies to the Nordel synchronous zone (Nordel, 2006a)). Because it is important that the general technical standards applying to the synchronous zone are adopted within all control areas, the relevant countries should incorporate these rules in their national legislation in order to clarify and entrench their legal status (cf. Knops (2008)).

Moreover, one must take note that the European regulatory regime on electricity is undergoing rapid developments. Directive 2009/72/EC is only a part of the third legislative package for an internal EU gas and electricity market, 'Third Energy Package' in short, which entered into force on 3 September 2009. This Package also includes Regulation 714/2009 on conditions for access to the network for cross-border exchanges in electricity, and Regulation 713/2009, which establishes an Agency for the Cooperation of Energy Regulators (ACER). On 3 March 2011, this directive needed to be transposed into national law by Member States, and the Regulations became applicable (European Commission, 2011). According to Regulation 714/2009, ACER needs to develop non-binding framework guidelines on particular topics, while ENTSO-E is requested to submit network codes that are in line with the relevant framework guidelines (European Commission, 2009c). According to ENTSO-E, ACER is expected to develop Framework Guidelines on balancing during 2011, which will lead to an ENTSO-E Balancing Network Code (ENTSO-E, 2011c). Because the network codes are to be developed for 'cross-border network issues and market integration issues' (European Commission, 2009c), this Balancing Network Code will probably cover balancing market integration, which is confirmed in ACER (2011).

Regarding the possible developments of balancing market harmonization and integration, it appears logical to consider the embedding of more specific balancing market rules on the multinational level. However, these developments will most likely (at first) take place within a balancing region that consists of several control areas. It is doubtful if they will take place for the entire European Union at a later stage, because of the context dependence of the performance of alternative balancing market designs. Furthermore, one can wonder if one common merit order list for entire Europe is a practical design. On the other hand, specific design variable values could be embedded in the directive if they are generally superior, and this could also be done for (the regional implementation of) a specific cross-border balancing arrangement. However, this raises the potential problem of the fragmentation of the regulatory regime for balance management. In general, the possible fragmentation and resulting inconsistencies in balancing market rules could become problematic for advanced forms of (regional) balancing market integration. This holds especially for a common merit order list, where a regional balancing energy market is created, and a regional System Operator is appointed. Noting the non-existence of 'regional legislation' in Europe, it appears that regional balancing market rules are to be embedded in national legislation of all involved countries, possibly creating legal conflicts.

Considering the issues of the embedding of balancing market rules in legal documents (directives, laws and codes), and the level of detail, consistency and hierarchy of these legal documents, this design variable clearly affects transparency. Institutional fragmentation will reduce the transparency of balancing market rules. If such fragmentation results in regulatory inconsistencies, transparency will be significantly damaged. Moreover, such flaws could give too many degrees of freedom to the System Operators, and in case of a financial interest (if SOs are allowed to keep the net settlement sum) could increase opportunities for gaming by SOs. The effects of this could be a decreased utilization efficiency and cost allocation efficiency. Furthermore, if rules on reserve capacity volumes, technical capabilities of balancing resources and real-time balancing in national legislation conflicts with the synchronous zone rules, the availability of balancing resources and balance quality in the entire zone could be affected. The inadequate embedding of operational procedures for the smooth execution of cross-border balancing could also damage the balance quality, e.g. if Area Control Errors are not adapted quickly enough.

Generally, in balancing regions where cross-border balancing has a very high costs reduction potential, there is more to lose from an inefficient utilization of this potential due to inconsistent legislation among control areas. The same can be said for balancing regions with large system imbalances and a tight supply of balancing resources, and the security improving potential cross-border balancing has in that occasion. Therefore, if coupled and liquid short-term markets and a small amount of interconnection capacity restrain the cross-border balancing potential, regional regulatory inconsistencies are less of a problem. Similarly, an abundance of balancing resources in combination with predictable generation and consumption portfolios reduce the negative impact of such inconsistencies.

The expected Balancing Network Code, indirectly enforced by the Third Energy Package, will cover cross-border balancing, and will thus probably form the main regulatory document including cross-border balancing rules. Still, however, there will be some risks of regulatory inconsistencies, as national balancing rules will continue to be embedded in national codes. This is emphasized by European Commission (2009c), which states that the European network codes 'shall be without prejudice to the Member States' right to establish national network codes which do not affect cross-border trade'. As even in a common merit order list at least the balance planning and settlement designs will remain national (if control area boundaries are retained), national balancing market designs and legislation must remain. However, it is not yet clear how detailed the cross-border balancing rules in this European code can and will be, and to what extent the code tackles the development of regional balancing markets, and the integration in a balancing region including both EU and non-EU countries. A viable option appears to be to allow the development of 'regional codes'(cf. van der Veen, Doorman, Grande, Abbasy, Hakvoort, Nobel and Klaar (2010)), which could be enforced by the European code and subject to its requirements, while applying specific cross-border balancing rules most beneficial and/or preferred for specific balancing regions. More in general, it appears best to limit the content of the European directive to general goals of balance management, in order to keep options open regarding balancing market design. After all, this effect estimation shows that the realization of high-level goals is dependent on the power system and market situation, which are also subject to on-going changes. Similarly, the European code should not specify detailed cross-border balancing rules. Also, national laws should keep specific balancing market rules to a minimum, save perhaps the most important, more 'political' choices, such as the allocation of reserve capacity costs and the net settlement sum (cf. Knops (2008)). The specific national balancing rules are best placed in national codes, and specific cross-border balancing rules in 'regional codes', to reduce the risks of regulatory inconsistencies.

Organization SOs and regulators : The organization of System Operators (SOs) and regulatory authorities (regulators) in a balancing region is also particularly relevant for balancing market integration. As considered under the variable 'national vs. regional legislation' increasingly integrated balancing markets require that balancing market rules shift more to the regional level. This is especially true for rules on cross-border balancing, which are expected to be incorporated in a European code dedicated to this topic (see above). Directly connected to this design issue is what are the relative roles and authorities of the national regulators in this. On the national level, regulators must approve the specific balancing market rules that are embedded in the code(s): According to the EU Directive, regulatory authorities ‘shall be responsible for fixing or approving sufficiently in advance of their entry into force at least the methodologies used to calculate or establish the terms and conditions’ for among others the provision of balancing services (European Commission, 2009a). ACER is not established to replace the national regulator, but ‘to assist the regulatory authorities ... in exercising, at Community level, the regulatory tasks performed in the Member States and, where necessary, to coordinate their action.’. (European Commission, 2009b). ACER has the responsibility to coordinate the development of European network codes, and thereby ’fills the regulatory gap at Community level’ (European Commission, 2009b). Regarding cross-border balancing, ACER is expected to develop Framework Guidelines on balancing during 2011, leading to an ENTSO-E Balancing Network Code (ENTSO-E, 2011c) that requires approval from ACER. The roles and responsibilities of national regulators and ACER on the area of balance management appear clear: National regulators approve national codes, and ACER European codes. Somewhat less clear are the roles and responsibilities in case of regional balancing markets. As discussed under ‘national vs. regional legislation’, a regional code embedding regional balancing market rules and enforced by the European balancing code appears a viable option to enable regional balancing markets. It must be determined to what extent ACER and the relevant national regulators are involved in the process of fixing or approving such a regional code. Regarding the roles and responsibilities of System Operators in the scope of balancing market integration, an increasing degree of integration will require an increasing coordination between System Operators. Furthermore, a higher number of control areas and System Operators in the balancing region makes coordination more difficult. In most cross-border balancing arrangements, System Operators will have equal roles and responsibilities that do not transcend the national activities much. It is more that national SO activities are expanded somewhat, some important ones being the adaptation of ACEs, the notification of activation of foreign bids, and the offering of excess national bid (additional voluntary pool). In a common merit order list, one of the SOs in the region is likely to be appointed the regional System Operator. In this case, it must be ensured that the regional SO cannot deviate from merit order activation in order to reduce the balancing costs for its own control area.

Considering the organization of regulators, a bad division of roles and responsibilities between national regulators and ACER appears most likely in the hypothetical case of regional balancing codes. This could form a large hurdle for the establishment of regional codes, and thereby prohibit the introduction of regional balancing markets and cross-border balancing. If regional cross-border balancing is realized directly through the expected European code, the roles and responsibilities are much more straightforward (although this could reduce the benefits of integration, see ‘national vs. regional legislation’). Assuming that a regional balancing market has been established, however, the organization of regulating authorities does not have an obvious effect. Considering the organization of System Operators, only a regional System Operator that is able to operate the common merit order list strategically in order to favour its own control area will have an impact. The effects of this could be a large reduction in utilization efficiency, price efficiency, and non-discrimination.

The opportunities for a regional SO to favour its own control area would rise in case more balancing service takes place. Thus, as for most other multinational variables, the generation and consumption portfolio, the short-term market design and liquidity and the interconnection capacity influence the impact on performance.

In case regional codes are not allowed, the organization of regulators is already covered by the establishment of ACER. In case regional codes are allowed and introduced, roles and responsibilities between national regulators and ACER must be clearly specified. A promising organization is that the national regulators together coordinate the development of a regional code, which then must be approved by both these regulators and ACER. The national regulators can check consistency with the national codes, while ACER checks consistency with the European code. The role of the regional System Operator in a common merit order list should be done by one of System Operators, unless an objective and efficient activation of balancing energy bids cannot be guaranteed.

Settlement of area imbalances : This design variable does not concern balancing market integration, but relates to balance management in a synchronous zone. The unintentional deviations, i.e. the deviations from scheduled control area interchange values should be settled, to compensate for the surplus/deficit energy exchanges. The unintentional deviations mainly arise from the Frequency Containment Reserve (FCR) energy dispatch automatically activated as a response to changes in system frequency. In case of the failure of a generation unit in one of the control areas, all control areas in the synchronous zone will automatically contribute to stabilizing frequency by means of this FCR energy dispatch (or primary control energy dispatch), resulting in surplus energy flows towards the particular control area. Three main design options are to settle unintentional deviations financially, to settle them physically, or to not settle them at all. In case of the physical settlement that occurs in ENTSO-E Continental Europe, positive deviations (unintentional import) in a certain recording period will be settled by scheduled additional export for a next compensation period, or vice versa. For the scheduling, so-called compensation programmes are used. The standard recording period and compensation period are one week, with the latter starting four days after the end of the former. Within these periods, a distinction is made between different tariff periods, for which a separate settlement takes place (UCTE, 2009b). This option appears much more practical than a financial settlement, which requires the determination of settlement prices, and an invoicing and payment system on the synchronous zone level, including an administrative body to execute it. Furthermore, the additional income/expenditure could enlarge the net settlement sum of national balancing markets, or lead to large fluctuations of the net settlement sum. This could thus require additional allocation within the national balancing markets, and reduce cost allocation efficiency. The third option of no settlement is the simplest one. It will not provide adverse market incentives, because BRPs continue to be subject to the national imbalance settlement regime. However, the amount of unintentional import or export could differ substantially between control areas. As unintentional deviations correspond with BRP imbalances in the control area that are settled with the System Operator, uneven deviations would again lead to larger net settlement sums. For the estimation of the effects of this design variable on performance criteria, we should consider the order of magnitude of unintentional deviations, compared to procured and dispatched balancing service volumes and BRP imbalance volumes. As unintentional deviations are primarily caused by FCR energy dispatch, and that FRR dispatch is aimed at removing these deviations, we estimate that the impact of the settlement of area imbalance is relatively small. Cost allocation efficiency could be affected moderately by the increase of (the absolute value of) the net settlement sum. Financial settlement would reduce transparency a bit, and moderately decrease operational efficiency.

Regarding context dependence, larger system imbalances could result in larger net settlement sums for the financial and no settlement options. Therefore, more unpredictable generation and consumption will increase the range of the potential impact of this design variable.

The best design option is probably the physical settlement of unintentional deviations, because this option is estimated to have by far the smallest impact on the net settlement sums of national balancing markets corresponding to the control areas in a synchronous zone.

