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Tanguy Janssen

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Economic analysis of the cross-border coordination of operation in the European power system

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“Even if the ultimate aim of economic theory is better policy, one does not best serve that aim by trying to make every journal article into a policy proposal.[...] There are plenty of people out there trying to change the world in various ways; the point of economic research is to understand it.”

Paul Krugman (1993)

Abstract

The electricity high voltage transmission networks are interconnected over most of the continents but this is not the case of the power system organizations. Indeed, as described with the concept of integrated power system, the organization over these large networks is divided by several kinds of internal borders. In this context, the research object, the cross-border coordination of operation, is a set of coordination arrangements over internal borders between differing regulatory, technical and market designs. These arrangements can include for instance the famous market couplings, some cost-sharing agreements or common security assessments among several other solutions.

The existence and improvement of the cross-border coordination of operation can be beneficial to the whole integrated power system. This statement is verified in the European case as in 2012 where several regional and continental coordination arrangements are successfully implemented.

In order to benefit from the European experience and contribute to support the European improvement process, this thesis investigates the cross-border coordination of operation in the European case with four angles of study. First, a modular framework is built to describe the existing solutions and the implementation choices from a regulatory point of view. Second, the thesis analyses the tools available to assess the impact of an evolution of the cross-border coordination. Third, the role of the European Union (EU) is described as critical both for the existing arrangements and to support the improvement process. The last angle of study focuses on two dimensions of the economic modes of coordination between Transmission System Operators (TSOs).

Key words: Power system, Market design, Electricity network interconnection, EU law, Optimization

Acknowledgements

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Abbreviations

Acronym	Full form
AAC	Already Allocated Capacity
AC	Alternative Current
ACE	Area Control Error
ACER	Agency for the Cooperation of Energy Regulators
ATC	Available Transfer Capacity
BA	Balancing
BRP	Balance Responsible Party
CACM	Capacity Allocation and Congestion Management
CASC	Capacity Allocating Service Company
CEER	Council of European Energy Regulators
CfD	Contract for Difference
CIM	Common Information Model
CMM	Capacity management module
CWE	Central Western Europe
DA	Day-Ahead
DC	Direct Current
DCAF	Day-Ahead Congestion Forecast
EC	European Commission
EMCC	European Market Coupling Company
ENTSO-E	European Network of Transmission System Operators for Electricity
ERGEG	European Regulators' Group for Electricity and Gas
ERI	Electricity Regional Initiative
EU	European Union
FB	Flow Based

FCR	Frequency Containment Reserve
FG	Framework Guidelines
FRM	Flow Reliability Margin
FRR	Frequency Restoration Reserve
FTR	Financial Transmission Right
GSK	Generation Shift Key
HHI	Herfindahl-Hirshmann Index
ID	Intra-Day
IEC	International Electrotechnical Commission
ITC	Inter-TSO Compensation
ITVC	Interim Tight Volume Coupling
LT	Long-Term
NC	Network Code
NCA	National Competition Authority
NERC	The North American Electric Reliability Corporation
NRA	National Regulatory Authority
NTC	Net Transfer Capacity
OTC	Over The Counter
PTDF	Power Transfer Distribution Factor
PST	Phase Shifting Transformer
PTR	Physical Transmission Right
PX	Power eXchange
RAM	Remaining Available Margin
RR	Replacement Reserves
RTO	Regional Transmission Organization
SEE	South East European
SOB	Shared Order Book
TEU	Treaty on European Union
TFEU	Treaty on the Functioning of the European Union
TLC	Trilateral Market Coupling
TRM	Transmission Reliability Margin
TSO	Transmission System Operator
TTC	Total Transfer Capacity

TYNDP	Ten Year Network Development Plan
UCTE	Union for the Co-ordination of Transmission of Electricity
UIoSI	Use It or Sell It

General introduction

As in 2012, the power systems fueling the economic activity are interconnected across large geographical areas. For instance, in Europe or North America, most of the electricity producers and final users are physically connected over the whole continent through the electricity transmission networks, except for some isolated areas. From an economic perspective, this situation can be described with the concept of integrated power system referring to an interconnected network with internal borders¹ creating a strong discontinuity in the economic organization of the system. In this conceptual framework, the implementation of cross-border coordination arrangements over the borders between differing internal area organizations can bring several benefits acknowledged by economists and engineers.