Table I.1 – Multi-criteria analysis results: Estimated effects of multinational balancing market design variables with a high impact

	Range of effects of different variable values on performance criteria	**Influence of contextual factors**	**'Best' variable value**
Balancing region boundaries	*All performance criteria*: very large	*Number & size of BRPs/BSPs*: large *Strategy of BRPs/BSPs*: moderate *Other factors*: very large	The inclusion of control areas with similar designs increases feasibility and the potential benefits of integration.
Control area boundaries	*Avail. of bal. res.*: very large *Balance plan. acc.*: moderate *Balance quality*: large *Price efficiency*: very large *Utilization eff.*: very large *Operational eff.*: small *Non-discrimination*: small *Transparency*: small *Soc. welf. of CB ex.*: unclear *Int. costs*: very large	*Power system size*: moderate *Interconnection capacity*: large *Transmission capacity*: large	No control area merging, unless feasible and system operation costs reduce.
Geographical distribution of reserves	*Avail. of bal. res.*: very large *Balance quality*: large *Price efficiency*: moderate *Utilization eff.*: large *Transparency*: small *Soc. welf. of CB ex.*: large *Int. costs*: moderate	*Power system size*: moderate *Gen. & cons. portfolio*: large *Short-term market design*: large *Short-term market liquidity*: large *Interconnection capacity*: very large	Regional dimensioning of FCR capacity. National dimensioning of FRR and RR capacity.
Cross-border balancing arrangements	*Avail. of bal. res.*: very large *Balance plan. acc.*: large *Balance quality*: large *Price efficiency*: very large *Utilization eff.*: very large *Cost all. eff.*: very large *Operational eff.*: large *Non-discrimination*: moderate *Transparency*: moderate *Soc. welf. of CB ex.*: very large *Int. costs*: large	*Power system size*: large *Generation portfolio*: large *Short-term market design*: large *Short-term liquidity*: large *Interconnection capacity*: large *Number of BSPs*: large	System imbalance netting as the first step, and a common merit order list as the final step.
Reservation of interconnection capacity for balancing	*Avail. of bal. res.*: very large *Balance plan. acc.*: moderate *Balance quality*: large *Price eff.*: very large *Utilization eff.*: very large *Cost all. eff.*: large *Soc. welf. of CB ex.*: very large *Int. costs*: small	*Power system size*: large *Gen. % cons. portfolio*: large *Short-term market design*: large *Short-term liquidity*: large *Interconnection capacity*: very large *Number of BSPs*: large	Consider reservation per case. If worthwhile: Use of optimized variable reservation on a daily basis.
Regional service provision rules	*Avail. of bal. res.*: very large *Balance plan. acc.*: large *Balance quality*: large *Price efficiency*: very large *Utilization eff.*: large *Cost all. eff.*: large *Operational eff.*: small *Non-discrimination*: very large *Transparency*: moderate *Soc. welf. of CB ex.*: moderate *Int. costs*: small	*Generation portfolio*: very large *Short-term market design*: moderate *Short-term market liquidity*: moderate *Transmission capacity*: moderate *Interconnection capacity*: moderate *Number and size of BSPs*: large *Strategy of BSPs*: moderate	Use of competitive markets. A daily regional reserve capacity market (if this makes sense). Marginal pricing for a regional balancing energy market. As few bid requirements as possible.

Table I.2 – Multi-criteria analysis results: Estimated effects of multinational balancing market design variables with a medium impact

	Range of effects of different variable values on performance criteria	**Influence of contextual factors**	**'Best' variable value**
Publication of regional information	*Avail. of bal. res.*: small *Balance planning acc.*: small *Balance quality*: small *Price efficiency*: small *Utilization eff.*: small *Non-discrimination*: very large *Transparency*: very large *Int. costs*: small	*Short-term market design*: moderate *Short-term market liquidity*: moderate *Interconnection capacity*: moderate *Number of BSPs*: moderate	International website with all relevant information and data combined. Real-time information for BRPs. If no gaming will arise: Information on bid ladder. Quick publication of prices after real-time.
Redistribution of balancing costs	*Balance quality*: large *Price efficiency*: large *Cost all. eff.*: very large *Operational eff.*: small *Non-discrimination*: large *Transparency*: moderate	*Generation portfolio*: moderate *Short-term market design*: moderate *Short-term market liquidity*: moderate *Interconnection capacity*: moderate	No pricing of surplus energy. Settlement of exchanged bids with average regulation/capacity prices. Distribution of energy in common merit order list proportional to system size. Only compensation of capacity costs of exchanged balancing energy in case of damaged security of supply.

Table I.3 – Multi-criteria analysis results: Estimated effects of multinational balancing market design variables with a low impact

	Range of effects of different variable values on performance criteria	**Influence of contextual factors**	**'Best' variable value**
National vs. regional legislation	*Avail. of bal. res.*: moderate *Balance quality*: moderate *Utilization eff.*: moderate *Cost allocation eff.*: moderate *Transparency*: very large	*Gen. portfolio*: large *Cons. portfolio*: moderate *Sh.-t. market design*: moderate *Sh.-t. market liquidity*: moderate *Interc. capacity*: moderate	The development of regional codes, enforced by the European code, to specify cross-border balancing rules. General goals in EU Directive; general cross-border rules in European code; general national rules in national law.
Organization SOs and regulators	*Price efficiency*: moderate *Utilization eff.*: moderate *Non-discrimination*: moderate	*Gen. portfolio*: moderate *Cons. portfolio*: moderate *Sh.-t. market design*: moderate *Sh.-t. market liquidity*: moderate *Interc. capacity*: moderate	In case of regional codes: approval by national regulators and ACER. In case of common merit order list: one of the SOs functions as regional SO, unless objectivity is not guaranteed.
Settlement of area imbalances	*Cost all. eff.*: moderate *Operational eff.*: moderate *Transparency*: small	*Gen. portfolio*: moderate *Cons. portfolio*: moderate	Physical settlement (by means of compensation programs).

J Effect estimation of cross-border balancing arrangements

In this appendix, the full qualitative evaluation of the effects of seven cross-border balancing arrangements on the performance criteria is presented below, and a summary is given in Table J.1. The results of the evaluation are presented in section 5.3. Three elements are included in this analysis: 1) Estimation of the effects of the cross-border balancing arrangements on performance criteria, 2) Estimation of the influence of the contextual factors on the impact of each arrangement, and 3) Consideration of the existence of a 'best' detailed design of the arrangement. These three points are consecutively treated in the below evaluation, and summarized in separate columns in Table J.1.

The seven included cross-border balancing arrangements are:

1. System imbalance netting
2. BSP-SO trading of balancing energy
3. BSP-SO trading of reserve capacity
4. A voluntary pool for balancing energy
5. A voluntary pool for reserve capacity
6. A common merit order for balancing energy
7. A common merit order for reserve capacity

System imbalance netting : System imbalance netting is the netting and redistribution of ACEs for the control areas in a balancing region. It is a simple process not requiring changes in market design. However, the availability of interconnection capacity for resulting surplus energy exchanges needs to be checked. The issue of pricing of system imbalance netting has been discussed under the design variable 'redistribution of balancing costs' (see appendix I), where it was concluded that not pricing the surplus energy appears most suitable. As all areas benefit from this arrangement, there is no need for payment and an additional pricing mechanism that only adds to the administrative costs and the complexity of the balancing market processes. A relevant detailed design choice not yet covered is the way the netted ACEs are redistributed to the control areas. It may be best to redistribute proportional to the system imbalance of the control areas, in order to give appropriate incentives to BRPs and BSPs in the different balancing markets.

Assuming that system surpluses and system shortages both occur about 50% of the time, system imbalance netting between two control areas is possible about 50% of the time. However, as a higher occurrence of system surpluses is probably the most common system balance state (see subsection 4.4.3), this potential for system imbalance netting will probably be lower than 50%. Moreover, the times that both system imbalances are large will also be limited. Therefore, we expect that the impact of system imbalance netting on the reduction of activated balancing energy volumes will be significant, but not very large. In the special case that system imbalance netting is applied to a very small area and a very large area (e.g. the Netherlands and Germany), the relatively impact will become very large for the small area, but very small for the large area. On the regional level, this means that system imbalance netting in a balancing region with control areas of varying size will have a lower regional effect than for a region with equally sized control areas.

Regarding the effects of the introduction of system imbalance netting in a balancing region on the balancing market performance criteria, this introduction can first of all be considered to substantially improve utilization efficiency and availability of balancing resources, due to the large reductions in activated balancing energy. Resulting from this, the price efficiency can also be expected to increase substantially. Although Balancing Service Providers might ask for higher prices to recover lost income resulting from the reduced activation or leave the balancing energy market, this will probably not form a serious counter-effect. After all, increasing bid prices will be counterproductive if this further reduces the rate of selection by the SO, while a shift to other markets is not an option for contracted reserves and resources that are out of merit order in other, earlier markets. The balance quality is likely to improve thanks to system imbalance netting, because the adaptation of ACEs is a quicker process than balancing energy dispatch. Therefore, Area Control Errors are likely to be diminished. Furthermore, imbalance prices will also decrease along with the balancing energy prices. However, Balance Responsible Parties will probably not reduce their portfolio balancing efforts, because the costs of these efforts are probably lower than the imbalance costs. Therefore, balance planning accuracy will at most decrease a little as a result of the lower incentives. Operational efficiency is only slightly affected by the additional process of the netting and redistribution of ACEs. Because system imbalance netting will only be applied if there is available interconnection capacity, the social welfare of cross-border exchanges is not affected. The impact on the remaining performance criteria is negligible.

Regarding the context dependence of the effects of system imbalance netting, the power system size has a very large influence. This has already been discussed above. The generation portfolio has a large influence, because it affects the system imbalance volumes. The wind power share in the generation mix is especially influential. Furthermore, if there are already a lot of flexible resources that are left to use for balancing in real-time, the benefits of system imbalance netting for the availability of balancing resources are smaller. Because the predictability of load is more fixed and independent (although this may change in the future), the influence of the consumption portfolio is estimated to be small. Interconnection capacity is estimated to only have a moderate influence for system imbalance netting, because the surplus energy flows will not be very large. Currently, the remaining interconnection capacity is large enough to facilitate this, although a tighter market coupling might change this. Thus, the design and the liquidity of short-term markets also affect the potential for system imbalance netting a little. Finally, if the number of competing BSPs in the individual control areas is small, the reduction in activated volumes caused by system imbalance netting may very well have a larger positive effect on competitiveness.

BSP-SO trading of balancing energy : BSP-SO trading enables that Balancing Service Providers can bid into the balancing energy markets of neighbouring control areas in the balancing region. In our definition of BSP-SO trading, it is the receiving SO who activates and settles exchanged bids. Activation by the ‘receiving SO’ (importing SO) requires the checking of available interconnection capacity, and the notification of the ‘connecting SO’ (exporting SO), so that he can adapt the energy schedule of the relevant BRP. In addition, the ACEs of both control areas should be adapted based on the exchanged bid. The BSP itself must be able to receive the control signal from the receiving SO. In order to facilitate the possibilities for BSPs to offer bids to foreign markets, bid requirements and final gate closure times are preferably harmonized; otherwise the exchange will only take place in one direction. The harmonization of the Schedule Time unit is also highly useful in this respect, because BSPs from a control area with an hourly balancing energy market will, upon selection in a quarter-hourly market, probably be unavailable for selection in the own area for the entire hour.

For this arrangement, a first detailed design choice is whether or not the Balancing Service Provider is required to purchase interconnection capacity. Although this would help to prevent a general exodus of bids to foreign markets (see below), it would probably do so by making foreign bidding totally financially unattractive. After all, the BSP cannot be sure of the selection of its balancing energy bid in real-time at the time of the interconnection capacity purchase. Besides, this capacity would be lost to the SO. Therefore, it is concluded that the SOs will check the availability of interconnection capacity right before the activation of a foreign bid.

Secondly, an important underlying design choice is whether or not BSPs are allowed to bid into two balancing energy markets at the same time. In theory, allowing this will result in a common merit order list without system imbalance netting, and substantially increase utilization and price efficiency. In practice, however, it will introduce a high uncertainty on the eventual availability of balancing energy services, and complicate the operational processes of real-time balancing. It could happen that control signals are sent simultaneously to the same automatic balancing resource, which would cause disputes between the involved SOs. Furthermore, a run for the cheapest balancing energy bids is likely to arise, in which SOs will more pro-actively activate cheap bids (in case the availability of interconnection capacity can be assumed). To prevent this, bidding into multiple markets at the same time will probably not be allowed, which we will assume here.

But then the next problem presents itself: In case of total freedom for BSPs to choose a balancing energy market, BSPs could massively bid into the most profitable market, i.e. the market with the highest regulation price. This is of course dependent on the availability of interconnection capacity, the difference in balancing energy prices between both areas, and the relative balancing energy demand. But if there is a high balancing energy exchange and additional profit potential, BSP-SO trading can pose serious threats for the availability of balancing resources. Moreover, it could also be the bids that are first in merit order, i.e. with the lowest bid price, that shift to foreign markets. This could ruin incentive compatibility, as balancing energy prices and imbalance prices could lose all proportionality with the local system balance state. Furthermore, this could affect the efficient utilization of balancing resources and an efficient use of interconnection capacity as well. The answer to this potential problem relates to another important detailed design choice: A restriction on foreign bidding imposed by connecting SOs. Such a restriction implies that the connecting SO must monitor foreign bidding, and thus must give permission to BSPs to offer into foreign markets. This must of course take place before the final gate closure time of both the own and the foreign market. There are various forms that the a priori permission process could take. However, the rules of this process should be unequivocal, so that the connecting SO cannot prevent BSPs from bidding elsewhere despite the fact that the performance in the connecting area would not have been affected. Most simple appears to be a volume limit in combination with permissions on a first-come-first-served basis. This design will definitely tackle the availability concern. Furthermore, there is no reason to assume that the cheapest bids will come first; it is more likely that the BSPs less frequently selected will apply. Also, the impact on national prices will be restricted by the volume limit. Finally, prohibiting the export of a specific set of cheapest balancing resources, which is not a straightforward process, will introduce discrimination in the balancing energy market.

A fourth design choice relates to the opportunities for gaming that arise for BSP that bid into foreign markets. Large price differences between control areas may lead to the following opportunistic behaviour: BSPs that bid into more expensive balancing energy markets and receive a high balancing energy price upon selection, have an incentive to not deliver if the imbalance price of the own control area is lower than its operating costs. If this occurs on a large scale, the balance quality in both control areas could be substantially damaged. Although the opportunities for gaming could be limited by the volume limit for foreign bidding mentioned above, a direct and effective measure would be to penalize the non-delivery of the balancing energy. This can be realized by the monitoring of the real-time power output of balancing resources. See the design variable ‘penalty for non-delivery’ (appendix H). This monitoring could be limited to the balancing resources offered abroad, and the costs of this could even be recovered by means of a fixed fee for exported bids. However, this could provide a barrier for BSPs to offer resources in another market (in case of the absence of real-time metering), or hamper the flexibility and speed of the selection process. If monitoring of balancing energy dispatch is standard in the control area, there are of course no opportunities for gaming in the first place.

Regarding the estimation of the impact of BSP-SO trading on balancing market performance, we assume that a volume limit is implemented, and that BSPs applying for foreign bidding are selected upon a first-come-first-served basis, but that it is too costly and cumbersome to check actual delivery to penalize non-delivery. This means that the amount of balancing energy exchange is restricted, but that there may be opportunities for gaming. First of all, price efficiency will be affected. This will definitely reduce regulation prices in the receiving (more expensive) area if successfully imported, but it will not necessarily increase regulation prices in the connecting (cheaper) area. This will only be the case if the reduction in balancing energy supply in the connecting area decreases competitiveness, and/or if the cheapest bids are exchanged. Again, it is more likely that the bids out of merit order apply, as they have most to win from foreign bidding. However, strategic non-delivery by BSPs whose bid have been selected abroad will cause additional imbalance in the connecting area, and the resulting additional activation will reduce price efficiency. Opportunities for such non-delivery are likely to exist, considering that the higher price level in the receiving area. In view of all this, we estimate a small increase of price efficiency on the regional level. Balance quality will be affected by the non-delivery. The utilization efficiency will undergo a similar increase thanks to the BSP-SO trading. The availability of balancing resources will not be affected in case the SO sets a safe volume limit for BSP-SO trading of bids. Furthermore, the cost allocation does not appear to be negatively affected by non-delivery, because the balancing energy exchange does not create separate balance settlement; it is the exporting BSPs that arbitrage between the two different price levels. Non-discrimination will not be affected if a mere volume limit is applied to decide on permitted exchanges. Because the permission process for export and the additional coordination between SO increase the transaction costs, operational efficiency is reduced moderately. The integration costs are also moderate; these include harmonization costs, and the development of the permission process. Finally, the social welfare of cross-border exchanges will increase a little, because the balancing energy exchange will enlarge the utilization of the interconnection capacity.

Of course the power system size influences the effects of BSP-SO trading: If the cheaper areas are small compared to the expensive areas, there is much less potential for BSP-SO trading. Because the generation portfolio (volumes and costs of flexible resources) determines for a large part the balancing energy price levels, this contextual factor also has a large influence on the exchange potential. The consumption has a small impact, as it affects system imbalance volumes and thus balancing energy demand. The interconnection capacity has a moderate influence on the physical potential to exchange balancing energy across control area borders, and day-ahead market design and liquidity also have a small effect on this. The balancing energy exchange could reduce competition between BSPs somewhat in the exporting areas and increase competition in the importing areas. On a regional level, it is not clear that the number of BSPs has an influence. The strategy of BSPs has a significant influence, however: If BSPs are willing to take risks, they will apply more for balancing energy exchange, and more often will behave strategically by not delivering requested energy.

BSP-SO trading of reserve capacity : BSP-SO trading of reserve capacity enables BSPs to offer reserve capacity in reserve capacity markets of neighbouring control areas. The receiving SO procures and settles imported bids. The result of that is that the equivalent balancing energy bids is part of the balancing energy bid ladder in the receiving area for the duration of the contract period. Like with BSP-SO trading of balancing energy, activation and settlement of those balancing energy bids are also carried out by the receiving SO. Thus, it can be seen that this arrangement involves both reserve capacity exchange and balancing energy exchange. Here, however, the availability of interconnection capacity must be ensured for the duration of contract period to ensure the availability of the foreign balancing service.

Here, harmonization of the bid requirements is highly preferable to facilitate equal opportunities for exchange by BSPs, but the harmonization of timing of the reserve capacity market is a prerequisite for reserve capacity exchange. Also, this timing has a very large impact on the potential and impact of reserve capacity exchange, because of the need for interconnection capacity. In line with the findings from the effect estimation of the timing of markets (see appendix H), we assume here that there is a daily reserve capacity market in all control areas in the balancing region. Considering that intra-day cross-border trade will still take place, it is logical to assume that interconnection capacity must be reserved to ensure its availability. However, we will consider a system in which there is no optimized variable allocation of interconnection capacity to reserve capacity exchange (see the variable 'reservation of interconnection capacity for balancing ' in appendix I), which means that the social welfare of cross-border exchange could be damaged.

The scope of cross-border trade of reserve capacity is restricted by mandatory shares of reserve capacity that must be procured within the control area, to ensure the geographical distribution of reserves, and by the need for interconnection capacity for the duration of the entire contract period. However, according to the UCTE Operation Handbook, up to 34% of secondary control and 50% of the sum of secondary and tertiary control reserves can be procured abroad in continental Europe (UCTE, 2009a). This is quite a large amount. In addition, the daily reserve capacity market enables a daily varying of reserved interconnection capacity, reducing the uncertainties on negative effects on the efficient use of this capacity. Because we have no evidence or reason to believe that day-ahead price differences will usually be larger than reserve capacity price differences (see below), we conclude that the potential for reserve capacity exchange is lower than for balancing energy exchange, but still quite large.

A first specific design option is again whether or not the BSP is required to pay for the interconnection capacity. In contrast to the balancing energy exchange, BSPs paying for the interconnection capacity makes more sense; this is also done for other forms of cross-border trade. However, if BSPs are required to purchase interconnection capacity before offering into a foreign reserve capacity market, they risk losing money due to being out of merit order, or due to the reserve capacity price being too low. A more sensible option would be to charge the BSPs with some interconnection fee after selection of a foreign reserve capacity bid. This fee could be set equal to the interconnection revenue resulting from the cross-border day-ahead market. However, as we will see below, the inclusion of BSP-SO trading of balancing energy in this arrangement makes it unfair to let the BSPs exporting reserve capacity pay for interconnection capacity.

Bidding into multiple reserve capacity market at the same time actually appears feasible, again in contrast to BSP-SO trading of balancing energy. After all, in this case the withdrawal of the bids in the other markets in case of selection does not have immediate consequences for the availability of balancing resources. Although it is still possible that allowing this will damage security of supply if too many bids are selected abroad, there is more time for adaptation of the reserve capacity procurement in the different control areas. In theory, this could lead to reserve capacity exchange with a very high utilization efficiency. However, this would require good coordination between SOs in the procurement process, and this process may then require a lot of iterations. Also, if the reserve capacity market clearing takes place before day-ahead market clearing, the procurement must be finished before day-ahead market clearing, because it must be known how much interconnection capacity is available for day-ahead cross-border trade. A reversed sequence of gate closure has been found to create better results, however(Abbasy et al., 2010a). It is concluded that bidding in multiple market is feasible but creates some non-transparency and transaction costs.

Because bidding into multiple markets appears possible and does not need to reduce operational security of supply, an a priori permission process for BSPs, in order to restrict the amount of reserve capacity exchange, is probably unnecessary. A penalty for non-delivery is still a relevant design option concerning the corresponding balancing energy exchange. The possibility of gaming by non-delivery is still present in this arrangement, and not only for the BSPs selected for reserve capacity exchange. Although on first sight it looks like BSPs must first be selected for reserve capacity exchange in order to gain access to this gaming opportunity, in practice the reserved interconnection capacity could be utilized for the import of other balancing energy services (see below). Regarding this, we can repeat here that a penalty for non-delivery and the required real-time monitoring could be introduced to prevent gaming, but that this would create additional measurement and settlement costs and a barrier to balancing service exchange.

An important additional design choice is whether or not the utilization of reserved interconnection capacity for the purpose of reserve capacity exchange is limited to the exchanged balancing services. If it is not, reserved interconnection capacity could be utilized by means of the exchange of other bids too, which would come down to BSP-SO trading of balancing energy with guaranteed minimum amount of available interconnection capacity. However, BSP-SO trading of balancing energy can only be allowed if the BSP selected for reserve capacity exchange does not pay for the interconnection capacity, otherwise other BSPs 'free-ride'. Considering that BSP-SO trading of balancing energy has been estimated to have a positive impact, we will assume that this form of cross-border balancing is also included in this arrangement.

Regarding the impact on performance, the basis for the effect estimation is formed by the estimations for BSP-SO trading of balancing energy, because this has just been assumed to be included in this arrangement. Therefore, the effects of the reserve capacity exchange have to be added up to those to the former estimations. The price efficiency of reserve capacity prices could be increased a lot (there is no volume limit required), but the potential for exchange will remain dependent on the reserved interconnection capacity. As a result, we estimate a moderate increase, which in addition to the effect of balancing energy exchange leads to the estimation that this arrangement will significantly increase price efficiency. We can give the same rationale for utilization efficiency. The availability of balancing resources can be increased if bidding in multiple markets is allowed. However, the resulting iterative procurement process will reduce transparency and the operational efficiency somewhat. The costs of realizing BSP-SO trading of reserve capacity related to the procurement process are not very high; this adds up to a large amount of integration costs for this arrangement. Finally, the social welfare of cross-border exchanges is altered by the reservation of interconnection capacity. In general, this reservation both reduces the economic value of day-ahead and intra-day trade, and improves the economic value of balancing service exchange (see discussion of the variable 'reservation of interconnection capacity for balancing' in subsection 5.1.2 and appendix I). To assess the latter, not only the reduction in reserve capacity costs should be taken into account, but also resulting decreases in balancing energy costs and imbalance costs. We tend to agree with ENTSO-E (2011d) that there is no reason to assume that reserve capacity price differences will always be smaller than day-ahead price differences. We estimate that the SOs will be able to make a reasonably accurate calculation on the day before delivery on a social welfare-maximizing allocation of interconnection capacity, and that allocation to cross-border balancing will occur more than sporadic. Adding that to the increase in interconnector utilization that the balancing energy exchange already achieves, we estimate that the social welfare of cross-border exchanges increases substantially.