Thus, in order to contribute to the improvement of the large integrated power system organization, the thesis analyzes the cross-border arrangements over the internal borders based on the case-study of the European integrated power system as in 2012.

This general introduction summarizes first the literature on the economic organization of large liberalized power systems. Then, the following paragraphs expose the guiding objective of the thesis and the analysis framework selected. Finally, this introduction shows how the thesis content is structured using five research angles.

¹In fact, there are several layers of borders including regulatory, technical and market borders, as detailed in section [I.1](#).

Introduction to the economic organization of large liberalized power systems

Power systems have been liberalized in several parts of the world during the two last decades (Glachant and Finon, 2003, Jamasb and Pollitt, 2005, Newbery, 2006, Sioshansi and Pfaffenberger, 2006) and several lessons have already been learnt (Joskow, 2008a). A core element of these reforms is the introduction of competitive activities within the organization of this network industry (Hunt, 2002). It is also acknowledged in these reforms that the electricity commodity requires a careful market design (Hogan, 2002) and that some activities including network activities should be handled by regulated monopolies (Sharkey, 1983, Baumol et al., 1983). To introduce the thesis, the following paragraphs emphasize how economic studies have analyzed the research object context made of the wholesale market design, the TSOs role and the cross-border issues. A more detailed description of the system organization is later developed in chapter I.

The wholesale markets are designed by the regulatory system² to coordinate market participants taking into account the specificities of the electricity commodity (Stoft, 2002, Wilson, 2002). It is in practice a sequence of markets starting long before the delivery period of the electricity product. Among these markets, a so-called spot market taking place the day prior to a delivery period has been designed as a key step of the sequence (Schweppe et al., 1988). To model the market participants behavior, economists have used auction theory and equilibrium models (von der Fehr and Harbord, 1993, Bolle, 1992, Green and Newbery, 1992). However, several of these studies considered only one step of the sequence, missing some characteristics of the power system assets. Thus, other studies have extended the analysis to a sequence of markets (Allaz and Vila, 1993, Green and McDaniel, 1999, Bessembinder and Lemmon, 2002, Kamat and Oren, 2004). Among them, Saguean (2007) has worked to combine on the one hand equilibrium models with several steps taking into account the uncertainty management in the agent behavior and on the other hand the details of the complex technical organization of short-term and real-time power system operation.

²This expression is used for instance by de Jong (2009) or by Bouttes and Leban (1995) to describe with a broad meaning a system producing a regulation for the economic and technical systems of a network industry. In this thesis, it refers to both the institutions and actors producing the regulation of a power system.

Aside from the wholesale markets, the TSOs are regulated monopolies in charge of the system operation³ over a part of a transmission network. As analyzed for instance by [Rious et al. \(2008\)](#) from a modular perspective, this actor has a key role for the cross-border exchanges. Thus, the thesis benefits from the existing literature on TSOs that has already addressed the four following sets of research topics. First, it has been analyzed how a TSO interacts with the transmission network users on its control area through tariffs for the access to the grid ([Pignon, 2003](#), [Rious, 2007](#)). Second, each TSO interacts with its regulatory system. In particular, a fundamental economic question is about the possibility to incentivize a TSO toward particular objectives ([Joskow, 2008b](#), [Glachant et al., 2012](#)). Part of the answers also lies in an adequate legal liability for each TSO ([Philippe & Partners, 2010](#)). Third, the actors in charge of the system operation on the transmission network interact with their owners according to the governance structure. For instance, when the owner also have financial interests in assets connected to the grid in the same area, this owner may have incentives to favor its assets at the expense of the global efficiency. This risk can be limited by the ownership unbundling, referring to a form of separation between the system operation, the network asset ownership and the generation asset ownership ([Rious, 2007](#), [Moselle, 2008](#), [Lévêque et al., 2009](#), [Supponen, 2011](#)). Fourth, some elements from this literature analyze the differences between a “heavy” TSO owning the transmission network assets and a “light” actor in charge of the system operation on the transmission network under the form of an Independent System Operator (ISO) without the transmission network assets. The second option could be more favorable to a cross-border integration over a meshed transmission network ([Lévêque et al., 2009](#)).