Again, the relative power system sizes and the generation portfolios have a large influence on the effects. The consumption portfolio again is estimated to have a small effect. However, the size of the interconnection capacity, the day-ahead market design and the liquidity of the market are relatively more important now, because the affect the potential and impact of the reservation of interconnection capacity for reserve capacity exchange. Therefore, their influence is higher than for the arrangement of BSP-SO trading of balancing energy. Here, the number of BSPs has some influence, because the simultaneous reserve capacity bidding in different markets will improve competition, which is more important if there are only a few BSPs with market power. This also depends on the strategy of BSPs.

An additional voluntary pool for balancing energy : This arrangement establishes an additional regional balancing energy market that services as a platform for the sharing of balancing energy bids by System Operators. The additional voluntary pool is a form of SO-SO trading, i.e. it is the connecting SO who decides to offer balancing energy services across the border. But the defining feature of this arrangement setting it aside from BSP-SO trading is that it is the connecting SO who activates and settles exchanged bids. Of course, this requires an additional payment by the receiving SO to the connecting SO, a design aspect that has been treated under the design variable 'redistribution of balancing costs' (see appendix I). In terms of information exchange, the receiving SO will request in real-time the activation of a balancing energy bid in the pool, and the connecting SO will do the actual activation. Therefore, the adaptation of the energy schedule of the relevant BRP will take place like normal. Also, it is less of a necessity that the bid requirements, gate closure times and Schedule Time Units are harmonized (compared to BSP-SO trading), although here such harmonization would facilitate cross-border exchanges as well.

First, it can be considered whether it is possible to bid into multiple markets at the same time. To answer this, we must consider the bid submission and selection process. First of all, bids offered in the additional pool could be utilized by different control areas in the balancing region. As soon as any SO selects the bid, the bid needs to be removed from the pool, and this SO will request activation of the bid. This feature is inherent to the additional voluntary pool, and an advantage compared to BSP-SO trading, where a bid can probably only be offered in one market at a time. The simultaneous incorporation of a bid in the own bid ladder and in the pool would create again uncertainties on the availability of these bids and the risk of losing the cheapest bids to other areas, as occurs in BSP-SO trading (see above). However, in this arrangement, the submission of a balancing energy bid in the additional voluntary pool by the connecting SO is not directly linked with a national bid. The connecting SO has the option to specify a bid price and volume without a specific bid in mind, and thus without placing a bid out of the bid ladder. The advantage of doing this is that the merit order activation is not interrupted and that the cheapest services are always activated. We conclude that it is unnecessary and suboptimal to remove bids from the national bid ladder because of submission in the pool.

The main detailed design issue is what is the method by which the connecting SO decides on the bid volumes and prices for the 'virtual' bids submitted in the additional voluntary pool. Regarding the total volume offered, the SO could be concerned that the availability of balancing resources would be negatively affected if all the submitted bid are selected by other SOs, and for this reason submit only a small total volume. However, it may very well be possible that bid submitted in the pool can be withdrawn. There is no reason why connecting SO should not be allowed to withdraw bids from the pool if the national system imbalance turn out to become quite large. However, it could very well happen that external SOs select an offered bid before the SOs have had the chance to withdraw it. Therefore, the option of withdrawal does not fully remove the problems surrounding the decision on bid prices. In theory, the connecting SO could specify bid prices without knowledge on the final national bid ladder in their area, but this will create the risk that the regulation price becomes higher than the specified bid price, resulting in a net loss. Although this could be tackled by setting high bid prices, this would reduce the attractiveness of those bids for other SOs. It appears more sensible to set the bid prices and volumes equal to actual bid prices and volumes in the national bid ladder, and withdraw the bids if these turn out to be necessary for maintaining the national system balance.

An important first sub-choice is here which bids the connecting SO will activate in case of the request from external SOs to activate balancing energy bids for exchange. If the regionally offered and selected bids correspond with bids that are out of merit order activation in the connecting area, activating these 'corresponding bids' would create discrimination between BSPs, because exported bids would receive a different, higher price than the national regulation price. The latter would give BSPs whose bids are exported an incentive to earn money by not delivering, as the national imbalance price is lower than the price it receives for its service. To prevent this, the connecting SO could just activate bids in merit order, and make no distinction between national use and export. The consequence is that the national regulation prices and imbalance prices will increase because of the balancing energy export, however. In addition, the net income from the balancing energy exchange for the connecting area becomes larger, reducing cost allocation efficiency. To wrap up, the choice between 'combined settlement' and ' separate settlement' of nationally used bids and exported bids has large consequences for non-discrimination, utilization efficiency and incentive compatibility (better for combined settlement) and for cost allocation efficiency and price levels (better for separate settlement).

Another sub-choice relates to the price that the receiving SO pays to the connecting SO for imported balancing energy. If the receiving SO includes the selected bids in his bid ladder mechanism, the receiving SO will pay the regulation price of the receiving area to the connecting SO as a compensation. Thus, a value-based price is paid to the connecting SO for exported bids, who thereby ends up with a net income (given that the regulation price in the receiving area is higher than the regulation price in the connecting area). In case of 'separate settlement', BSPs whose bids have been exchanged are out of merit order activation in the connecting area, and should receive their own bid price. Therefore, the price that the receiving SO pays should be at least this price, in order for the connecting SO not to lose money on the exchange. Paying the regulation price of the receiving area will create a benefit for the connecting area, which appears fair; the receiving area already benefits from the activation of the cheaper imported bid(s).

The net income must somehow be redistributed within the connecting area. This is another design choice. We assume that this is either given back to the system users through the adaptation of the system services tariff, or through proportional fees to the BRPs (see 'allocation of net settlement sum' in appendix H). If the income would be given to the BSPs whose bids are exchanged, some discrimination between BSPs would be introduced, and BSPs could have incentives to not deliver energy (see 'penalty for non-delivery' in appendix H) or to increase bid prices in order to be selected for export. If the income would be kept by the connecting SO, he would have a financial interest, giving a perverse incentive to maximize income from cross border balancing.

If regionally offered bids are selected by external SOs before they can be withdrawn in case they unexpectedly fall within merit order in the connecting area, the regulation price in the own area is affected. To prevent this, and also to prevent any reduction in the availability of balancing resources, connecting SOs will probably aim to offer only the bids that will (quite) certainly not be within merit order, despite the option of withdrawal.

For the estimation, we assume that submitted bids in the pool resemble bids in the national bid ladders, that exchanged balancing energy is settled with the regulation price of the receiving area, that only bids that are quite certainly out of merit order are offered, and that these bids are withdrawn if needed for national system balancing. Finally, we assume that a separate settlement of exported bids is applied, considering that connecting SOs will probably prefer that national balancing energy prices and imbalance prices are not affected by the balancing energy exchange.

The last assumption on separate settlement of exported bids has a large impact on the similarities between other cross-border balancing arrangements. With combined settlement, the additional voluntary pool would look more like the common merit order list. The assumed separate settlement has more of BSP-SO trading, including the risks of inefficient utilization of bids and adverse incentives to not deliver balancing energy. However, in the additional voluntary pool the SOs control the balancing energy exchange in detail, which may increase the amount of balancing energy exchange realized, and will reduce the negative effects on the availability of balancing resources and on utilization efficiency. Compared to the common merit order list, the utilization efficiency of the voluntary pool is dependent on the bid submission into the pool by connecting SOs, and on the selection of submitted bids by other SOs. Concerning the bid submission by connecting SOs, SOs may not have enough incentives to offer bids into the regional pool, considering that it means additional efforts, while it is not allowed to keep the related profits. Furthermore, the utilization efficiency and availability of resources could reduce if offered bids turn out to be valuable nationally. Concerning the bids selected by other SOs, SOs may fail to see the opportunity to utilize cheaper bids, SOs may not accept the delay in activation, and bids could be selected by an external SO that would benefit less than another external SO.

Following the above, the impact of the additional voluntary pool for balancing energy on price efficiency and utilization efficiency is estimated to be large. The availability of balancing resources is also enlarged to a high degree thanks the regional pool. Balance planning accuracy could be reduced a bit due to the lower imbalance prices in the importing areas. The balance quality could be reduced a bit as a result of the delay in activation, and due to non-delivery by BSPs whose bids are exported. The cost allocation efficiency is moderately reduced because of the net income earned by the balancing energy exchange. In case bids are exported while within merit order, a net loss might arise. Because there are much more transaction costs between SOs, the operational efficiency will reduce by a large extent. Significant transparency reduction and discriminatory market conditions arise, because SOs have a lot of freedom regarding the bid submission and withdrawal, and exported bids often receive a higher reward. The integration costs are estimated as large; a regional platform for the offering of bids is required, and a reliable communication system between SOs must be installed. The social welfare of cross-border exchanges will increase moderately: Only the remaining interconnection capacity after day-ahead and intra-day cross-border trade will be used, which is probably not a large quantity.

The generation portfolio is a very important contextual factor, because the portfolios in different areas determine for an important part the relative balancing energy price level in different balancing energy markets, and the level of balancing energy demand (system imbalance) and supply (bid volumes) in the different markets, which in turn determines the potential costs reductions. The consumption portfolio and the power system size have a similar influence as the earlier arrangements. Because the additional pool create large opportunities for exchange, short-term market design and liquidity and the interconnection capacity have a larger influence than for BSP-SO trading of balancing energy. The number of BSPs can have a large influence, because the additional voluntary pool has the potential to significantly increase the competition between BSPs.

An additional voluntary pool for reserve capacity : An additional voluntary pool for reserve capacity creates a regional platform on which connecting SOs in the balancing region can offer national reserve capacity bids to other SOs. The connecting SO procures and settles the exchanged bids, including the corresponding balancing energy bids, upon request by the receiving SO. For this, it receives compensation from the receiving SO. The procurement of external reserve capacity bids require the reservation of interconnection capacity, in order to ensure its availability for the duration of the contract period.

Like for BSP-SO trading of reserve capacity, harmonization of the timing of reserve capacity markets is a prerequisite for reserve capacity exchange, and harmonization of the bid requirements highly improves the possibilities for exchange. In addition, it is estimated again that the potential for reserve capacity exchange is quite large, despites the restriction imposed by the minimum reserve requirements of control areas and the need for available interconnection capacity. In addition, it is assumed again that a daily reserve capacity market is in place.

Here, it is definitely the receiving SO who should reserve the cross-border capacity, because the BSPs are not involved in the reserve capacity exchange, and it is the receiving SO who benefits from the exchange. Thus, this is not really a detailed design choice for this arrangement.

First, it should be decided if the reserved interconnection capacity can also be utilized for the balancing energy exchange of bids that do not correspond with the exchanged reserve capacity bids. This should be possible, because it maximizes the efficient utilization of the reserved interconnection capacity for cross-border balancing. Therefore, it is assumed that this arrangement also includes an additional voluntary pool for balancing energy (similar to the assumption for BSP-SO trading of reserve capacity).

A second detailed design choice concerns again the bidding into multiple reserve capacity markets at the same time. This is a possibility, although selection in the market of the connecting area should overrule the earlier selection in another market, in order to prevent inefficient exchanges and costs increases for exporting area. Thus, the procurement process should be an iterative process, and be coordinated with the reservation of interconnection capacity. This is similar to BSP-SO trading of reserve capacity. Compared to the additional voluntary pool for balancing energy, the potential for exchange can be utilized much more, i.e. much more bids can be offered in the regional pool, thanks to the known demand (namely the reserve requirement volume) and the day-ahead time frame, which reduces the security threats of this form of cross-border balancing.

The main detailed design choice concerns again the method by which the connecting SO decides on reserve capacity bid volumes and prices. Also in the case of reserve capacity bids, it appears best for cost allocation efficiency that the offered bids should resemble the national bids. Here, however, the choices on bid activation, pricing and settlement are much simpler. Due to the fixed demand and the iterative day-ahead procurement process, there is no risk of exporting bids that could have been used nationally. Because pay-as-bid pricing is usually applied, it is obvious that BSPs should receive the bid price for exported bids, and that the receiving SO pays the bid price of the exchanged bid to the connecting SO. As a result, reserve capacity exchange can be realized at maximum utilization efficiency, and will not affect cost allocation efficiency. In case marginal pricing is used, the same design choices play a role as for balancing energy. We assume that pay-as-bid pricing is used in the reserve capacity markets.