Most of these studies about the wholesale market designs and the TSOs often acknowledge the need to handle cross-border issues over the internal borders of an integrated power system ([Pignon, 2003](#), [Saguan, 2007](#), [Rious et al., 2008](#), [Dubois, 2009](#)). Moreover, several contributions have studied specifically the paths toward further integration ([Costello, 2001](#), [Bergman, 2003](#), [Meeus et al., 2005](#), [Glachant and Lévêque, 2009](#)). From this global perspective, the integration process can be splitted into two sets of action: investments in large infrastructures and the implementation of new coordination arrangements. Concerning the second set, the coordination over internal borders can take

³The system operation “covers the complete area of activities for operating an electric power network, including security, control and quality in terms of fixed technical standards, principles and procedures, but also the synchronous operation of interconnected power systems” ([ACER, 2011d](#)).

the form either of a fusion between areas with only one remaining TSO over the merged areas or of a set of coordinating arrangements between areas with different TSOs and different organizations (Pignon, 2003, Costello, 2001). At this level of detail, the coordination of operation is a subset of the coordination arrangements which coherence is first defined in chapter I and then detailed in chapter II. In a few words, the coordination of operation can be defined by the two economic problems it shall solve: how to determine and allocate a scarce resource for cross-border exchange to improve the global system efficiency at fixed infrastructures and how to handle the various cross-border externalities related to the interconnection between areas and to the cross-border exchanges.

Concerning more precisely the coordination of operation in the European case, the literature has been enriched during the last decade by the analysis of specific coordination arrangements with a narrower focus. Without entering into the details at this stage of the thesis⁴, these studies are for instance about solutions for congestion management (Bjørndal et al., 2003, Ehrenmann and Smeers, 2005), about the interaction between internal area and cross-border congestion management (Glachant and Pignon, 2005, Willems and Sadowska, 2012), about balancing arrangements (Vandezande, 2011, Jaehnert and Doorman, 2012), about the role and regulation of market platforms involved in cross-border coupling of markets (Boisseleau, 2004, Glachant, 2010, Meeus, 2011b), about information sharing (Benintendi and Boccard, 2003), about the need of stronger European regulation (Boucher and Smeers, 2002) and about legal aspects of the cross-border coordination and the improvement process (de Jong, 2009, Bonafé Martinez, 2010). Moreover, the economic literature also benefits from the contributions to the debate from the European TSOs (ETSO, 2001a, 2004, ETSO and EuroPEX, 2008).

Based on this literature about the economic organization of an integrated power system and the more detailed analysis of specific cross-border arrangements in the European case, this thesis contributes to the economic analysis of the cross-border coordination of operation.

⁴A definition of the technical terms can be found in appendix A. The coordination arrangements related to the research object are defined in details in chapter II.

Underlying analysis framework and guiding objectives of the thesis

The underlying theoretical framework of the research project stems from the new institutional economics⁵. More precisely, the selected cornerstones are that institutions, understood as the ‘rules of the game’, matter (Williamson, 2000), that some institutions cannot be changed on a more or less short term perspective (North, 1990), and that the management of common pool resources and public goods may require complex institutions tailored to each situation (Ostrom, 2010).