The effects of the additional voluntary pool for balancing energy form the basis for the estimation of the effects of the additional voluntary pool for reserve capacity, because the former arrangement has been assumed to be included in the latter. In general, the impact of this cross-border balancing arrangement is dependent on the offering strategies of the connecting SOs. If they are somehow dedicated to make the best use of the potential for reserve capacity exchange, more exchange will emerge. Of course, the potential itself is dependent on the level of interconnection capacity reservation that is expected to increase social welfare. We estimate that the reserve capacity exchange is moderately large, causing a moderate decrease in price efficiency. Adding this effect to that of the voluntary pool for balancing energy, the aggregate effect on utilization efficiency and price efficiency is estimated to be very large. The increase in availability of reserve capacity also adds up to a very large increase of the availability of resources. Compared to the additional voluntary pool for balancing energy, this arrangement does not further affect balance quality. Non-discrimination is not further affected as a result of pricing exchanged bids no different than other bids. Cost allocation efficiency is not affected, also due to the pay-as-bid pricing. The transparency is further reduced by the coordinated procurement processes and the interconnection capacity allocation process, and operational efficiency drops further due to the additional transactions related to reserve capacity exchange. The integration costs also increase some more. Finally, the social welfare of cross-border exchanges will increase a lot compared to the voluntary pool for balancing energy, because the reserve interconnection capacity will be utilized both for reserve capacity exchange and balancing energy. This leads to the estimation of a very large increase in social welfare.

Similar to the voluntary pool for balancing energy, the power system size has a large influence, the generation portfolio has a very large influence, and the consumption portfolio has a small influence on the effects of this arrangement. Because the effects of this arrangement depend to a large degree on the potential for welfare-enhancing interconnection capacity reservation, the interconnection capacity has a very large influence, and the short-term market design and liquidity have a large influence. The number of BSPs has again a large influence, because of its direct relation to competitiveness, and for the same reason the strategy of BSPs has an influence too.

A common merit order list for balancing energy : In this arrangement, a regional System Operator places all balancing energy bids, collected and forwarded by the different SOs in the balancing region, in a regional bid ladder. He balances supply and demand for the balancing region as a whole, which means that system imbalance netting implicitly takes place, and that the regionally cheapest bids are activated to resolve the remaining regional imbalance. Probably, all automatic FRR bids are connected to a regional Load-Frequency Control (LFC) system, which implies that the regional SO directly sends control signals to balancing resources in order to dispatch balancing energy. Also, manual RR bids will probably be activated by the regional SO. In case balancing energy is exchanged across borders, the availability of interconnection capacity must be checked, and Area Control Errors (ACEs) must be adapted. The connecting SOs must be notified, so that they can adapt energy schedules, and can take the into account the impact on power flows in their transmission network. Because the balance planning and settlement processes are tied to the control area, settlement of the activated balancing energy bids will still be carried out by the national SOs. As a consequence, a redistribution of balancing energy costs should take place, where the net importing SOs pay the net exporting SOs for the exchanged balancing energy. The common merit order list is, like the additional voluntary pool, a form of SO-SO trading, but here the balancing energy exchange is not voluntary. No decision on the offering of balancing energy across border needs to be made; all bids are bundled regionally. Unlike in the voluntary pool, it is the regional SO who activates the bids. However, the connecting SO still executes the basic settlement processes. Thus, the BSP is still a passive stakeholder who does not notice the balancing service exchange, unlike under BSP-SO trading and the additional voluntary pool (although here it depends on the detailed activation and settlement choices).

The introduction of a common merit order list requires the harmonization of quite a lot of balancing market design variables. The regional balancing energy market implies at least the harmonization of the procurement method, market timing, balancing service pricing and bid requirements for the balancing energy market. Actually, these prerequisites relate more to integration, but as the balancing market rules remain embedded in national codes, one can still speak of harmonization. In addition, the Schedule Time Unit (STU) must be harmonized. After all, the STU length is equal to the time unit used within the balancing energy market. Furthermore, the harmonization of imbalance pricing mechanisms will significantly improve performance. A single regulation pricing mechanism calls for a single imbalance pricing mechanism, so that the real-time costs are equally and efficiently allocated to Balance Responsible Parties (BRPs), and BRPs receive equal and appropriate incentives in all control areas.

The allocation of balancing energy exchange volumes to different control areas in the balancing region is complicated a bit by the system imbalance netting that goes together with the centralized balancing energy dispatch. As discussed under the effect estimation of the ‘redistribution of balancing costs’ in appendix I, the allocation of balancing energy costs depends on the redistribution of ACEs. Because of the implicit inclusion of system imbalance netting in this arrangement, we also incorporate here the assumptions made for system imbalance netting above, including a redistribution of ACEs based on original system imbalance volumes. Having done that, the net balancing energy import/export flow into/out of each control area can be determined. From this, it can be derived what balancing energy volumes need to be settled between which SOs (on a net basis).

Again, some details related to this arrangement are too obvious to be considered detailed design choices. The role of the regional SO is logically taken up by one of the System Operators of the control areas in the balancing region. A SO has the knowledge and capabilities to fulfil this role. The only concern is that it must be ensured that the regional SO cannot deviate from merit order activation in order to reduce the balancing costs for its own control area, or for security reasons. Next, in cases of congestion between the control areas, the region should be split up into what Nordel calls ‘regulation areas’: areas with a separate regulation price, and thereby a separate imbalance price (Nordel, 2008a). In theory, uniform prices could be maintained in STUs with inter-area congestions, but this would create no locational incentives to Balancing Service Providers to offer balancing services or to Balance Responsible Parties to reduce imbalances.

A relevant detailed design choice relates to the pricing of exchanged balancing energy bids in cases of congestion, and resulting balancing energy market splitting. Without congestion, one regional regulation price will be applied to settle all balancing energy bids. Logically, exchanged balancing energy is also settled between System Operators with this uniform price. This assumes that marginal pricing is applied. If pay-as-bid pricing were to be applied, a lot more redistribution between System Operators would be needed, assuming that the connecting SOs pay for the activated bids. In that case, considering that the uniform imbalance price becomes the weighted average of the bid prices, and that the income from imbalance settlement should for each SO equally pay for dispatched balancing energy, redistribution would become very non-transparent and complicated. In addition, the incentive compatibility would be heavily damaged by the fact that the reward for balancing energy delivery would usually be different from the penalty for imbalance. Therefore, we assume that marginal pricing is applied. In case of congestion, the balancing region will split into two or more 'regulation areas'. The regional bid ladder is equally split up into two or more bid ladders, where each of the ladders include the bids originating from the own area(s). The marginally activated bid on each of these ladders determines the regulation price in the regulation area. The activated bids in each regulation area are settled with the local regulation price. Here, the decision must be made with what price the exchanged balancing energy is settled. This issue has been discussed under the design variable 'redistribution of balancing costs' (see appendix I), and is similar to the inter-SO settlement issue for the additional voluntary pool (see above). Generally, a price could be set equal to the regulation price of the importing regulation area, the regulation price of the exporting regulation area, or somewhere in between. The choice made determines how the financial value of the balancing energy exchange is distributed among areas. As for the additional voluntary pool, we assume that exchanged energy is settled with the regulation price of the importing area. It is fair that the exporting area fully receive the value of the cross-border exchanges, because the importing areas already benefit from the general price reductions effectuated by the common merit order list, while the exporting areas are faced with price increases.

An interesting consideration is whether it is possible to settle all exchanged balancing energy separately from bids that have been activated for the national system balance, in order not to influence balancing energy prices and imbalance prices due to balancing energy export. Indeed, it appears to be possible in theory; it will look like the additional voluntary pool with a separate settlement of exported bids. Apart from the negative effects this has on transparency and operational efficiency, and goes against the fundamental idea of a single regional market, this would again introduce discrimination between nationally used bids and exported bids, and give an adverse incentive to BSPs to not deliver balancing energy. For these reasons, we assume that no separate settlement of nationally used bids and exported bids takes place.

Considering the effects on costs, the common merit order list generally reduce the total regional balancing energy costs for three reasons: Because system imbalance netting reduces the amount of activated balancing energy, because the regional selection of the cheapest bids reduces the bid prices of the bids within merit order activation, and because the level of competition between Balancing Service Providers will increase. Probably, the second reason has the largest effects on costs reductions, but this depends among other things on power system sizes, the degree of balancing energy exchange, marginal costs of balancing resources, and exertion of market power. Although the large balancing energy exchange volumes that may emerge can cause a significant rise of regulation and imbalance prices in the exporting areas, the prices in the importing areas are likely to decrease more. One should be aware, however, that this is not necessarily true: It is possible that the additionally selected bids cause a price increase in the exporting area that is higher than the price decrease in the importing area. Moreover, the net effect of the introduction of the common merit order list on the total regional balancing energy costs could theoretically be negative. This net effect depends on the changes in the bid ladder curves (price jumps and drops) and the changes in the volumes of activated balancing energy (system imbalance volumes). Also, changes in BSP bidding strategies could contribute to that, in case the balancing energy exchange potential gives BSPs with cheap resources relatively more market power to increase prices (by bidding just below the price level of the expensive areas). Crucially, however, the total activated balancing energy volume will significantly reduce due to system imbalance netting. Taking that into account, the total balancing energy costs are very likely to reduce. In addition, the much higher supply of balancing energy (thanks to the common merit order) in combination with the lower demand (thanks to system imbalance netting), will probably increase competition a lot, which should reduce market power, and thereby submitted prices.

Another consideration is the general effect that the lower balancing energy profits for BSPs has on their bidding strategies. If the common merit order list significantly reduces these profits, BSPs may decide to utilize their resources differently, reducing the amount of offered balancing energy. Furthermore, they might decide to increase their bid prices. However, the first response is not likely to have a large effect, because the balancing energy market is the last market to make a profit on, and because the reserve capacity contracting by the SOs guarantees the submission of a large minimum amount of balancing energy bids. The second response will probably not increase the profits of BSPs, because the enhanced competition will than further shift the rate of selection of their bids down towards zero. A last effect relates to the change in behaviour of Balance Responsible Parties. After all, the lower regulation prices go together with lower imbalance prices. This could bring BRPs to decrease their portfolio balancing efforts somewhat, in case the costs of these efforts become higher than the imbalance costs of the prevented imbalance volumes. As an effect, activated balancing energy volumes and thus prices could increase again. However, we estimate that the portfolio balancing costs are not very large, and generally smaller than the imbalance costs that will develop in a common merit order list. Therefore, balancing energy costs are not expected to increase as a result of larger BRP imbalances.

The impact of the common merit order list on utilization efficiency is clearly very large: System imbalance netting is applied, and the cheapest balancing energy bids regionally availability are utilized. The impact on price efficiency will also be very large, as the possible negative effects on bid prices and volumes (see above) are not expected to have a significant effect. The same estimation is made for the availability of balancing resources, again due to the system imbalance netting in combination with the integrated market. The higher availability of resources may also increase the activation of fast resources, while system imbalance netting reduces the ACEs. Both developments increase the balance quality. The balance planning accuracy is not expected to be significantly affected; the small reduction in portfolio balancing efforts in the importing areas is compensated by the small increase in the exporting areas. Cost allocation efficiency is moderately diminished by the income generated by balancing energy export. The operational efficiency is estimated to be reduced only moderately, because the centralized balancing service provision limits the increase in the number of transactions. Because balancing energy dispatch and settlement processes are integrated and executed without leaving many choices for System Operators, non-discrimination is not affected. Compared to separate balancing markets, the transparency is still affected to a small extent due to the balancing market integration. The integration costs are very large, because of the required harmonization steps, and due to the costs of integrating the LFC systems, ICT systems and administrative processes. The social welfare of cross-border exchanges will rise to a large degree; available interconnection capacity will be used for whenever there is an opportunity for cross-border balancing.

With regard to the influence of contextual factors, the same evaluations have made for the common merit order list for balancing energy as for the additional voluntary pool for reserve capacity, which can be explained by our estimation that the level of balancing service exchange is similar in both arrangements. After all, the interconnection capacity reservation in the voluntary pool for reserve capacity guarantees its availability for both reserve capacity exchange and balancing energy exchange, which is estimated to weigh up against the less efficient offering and utilization of balancing services.

A common merit order list for reserve capacity : In a common merit order list for reserve capacity, the reserve capacity markets have been integrated into one regional reserve capacity market, which is operated by a regional System Operator to procure the cheapest reserve capacity services for the balancing region. As opposed to balancing energy, the cross-border exchange of reserve capacity is not only restricted by the availability of interconnection capacity, but also by the requirement to at least procure 50% of FRR and RR capacity within the own control area (i.e., the geographical distribution of balancing resources must be safeguarded). The regional SO calculates the socially optimal allocation of interconnection capacity to balancing service exchange, and determines the regionally cheapest procurement given all the reserve capacity bids collected by the SOs and forwarded to the regional SO. The regional SO notifies the results to the SOs, who procure and settle the reserve capacity services located within their own control area. The cross-border exchange of reserve capacity is settled between System Operators. In real-time, the reserved interconnection capacity will be utilized in the regional balancing energy activation process, which is carried out as described under the arrangement of the common merit order list for balancing energy.

The creation of an integrated regional reserve capacity market requires the harmonization of the procurement method, market timing, balancing service pricing mechanisms and bid requirements for the reserve capacity market. Actually, these prerequisites relate more to integration, but as the balancing market rules remain embedded in national codes, one can still speak of harmonization. Harmonization of the STU length and the imbalance pricing mechanism are more relevant for the common balancing energy market (which is included in this arrangement as well).

There are not a lot of detailed design choices related to the common merit order list for reserve capacity, because of the centralized and optimized submission and section process. Because balance settlement remains tied to the control area boundaries, additional settlement between SOs to compensate for exchanged reserve capacity must take place. Pay-as-bid pricing is typically used for remuneration of reserve capacity services. In this arrangement, reserve capacity will still be procured for particular control areas, which probably makes it not very difficult to allocate the costs of specific exchanged bids to receiving SO. Here, there is not really a design choice; exchanged bids will be settled with bid prices. Marginal pricing is likely to increase reserve capacity prices and costs much more. This holds especially for the exporting areas, unless a separate settlement is applied to exported bids, which would introduce again some discrimination between BSPs. Thus, we conclude that pay-as-bid pricing is applied in the common reserve capacity market, which does not leave any choice on pricing of selected and exchanged bids.

The existence of a common merit order list for reserve capacity implies that there is also a merit order list for balancing energy. Therefore, the detailed design choices playing a role for the common merit order list for balancing energy and system imbalance netting are also relevant for this arrangement. The same assumptions will be made for this arrangement, which means that the assessment of the impact of this arrangement can be based on that of the common merit order list for balancing energy.

In terms of the general effects of the common merit order list for reserve capacity, it is first important to consider if it is possible to reduce the total amount of procured reserve capacity. We believe that the national reserve requirements of the separate control areas cannot easily be reduced, because System Operators cannot rely on a continuous availability of interconnection capacity. Secondly, it is estimated again that the reservation of interconnection capacity for cross-border balancing will quite frequently be socially optimal, enabling a large level of reserve capacity exchange. Thirdly, the reserved interconnection capacity creates a guaranteed minimum potential for balancing energy exchange, and thus will effectuate a high degree of such exchange. Compared to the common merit order list for balancing energy, this will result in larger balancing energy exchange volumes, on top of the reserve capacity exchange.

Regarding the specific effects of the common merit order list of reserve capacity, the availability of balancing resources is expected increase massively, because of the utilization of the reserved interconnection capacity for both reserve capacity exchange and balancing energy exchange. As a result of this, and of the system imbalance netting and the enhanced competition, utilization efficiency and price efficiency will also increase hugely. The balance planning accuracy is not affected on a net regional basis, and balance quality is not further changed compared to the common merit order list for balancing energy. Cost efficiency and non-discrimination are not further changed either. Next, the operational efficiency is significantly reduced further, because the regional reserve capacity market and the higher level of cross-border balancing generate more transactions, including the calculation of the optimal allocation of interconnection capacity. Transparency decreases a bit further, and the internationalization costs increase more. Finally, the social welfare of cross-border exchanges increases more than for a common merit order list for balancing energy alone, leading to the estimation of a very large increase.

Concerning the influence of contextual factors, we assume that these have a similar impact as for the common merit order list for balancing energy. Obviously, the interconnection capacity (availability) and the generation portfolio (supply and cost level of balancing resources) have a very large influence on the effects of this cross-border balancing arrangement.

Table J.1 – Multi-criteria analysis: Estimated effects of cross-border balancing arrangements

	Effects of introduction of arrangement on performance criteria	**Influence of contextual factors**	**'Best' detailed design**
System imbalance netting	*Avail. of bal. res.*: large increase *Balance plan. acc.*: small reduction *Balance quality*: moderate increase *Price efficiency*: moderate increase *Utilization eff.*: large increase *Operational eff.*: small reduction	*Power system size*: very large *Generation portfolio*: large *Consumption portfolio*: small *Short-term market design*: small *Short-term market liquidity*: small *Interconnection capacity*: moderate *Number of BSPs*: moderate	No pricing of surplus energy. Proportional redistribution of ACEs based on system imbalance volumes.
BSP-SO trading of balancing energy	*Balance quality*: moderate reduction *Price efficiency*: small increase *Utilization eff.*: small increase *Operational eff.*: moderate reduction *Soc. welf. of CB ex.*: small increase *Int. costs*: moderate	*Power system size*: large *Generation portfolio*: large *Consumption portfolio*: small *Short-term market design*: small *Short-term market liquidity*: small *Interconnection capacity*: moderate *Strategy of BSPs*: moderate	BSPs do not need to purchase interconnection capacity. Bidding into two markets at the same time is not allowed. An a priori selection process in the connecting area using a volume limit and FCFS rule. No penalty for non-delivery unless easy and cheap.
BSP-SO trading of reserve capacity	*Avail. of bal. res.*: moderate increase *Balance quality*: moderate reduction *Price efficiency*: large increase *Utilization eff.*: large increase *Operational eff.*: large reduction *Transparency*: moderate reduction *Soc. welf. of CB ex.*: large increase *Int. costs*: large	*Power system size*: large *Generation portfolio*: large *Consumption portfolio*: small *Short-term market design*: moderate *Short-term market liquidity*: moderate *Interconnection capacity*: large *Number of BSPs*: moderate *Strategy of BSPs*: moderate	BSPs should not pay for interconnection capacity. Bidding in multiple reserve capacity markets is possible. Reserved interconnection capacity can be utilized for balancing energy exchange of other bids too. Regarding balancing energy: Same as BSP-SO trading for balancing energy.
An additional voluntary pool for balancing energy	*Avail. of bal. res.*: large increase *Balance plan. acc.*: small reduction *Balance quality*: moderate reduction *Price efficiency*: large increase *Utilization eff.*: large increase *Cost all. eff.*: moderate reduction *Operational eff.*: large reduction *Non-discrimination*: large reduction *Transparency*: moderate reduction *Soc. welf. of CB ex.*: moderate increase *Int. costs*: large	*Power system size*: large *Generation portfolio*: very large *Consumption portfolio*: small *Short-term market design*: moderate *Short-term market liquidity*: moderate *Interconnection capacity*: large *Number of BSPs*: large *Strategy of BSPs*: moderate	Bidding in multiple balancing energy markets is possible. Bids submitted to the pool are identical to bids in the national bid ladders. Exchanged energy is settled with regulation price of receiving area. Separate settlement of exported bids; BSPs receive bid price. Connecting SOs withdraw bids if needed to balance own system.
An additional voluntary pool for reserve capacity	*Avail. of bal. res.*: very large increase *Balance plan. acc.*: small reduction *Balance quality*: small reduction *Price efficiency*: very large increase *Utilization eff.*: very large increase *Cost all. eff.*: moderate reduction *Operational eff.*: very large reduction *Non-discrimination*: moderate reduction *Transparency*: large reduction *Soc. welf. of CB ex.*: very large increase *Int. costs*: very large	*Power system size*: large *Generation portfolio*: very large *Consumption portfolio*: small *Short-term market design*: large *Short-term market liquidity*: large *Interconnection capacity*: very large *Number of BSPs*: large *Strategy of BSPs*: moderate	Bidding in multiple reserve capacity markets is possible. Reserved interconnection capacity can be utilized for balancing energy exchange of other bids too. Bids submitted to the pool are identical to national bids. Use of pay-as-bid pricing. Regarding balancing energy: Same as additional voluntary pool for balancing energy.
A common merit order list for balancing energy	*Avail. of bal. res.*: very large increase *Balance quality*: moderate increase *Price efficiency*: very large increase *Utilization eff.*: very large increase *Cost all. eff.*: moderate reduction *Operational eff.*: moderate reduction *Transparency*: small reduction *Soc. welf. of CB ex.*: large increase *Int. costs*: very large	*Power system size*: large *Generation portfolio*: very large *Consumption portfolio*: small *Short-term market design*: large *Short-term market liquidity*: large *Interconnection capacity*: very large *Number of BSPs*: large *Strategy of BSPs*: moderate	One of the SOs takes up the role of regional SO. Splitting into different price areas for STUs with congestion between borders. Exchanged energy is settled with regulation price of receiving area. No separate settlement of nationally used and exported bids. Regarding system imbalance netting: Same as for system imbalance netting.
A common merit order list for reserve capacity	*Avail. of bal. res.*: huge increase *Balance quality*: moderate increase *Price efficiency*: huge increase *Utilization eff.*: huge increase *Cost all. eff.*: moderate reduction *Operational eff.*: very large reduction *Transparency*: moderate reduction *Soc. welf. of CB ex.*: very large increase *Int. costs*: huge	*Power system size*: large *Generation portfolio*: very large *Consumption portfolio*: small *Short-term market design*: large *Short-term market liquidity*: large *Interconnection capacity*: very large *Number of BSPs*: large *Strategy of BSPs*: moderate	Application of pay-as-bid pricing. Reserved interconnection capacity capacity can be utilized for balancing energy exchange of other bids. Regarding common market for balancing energy: Same as for common merit order list for balancing energy.

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Summary

Power system balancing in liberalized electricity markets

An uninterrupted electricity provision is generally taken for granted, and only during black-outs we come to see how much we rely on it. Balance management is a power system operation service vital for ensuring security of supply. It involves the continuous, real-time balancing of power demand and supply in a power system. In vertically integrated electricity systems, it is relatively easy to maintain the system balance, but unbundling has separated the 'branches' of power transmission and power generation and supply. This separation necessitated the introduction of a balancing market. The balancing market is the regulatory regime in an electricity market (power system) that establishes market-based balance management.

With the on-going development of electricity market integration in Europe, the possible development of balancing market internationalization has received an increasing amount of attention from the European electricity sector. A distinction can be made between balancing market harmonization and balancing market integration. Where balancing market integration deals with the exchange of balancing services between different national balancing markets (control areas), balancing market harmonization concerns the equalization of market rules in different balancing markets. This research aims to obtain an overview of the content and possible impact of balancing market design and internationalization. The focus is on European markets that include a voluntary power exchange and freedom of dispatch, and Northern Europe (the Nordic region, Germany and the Netherlands) is adopted as a case study. The research question is the following:

> *To what extent can the design and decision making on multinational balancing markets in Europe improve balancing market efficiency without endangering security of supply?*

Balancing market design framework

A comprehensive assessment of balancing markets requires a design framework that lists all the important requirements and design variables for balancing markets. Based on existing literature on balancing market design and integration, a balancing market design framework has been composed and presented. This framework consists of a reference model, an evaluation set, and a design space. The reference model introduces the concepts of the national balancing market and the multinational balancing market and provides standard terminology, the evaluation set offers a set of performance criteria, and the design space lists the relevant design variables.

In the reference model the structure of the balancing market is defined. A balancing market consists of three main pillars or phases, i.e. balance planning, balancing service provision, and balance settlement, and three main actors, i.e. 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 activated balancing energy are settled on a STU basis. BRPs with a shortage pay the short imbalance price for each MWh of deviation, and BRPs with a surplus receive the long imbalance price. Balancing services consist of two main types: balancing energy, i.e. the real-time adjustment of balancing resources to maintain the system balance, and reserve capacity, i.e. the contracted option to dispatch balancing energy during the contract period. Furthermore, one can also differentiate between upward regulation and downward regulation, and between Frequency Containment Reserves (FCR), Frequency Regulation Reserves (FRR), and Replacement Reserves (RR), which have a different function and activation method.