In this theoretical framework, the rationale to study a set of cross-border coordination arrangements in an integrated power system is supported by the combination of two arguments. First, improving the coordination across internal borders of an integrated power system can ensure a better allocation of the limited resources and existing infrastructures of the whole power system. This statement widely acknowledged in the economic analyses of power systems is developed in section I.3.2 and in chapter III about the impact assessment of new coordination arrangements. As described above in the literature review, the solutions can be divided into two branches: adopting a common deeply harmonized organization and merging the neighboring areas under a single TSO or adding cross-border coordination arrangements over the border between different organizations (Costello, 2001, Pignon, 2003). The second argument is that some institutional elements of the system may not be negotiable on a short term perspective (North, 1990, Williamson, 2000, Aoki, 2001). In other words, the possibility to merge the areas can be limited by the pre-existence of strong local organizations and the cost of modifying them. For instance in the European case, the internal organization of each area of the integrated power system, including the TSO features, may be to a large extent taken as constraints in the decision process and in the study⁶. Thus, a set of cross-border coordination arrangements can end up being the only feasible solution to improve an imperfect coordination over internal borders of the integrated power system.

⁵The term new institutional economics refers to an interdisciplinary approach borrowing from various social sciences to explain, among other research questions, what institutions are and what purposes they serve. See for instance the definition proposed by the International Society for New Institutional Economics (ISNIE) on the webpage <http://www.isnie.org/about.html>, last visited January 2012.

⁶This statement is supported by the day-to-day observation of the negotiation process as well as by the past decades of strong involvement of the national level of governance as summarized in the historical perspective on the European electrification (See appendix B.1).

In practice, cross-border coordination arrangements appear adequate in several large integrated power systems in the world. This is for instance the path chosen in the European integration process that started in the last decades as introduced in the historical perspective (appendix B.1). Besides, even in the United States where some successful organization known as Regional Transmission Organizations (RTOs) extend their control areas, several internal borders remain around them (Hogan, 2001) and it may be worth improving the coordination over these borders.

The European case has been selected as the thesis case study because of the numerous sources available for empirical observations and in order to support the European integration process taking place as in 2012. Note that the European process in question focuses on the countries whose TSOs are members of an association called European Network of Transmission System Operators for Electricity (ENTSO-E). Thus, the geographical area considered is smaller than the European continent⁷.

In coherence with the selection of the research object, the guiding objectives of the thesis are twofold. Through the observation of the European case-study, the thesis project aims first at enriching the existing theoretical understanding about the cross-border coordination of operation. Through the adaption and development of theoretical frameworks to analyze the case-study, the second objective is to support the current process taking place in Europe to improve the cross-border coordination of operation.

Research questions and thesis content

The thesis content is structured around five chapters corresponding to different angles of analysis of the research object. In the research process, the selection of these angles have been deeply guided by the first steps of a method called the ‘function-based legal design analysis’ formalized by Knops (2008b) aiming at fostering decisions about the most adequate legal organization for this function. Indeed, these first steps identify the relevant informations to support a decision process and this method has been applied by its author to the analysis of several power system regulatory issues.

⁷As defined by the Oxford dictionary, Europe is “a continent of the northern hemisphere, separated from Africa to the south by the Mediterranean Sea and from Asia to the east roughly by the Bosphorus, the Caucasus Mountains, and the Ural Mountains”. See webpage <http://oxforddictionaries.com/definition/english/Europe?q=europe>, last visited january 2013. As a consequence, the research scope do not include the coordination arrangements between Russia, Bielorrussia and their European neighbors.

The first chapter defines the research object by its role within an integrated power system and within an integration process. In particular, the cross-border coordination of operation is defined as a set of solutions for two economic problems: (1) determine and allocate a scarce resource for cross-border exchanges between areas of an integrated power system at a time horizon with fixed infrastructures; and (2) handle the cross-border issues that may appear due to the interconnections between areas and due to their use for cross-border exchanges. This chapter also selects and defines a set of concepts⁸ relevant to describe an integrated power system organization, focusing on the transmission network and wholesale market. Concerning the role of the research object in an integration process, a simple model is used to analyze the interaction between the improvement of the cross-border coordination of operation and the investments in large infrastructures.

After this introductory chapter, the first part of the thesis focuses on the coordination arrangements for the cross-border coordination of operation and the tools to assess their impact.