Geographically, a synchronous zone is often divided in control areas, i.e. power system areas for which a system balance is maintained separately. For the topic of balancing market integration, a relevant concept is that of ‘cross-border balancing’, i.e. the exchange of energy between control areas for the purpose of balance management. To realize this, a cross-border balancing arrangement must be introduced. Four main arrangements are system imbalance netting, BSP-SO trading, an additional voluntary pool, and a common merit order list. Of these, system imbalance netting just involves the netting of opposite system imbalances. BSP-SO trading enables BSPs to offer balancing services in foreign balancing markets. In a voluntary pool, SOs exchange balancing services on a voluntary basis. In a common merit order list, balancing service markets are integrated into one regional market.

In the evaluation set, requirements, performance criteria and performance indicators for balancing markets are formulated. Obviously, two fundamental requirements that a balancing market must meet are economic efficiency and security of supply. Lower-level requirements directly correspond to the formulated performance criteria. The balancing market performance criteria set consists of eleven criteria, the majority of which can be linked to one of the fundamental requirements. In the design space, all the relevant balancing market design variables are listed. Despite the high aggregation level, as many as thirty-five design variables have been identified, of which twenty-four are nationally oriented and eleven are internationally oriented.

Impact of national design and harmonization

In an initial system analysis of factors and links in the balancing market, three main feedback loops have been found: the ‘reserve capacity loop’, the ‘balancing energy loop’, and the ‘imbalance loop’. The first two represent the feedback between the volumes and prices of offered balancing services and the volumes and prices of procured balancing services. The 'imbalance loop' represents the feedback between individual and system imbalance volumes and imbalance prices and costs. These three feedback loops are all negative feedback loops. They form the core of the functioning of the balancing market, constituting the incentive mechanisms that aim to provide appropriate incentive to the balancing market participants (BRPs and BSPs).

The main analysis is formed by a multi-criteria analysis of the possible effects of the national design variables, which also includes an evaluation of the influence of the main contextual power system and power market factors, and a consideration of the generalizability of best-performing design variable values. Based on this analysis, it is concluded that the national balancing market design as a whole has a large total impact on all performance criteria, that most design variables have a significant impact on performance, that the performance criterion 'availability of balancing resources' is affected the most by the national balancing market design, and that the generation portfolio is by far the most influential contextual factor. The impact of national balancing market design has been estimated to be similar for economic efficiency and security and supply; both criteria take up a major share of the aggregate impact level of national design. However, the specific order in impact level of individual design variables appears not to deliver concrete insights. The results of the multi-criteria analysis show that in-depth qualitative analysis can generate numerous arguments to support the superiority of specific national design variable values, despite the high context dependence of effects. Next, an agent-based simulation has been carried out for the imbalance pricing mechanism, taking into account the portfolio balancing strategies of Balance Responsible Parties. The results indicate that the impact of the imbalance pricing mechanism on system imbalance volumes is very small, but that the imbalance costs for BRPs differ a lot between mechanisms, with single pricing leading to the lowest imbalance costs.

The case study of Northern Europe enables the exploration of the impact of harmonization for a specific case. Remarkably, the balancing market designs of the Nordic region, Germany and the Netherlands are completely different. This suggests there is no obvious 'best' variable value that is applicable to all power systems and markets, and that it will be very challenging to fully harmonize national balancing markets in Europe. A promising harmonization design for Northern Europe, involving eight design variables, has been formulated and evaluated. This design has been found to potentially improve the performance of all three balancing markets to a high degree. From this exercise we conclude that the insights from the system analysis and the multi-criteria analysis effectively support the formulation of a promising harmonization design for a specific case. Also, the exercise shows that the performance improvement will not be equally large in the different national balancing markets, and that the values for some performance criteria will deteriorate (nationally).

A main finding from the national analyses is that, although one cannot generalize on the impact of balancing market harmonization on balancing market performance due to the dependency on initial designs and the proposed harmonization design, the impact of well-considered harmonization adapted to the specific case can be expected to have a large positive impact on balancing market performance in all involved control areas.

Impact of multinational design and integration

A similar multi-criteria analysis has been executed to assess the effects of the multinational balancing market design variables, and also to evaluate the impact of the main cross-border balancing arrangements. The results show that multinational balancing market design as a whole also has a large impact on all balancing market performance criteria, but that this total impact is smaller than for national balancing market design. This can be explained by the smaller number of multinational variables. Regarding the cross-border balancing arrangements, the three arrangements with the best outcome have an equally large positive impact on balancing market performance, even though individual effects on performance criteria were evaluated quite differently. These are system imbalance netting, a common merit order list for balancing energy, and a common merit order list for reserve capacity. The additional voluntary pool arrangements and BSP-SO trading of balancing energy result in a negative net effect, but this is largely due to negative effects on criteria like operational efficiency and internationalization costs, which offset the improvement of utilization efficiency, price efficiency and availability of balancing resources.

To analyse the impact of the arrangements for the case study of Northern Europe, the agent-based simulation study has been extended to represent cross-border balancing between the North-European areas. The results show that the choice for an arrangement has a major impact on not only the total balancing energy costs, but also on the imbalance costs for BRPs. On a regional level, these costs decrease to a very large degree thanks to the import of most of the balancing energy for Germany and the Netherlands from the Nordic region, which has a large oversupply of cheap hydropower balancing bids. For system imbalance netting the reductions are small but equally large in all areas. For the other arrangements the area with the highest costs (Germany) benefits most, while the area with the cheapest balancing services (the Nordic region) faces price increases under BSP-SO trading and a common merit order list.

A main generalizing conclusion on balancing market integration is that system imbalance netting and a common merit order list generally have a large positive impact on balancing market performance in the balancing region. For BSP-SO trading and an additional voluntary pool, the magnitude and direction of effects depend a lot on the detailed design of the arrangement.

Synthesis and decision making

Comparing the estimated effects of cross-border balancing arrangements with those of national balancing markets, it becomes apparent that, in general, balancing market harmonization has a higher potential to improve balancing market performance than balancing market integration. This is due to the high number of national design variables, many of which have a large effect on performance. However, a general statement on the relative values of harmonization and integration cannot be made, because harmonization can take so many forms. Anyhow, the possibilities of harmonization and integration should be studied both. This will take place naturally if a common merit order list is striven for, which has been found to have the most positive impact of all cross-border balancing arrangements. This is because for this arrangement some prerequisite harmonization is needed.

Decision makers on balancing market internationalization, i.e. System Operators, energy regulators and governments, should, recognizing the myriad of design options, possible goals and uncertainties, adopt a systematic and deliberate approach to decision-making. We propose a structured decision-making process, which is divided into three phases: a design phase, an analysis phase, and a decision phase. The formulation of the design problem and of promising design alternatives in the first phase can be greatly supported by the balancing market design framework presented in this thesis, while in the analysis phase the analysis approach and generated insights from the multi-criteria and agent-based analyses support the structuring and execution of an effective analysis. The design and analysis steps should be attuned to the specific case. After a decision has been made to create a multinational balancing market design, another choice should be made about the transition process to be followed. A transition in multiple steps increases the flexibility of the internationalization process, but will bring about higher switching costs.

Coming back to the research question, we conclude that the development of multinational balancing markets in Europe has the potential to highly improve both the economic efficiency and the security of supply of all involved national balancing markets, but that a structured and deliberate approach to design and decision making is required to maximize the chance of successful decision making on balancing market internationalization.

Samenvatting

Balanshandhaving van elektriciteitssystemen in geliberaliseerde elektriciteitsmarkten

Een ononderbroken voorziening van elektriciteit wordt vaak als vanzelfsprekend aangenomen, en slechts bij stroomuitval realiseren we ons hoeveel we er ons op verlaten. Balanshandhaving is een operationele elektriciteitsvoorzieningsdienst die van vitaal belang is voor het waarborgen van de leveringszekerheid. Het behelst een continu, real-time balanceren van elektriciteitsvraag en -aanbod in een elektriciteitssysteem. In verticaal geïntegreerde elektriciteitssystemen is het relatief gemakkelijk om de systeembalans the handhaven, maar ontbundeling heeft de 'takken' van elektriciteitstransmissie en -opwekking van elkaar gescheiden. Door deze scheiding ontstond de noodzaak voor een balanceringsmarkt. De balanceringsmarkt is het regulatorische regime in een elektriciteitsmarkt (elektriciteitssysteem) dat marktgebaseerde balanshandhaving tot stand brengt.

Door de voortdurende ontwikkeling van de integratie van elektriciteitsmarkten in Europe heeft de mogelijke ontwikkeling van de internationalisering van balanceringsmarkten een groeiende hoeveelheid aandacht ontvangen van de Europese elektriciteitssector. Een onderscheid kan worden gemaakt tussen harmonisatie en integratie van balanceringsmarkten. Waar de integratie van balanceringsmarkten over de uitwisseling van balanceringsdiensten tussen verschillende nationale balanceringsmarkten (controlegebieden) gaat, betreft de harmonisatie van balanceringsmarkten het egaliseren van marktregels in verschillende balanceringsmarkten. Dit onderzoek heeft tot doel een overzicht te verkrijgen van de inhoud en mogelijke impact van het ontwerp en de internationalisering van balanceringsmarkten. De focus ligt op Europese markten met een vrijwillige stroombeurs en vrijheid van fysieke levering, en Noord-Europa (de Noorse regio, Duitsland en Nederland) is als case study genomen. De onderzoeksvraag luidt als volgt:

> *In hoeverre kan het ontwerp en de besluitvorming van/over multinationale balanceringsmarkten in Europa de efficiëntie van balanceringsmarkten verbeteren zonder de leveringszekerheid in gevaar te brengen?*

Raamwerk voor het ontwerpen van balanceringsmarkten

Een allesomvattende waardering van balanceringsmarkten heeft een ontwerp-raamwerk nodig dat alle belangrijke eisen en ontwerpvariabelen voor balanceringsmarkten in kaart brengt. Gebaseerd op de bestaande literatuur over het ontwerp en de integratie van balanceringsmarkten is er een raamwerk voor het ontwerpen van balanceringsmarkten opgesteld en gepresenteerd. Dit raamwerk bestaat uit een referentiemodel, een evaluatieset, en een ontwerpruimte. Het referentiemodel introduceert de concepten van de nationale balanceringsmarkt en de multinationale balanceringsmarkt en levert standaardterminologie, de evaluatieset levert een set van prestatiecriteria, en de ontwerpruimte presenteert de relevante ontwerpvariabelen.

In het referentiemodel wordt de structuur van de balanceringsmarkt gedefinieerd. Een balanceringsmarkt bestaat uit drie pijlers of fases, nl. balansplanning, balanceringsdienstvoorziening, en onbalansverrekening, en drie hoofdactoren, nl. de netbeheerder (SO), aanbieders van balanceringsdiensten (BSPs), en programmaverantwoordelijke partijen (BRPs). In de fase van balansplanning sturen de BRPs energieprogramma's aan de SO op de dag voor levering, waarin de geplande energieproductie en -consumptie voor iedere programmatijdseenheid (STU) op de dag van levering staat vermeld. In de fase van balanceringsdienstvoorziening sturen de BSPs biedingen op aan de SO, die door de SO in prijsvolgorde worden afgeroepen om de systeembalans te herstellen. In de fase van onbalansverrekening wordt de energieonbalans (programma-afwijkingen) van BRPs en geactiveerde balanceringsenergie verrekend per STU. BRPs met een tekort betalen de 'onbalansprijs voor tekorten' voor iedere MWh onbalans, en BRPs met een overschot ontvangen de 'onbalansprijs voor overschotten'. Er bestaan twee typen balanceringsdiensten: balanceringsenergie, d.w.z. de real-time aanpassing van balanceringsmiddelen om de systeembalans te handhaven, en reservecapaciteit, d.w.z. de gecontracteerde optie om balanceringsenergie gedurende de contractperiode af te roepen. Verder kan men ook een onderscheid maken tussen opregelen en afregelen, en tussen frequentiebeheersingsreserves (FCR), frequentiereguleringsreserves (FRR) en vervangingsreserves (RR), welke een verschillende functie en activeringsmethode hebben.

Geografisch gezien is een synchrone zone vaak verdeeld in controlegebieden, d.w.z. elektriciteitssysteemgebieden waarvoor een aparte systeembalans wordt bewaard. Voor het onderwerp van integratie van balanceringsmarkten is 'cross-border balancing', d.w.z. de uitwisseling van energie tussen controlegebieden voor de balanshandhaving, een relevant concept. Om dit te realiseren moet er een ' cross-border balancing arrangement' worden geïntroduceerd. Vier hoofd-arrangementen zijn 'system imbalance netting', BSP-SO handel, een additionele vrijwillige pool, en een gezamenlijke biedladder. Van deze vier betekent system imbalance netting enkel het tegen elkaar wegstrepen van tegenovergestelde systeemonbalans. BSP-SO handel stelt BSPs in staat om balanceringsdiensten aan te bieden in buitenlandse balanceringsmarkten. In een vrijwillige pool wisselen SOs balanceringsdiensten uit op vrijwillige basis. In een gezamenlijke biedladder worden balanceringsmarkten samengevoegd in één regionale markt.

In de evaluatieset zijn eisen, prestatiecriteria en prestatie-indicatoren voor balanceringsmarkten geformuleerd. Twee duidelijke fundamentele eisen voor balanceringsmarkten zijn economische efficiëntie en leveringszekerheid. Onderliggende eisen corresponderen direct met de geformuleerde prestatiecriteria. De set van prestatiecriteria voor balanceringsmarkten bestaat uit elf criteria, de meerderheid waarvan gekoppeld kan worden aan één van de fundamentele eisen. In the ontwerpruimte zijn alle relevante ontwerpvariabelen voor balanceringsmarkten opgenomen. Ondanks het hoge aggregatieniveau zijn er maar liefst vijfendertig variabelen geïdentificeerd, waarvan er vierentwintig nationaal en elf internationaal georiënteerd zijn.

Impact van nationaal ontwerp en harmonisatie

In een initiële systeemanalyse van de factoren en relaties in de balanceringsmarkt zijn drie feedback loops gevonden: 'de reservecapaciteit-loop', de 'balanceringsenergie-loop', en de 'onbalans-loop'. De eerste twee representeren de feedback tussen de volumes en prijzen van aangeboden balanceringsdiensten en de volumes en prijzen van afgeroepen balanceringsdiensten. De 'onbalans-loop' representeert de feedback tussen individuele onbalans en systeemonbalans en onbalansprijzen en -kosten. Deze drie feedback loops zijn alle negatieve feedback loops. Zij vormen de kern van de werking van de balanceringsmarkt, en vormen de aansporingsmechanismen die geschikte prikkels beogen te geven aan balanceringsmarktpartijen (BRPs en BSPs).

De hoofdanalyse is een multi-criteria analyse van de mogelijke effecten van de nationale ontwerpvariabelen, die ook een evaluatie van de invloed van de belangrijkste contextuele factoren in elektriciteitssystemen en -markten bevat, en een overweging van de generaliseerbaarheid van best-presterende waarden van ontwerpvariabelen. Gebaseerd op deze analyse wordt geconcludeerd dat het nationale ontwerp van de balanceringsmarkt als geheel een grote impact heeft op alle prestatiecriteria, dat de meeste variabelen een grote impact hebben, dat het prestatiecriterium 'beschikbaarheid van balanceringsmiddelen' het meest wordt beïnvloed door het nationale ontwerp, en dat de productieportfolio verreweg de meest invloedrijke contextuele factor is. De impact van het nationale ontwerp is naar schatting vergelijkbaar voor economische efficiëntie en leveringszekerheid; beide criteria dragen voor een groot deel bij aan de totale impact van het nationale ontwerp. Echter, de specifieke volgorde van impactniveau van individuele ontwerpvariabelen lijkt geen concrete inzichten op te leveren. De resultaten van de multi-criteria analyse laten zien dat een grondige kwalitatieve analyse verscheidene argumenten kan leveren om de superioriteit van specifieke waarden van nationale ontwerpvariabelen aan te tonen, ondanks de hoge context-afhankelijkheid van de effecten. Vervolgens is een agent-based simulatie uitgevoerd voor het onbalansprijsmechanisme, rekening houdend met de strategieën van portfolio-balancering van programmaverantwoordelijke partijen. De resultaten duiden aan dat het effect van het onbalansprijsmechanisme op systeemonbalansvolumes zeer klein is, maar dat de onbalanskosten voor BRPs zeer verschillen tussen de mechanismes. 'Single pricing' leidt tot de laagste onbalanskosten.

De case study van Noord-Europa maakt het mogelijk om de impact van harmonisatie voor een specifieke casus te exploreren. Opmerkelijk genoeg zijn de nationale ontwerpen van de balanceringsmarkt compleet verschillend in de Noorse regio, Duitsland en Nederland. Dit suggereert dat er geen duidelijke 'beste' waarden voor variabelen bestaan die toepasbaar zijn voor alle elektriciteitssystemen en -markten, en dat het een grote uitdaging zal zijn om nationale balanceringsmarkten in Europa volledig te harmoniseren. Een veelbelovend harmonisatie-ontwerp voor Noord-Europa, waarin acht ontwerpvariabelen zijn betrokken, is geformuleerd en geëvalueerd. De bevinding is dat dit ontwerp de prestatie van alle drie de balanceringsmarkten in potentie in hoge mate kan verbeteren. Uit deze evaluatie leiden we af dat de inzichten van de systeemanalyse en de multi-criteria analyse goed kunnen worden benut om een veelbelovend harmonisatieontwerp voor een specifieke casus te ontwerpen. Ook laat de evaluatie zien dat de prestatieverbetering niet even groot zal zijn in de verschillende nationale balanceringsmarkten, en dat de waarde voor sommige prestatiecriteria (nationaal) zal verslechteren.

Een belangrijke bevinding van de nationale analyses is dat, hoewel men niet kan generaliseren m.b.t. de impact van harmonisatie van balanceringsmarkten als gevolg van de afhankelijkheid van de initiële ontwerpen en het voorgestelde harmonisatie-ontwerp, de impact van een weloverwogen harmonisatie dat is afgestemd op de specifieke situatie verwacht kan worden een zeer positief effect te hebben op de prestatie van balanshandhaving in alle betrokken controlegebieden.

Impact van multinationaal ontwerp en integratie

Een vergelijkbare multi-criteria analyse is uitgevoerd om de effecten van ontwerpvariabelen voor multinationale balanceringsmarkten te waarderen, alsook om de impact van de belangrijkste cross-border balancing arrangementen te beoordelen. De resultaten laten zien dat het ontwerp van de multinationale balanceringsmarkt als geheel een grote impact heeft op alle prestatiecriteria, maar dat de totale impact kleiner is dan voor het nationale ontwerp. Dit kan worden verklaard door het kleinere aantal multinationale variabelen. Wat betreft de cross-border balancing arrangementen, de drie arrangementen met het beste rendement hebben een even grote positieve impact, ondanks het feit dat individuele effecten op prestatiecriteria uiteenlopen. Dit zijn system imbalance netting, een gezamenlijke biedladder voor balanceringsenergie, en een gezamenlijke biedladder voor reservecapaciteit. De additionele vrijwillige pool en BSP-SO handel van balanceringsenergie hebben een negatief netto effect, maar dit komt voor een groot deel door de negatieve effecten op criteria als operationele efficiëntie en internationaliseringskosten, welke de verbetering van benuttingsefficiëntie, prijsefficiëntie en beschikbaarheid van balanceringsmiddelen teniet doen.

Om de impact van de arrangementen te analyseren voor de case study van Noord-Europa, is de agent-based simulatie uitgebreid om cross-border balancing tussen de Noord-Europese gebieden na te bootsen. De resultaten laten zien dat de keuze voor een arrangement niet alleen een grote impact heeft op de totale kosten voor balanceringsenergie, maar ook op de onbalanskosten voor BRPs. Op een regionaal niveau nemen deze kosten in hoge mate af, dankzij de import van het merendeel van de balanceringsenergie voor Duitsland en Nederland vanuit de Noorse regio, welke een groot overschot aan goedkope waterkracht-biedingen bezit. Voor system imbalance netting zijn de reducties klein maar even groot in alle gebieden. Voor andere arrangementen profiteert het gebied met de hoogste kosten (Duitsland) het meest, terwijl het gebied met de goedkoopste balanceringsdiensten (de Noorse regio) te maken krijgt met prijsverhogingen onder BSP-SO handel en een gezamenlijke biedladder.

Een belangrijke algemene bevinding voor de integratie van balanceringsmarkten is dat system imbalance netting en een gezamenlijke biedladder een grote positieve impact op de balanceringsmarkt-prestatie hebben. Voor BSP-SO handel en een additionele vrijwillige pool hangen de grootte en richting van de effecten voor een groot deel af van het gedetailleerde ontwerp van het arrangement.

Synthese en besluitvorming

De vergelijking van de ingeschatte effecten van cross-border balancing arrangementen met die van nationale balanceringsmarkten laat zien dat de harmonisatie van balanceringsmarkten een grotere potentie heeft om de prestatie van balanshandhaving te verbeteren dan de integratie van balanceringsmarkten. Dit komt door het hoge aantal nationale ontwerpvariabelen, waarvan vele een groot effect hebben. Echter, een algemene uitspraak over de relatieve waarde van harmonisatie en integratie kan niet worden gedaan, omdat harmonisatie zo veel vormen kan aannemen. Hoe dan ook, de mogelijkheden van harmonisatie en integratie zouden beide moeten worden bestudeerd. Dit zal automatisch het geval zijn als naar een gezamenlijke biedladder wordt gestreefd, welke de grootste positieve impact blijkt te hebben van alle arrangementen. Dit is omdat enige harmonisatie noodzakelijk is voor dit arrangement.

Besluitvormers over de internationalisering van balanceringsmarkten, d.w.z. netbeheerders, reguleringsautoriteiten en regeringen, zouden een systematische en weloverwogen aanpak van besluitvorming moeten aannemen, als gevolg van het hoge aantal ontwerpopties, mogelijke doelen en onzekerheden. Wij stellen een gestructureerd besluitvormingsproces voor, welke is verdeeld in drie fases: een ontwerpfase, een analysefase, en een besluitfase. De formulering van het ontwerpprobleem en van veelbelovende ontwerpalternatieven in de eerste fase kan goed worden ondersteund door het raamwerk voor het ontwerpen van balanceringsmarkten dat in dit proefschrift is gepresenteerd. In de analysefase kan de analyse-aanpak en de gegenereerde inzichten uit de multi-criteria en agent-based analyses de structurering en uitvoering van een effectieve analyse ondersteunen. De ontwerp- en analysestappen moeten worden afgestemd op de specifieke casus. Als een keuze voor een bepaald ontwerp voor een multinationale balanceringsmarkt is gemaakt, moet er vervolgens voor een bepaald transitieproces worden gekozen. Een transitie in meerdere stappen vergroot de flexibiliteit van het internationaliseringsproces, maar zal hogere implementatiekosten met zich meebrengen.

Terugkomend op de onderzoeksvraag concluderen we dat de ontwikkeling van multinationale balanceringsmarkten in Europa de potentie heeft om de economische efficiëntie en de leveringszekerheid in alle betrokken nationale markten in hoge mate te verbeteren, maar dat een gestructureerde en weloverwogen aanpak van het ontwerp en de besluitvorming noodzakelijk is om de kans op succesvolle besluitvorming over internationalisering van balanceringsmarkten te maximaliseren.

Curriculum Vitae

Reinier van der Veen was born on May 4th 1984 in Amsterdam (the Netherlands). He finished high school (VWO) at the Christelijk Lyceum Delft in 2002. Subsequently, he followed the main bachelor and master study at the faculty of Technology, Policy and Management (TPM) of Delft University of Technology. He obtained the master degree in Systems Engineering, Policy and Management in 2007, with the specialization profile Energy. His graduation project in the section Energy & Industry included a five-month internship at TenneT TSO B.V. (section Monitoring & Development), resulting in a master thesis titled 'Balancing market performance in a decentralized electricity system in the Netherlands'.

Begin 2008, Reinier started with a PhD research at TPM, in the section Energy & Industry. This research was part of the international research project 'Balance Management in Multinational Power Markets', which ran from 2007 to 2011. In 2008 and 2009, Reinier worked on his PhD research at TenneT, in the section Monitoring and Development, part of the business unit System and Operation.

During his research, Reinier wrote and presented several conference papers about the design and effects of national and multinational balancing markets, published a journal paper, and was a co-author of some of the final project documents. He has also supervised students in different courses at the faculty of TPM.

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