Chapter II applies the modular analysis principles (Baldwin and Clark, 2000) and divides the two economic functions of the cross-border coordination of operation into eight modules. The first aim of the resulting modular framework is to overcome the technical complexity of the research object by defining sub-problems adapted for more in depth economic studies, including the interactions between modules. The second aim is to show through the description of each module that there are many perspectives of improvement of the current arrangements in place in Europe as in 2012. This chapter offers a more detailed description of the research object and it identifies lessons emerging from the current debate.

Chapter III analyzes how the impact of new coordination arrangements can be assessed in terms of gross aggregated benefits, costs and distribution effects. The results can indeed be used either in a decision process to select new solutions or to monitor the effect of past decisions. From a theoretical perspective, the chapter shows how a selection of impact assessment tools from microeconomics (Varian, 1992) and from international trade economics (Krugman and Obstfeld, 2008) can be adapted to the technical specificities of this industry and of the cross-border coordination in particular. In addition,

⁸Additionally, appendix A offers a glossary of terms and concepts used to describe the research object.

the empirical contribution of this chapter is to gather orders of magnitude of the impact of the improvement process in the European case as in 2012.

The second part of the thesis takes a wider institutional perspective and adds two contributions to the economic analysis of the involvement of the EU and the TSOs, in the cross-border coordination of operation and in the process to improve the coordination arrangements.

Chapter IV focuses on the EU's role. Indeed, common institutions are necessary to manage public goods such as the system adequacy and common pool resources such as the cross-border exchange capacities (Ostrom, 2010). After the description of the role of the EU law in a multilevel energy governance, the chapter analyzes how EU non-binding initiatives, including the support of multi-national research projects, support the integration process by fostering new agreements, innovation and the diffusion of good practices.

Chapter V investigates how the TSOs interact in an integrated power system from an institutional perspective (Williamson, 1991, 2000). More precisely, it analyzes two dimensions of the economic modes of coordination between TSOs: a categorization of the contracts inspired by the work of Knops (2008a) and the geographical expanse of the coordination. After an empirical observation of the arrangements in place in a large European region, the analysis shows that the use of common subsidiaries between TSOs to implement some coordination tasks is promising and that the regional dimension is often used in the European integration process as in 2012.

The concluding chapter is followed by a glossary, a parallel with neighboring research objects and additional elements of analysis from history law and other areas of study.

Chapter I

Defining the cross-border coordination of operation in the European power system

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“While differing widely in the various little bits we know, in our infinite ignorance we are all equal.”

Karl Popper¹

The concept of integrated power system shall refer to an interconnected network which institutional organization is divided up by several layers of internal borders. In this conceptual framework, this introductory chapter defines the cross-border coordination of operation by its role within an integrated power system and within an integration process. More precisely, the chapter introduces step by step the internal borders, how the system is organized on each side of the borders in the European case and that cross-border coordination arrangements can take place over these borders for the benefits of the integrated power system.

The preliminary section [I.1](#) defines first a set of key regulatory, technical and market borders illustrated with the European case as in 2012. It shows how the different kinds of borders do not exactly come on top of each other. Thus, two different geographical borders can cover two very different sets of cross-border issues.

Then, section [I.2](#) describes the theoretical organization in a single control area that would be isolated and homogeneous in term of regulation, i.e. without cross-border issues apart from some internal market borders. This section introduces a selection of concepts such as the sequence of time horizons and the congestion management principles that shall be useful to understand the following analysis, focusing on the elements related to wholesale market, the transmission network operation and a function known as the system operation.

Finally, the cross-border coordination of operation is defined in section [I.3](#) as a set of cross-border arrangements over the internal borders of an integrated power system addressing two economic problems. This last section also shows why it is worth working

¹In *Conjectures and Refutations: The Growth of Scientific Knowledge* (1963).

on the improvement of the cross-border coordination of operation as a part of an integration process. To this aim, the potential benefits of the cross-border coordination arrangements are introduced through a combination of three theoretical frameworks. Moreover, the analysis draws policy recommendations from an analytical model of the interaction between the improvement of the cross-border coordination of operation and the investments in large infrastructures.

I.1 Definition of internal borders in an integrated power system organization

This preliminary section shows first that, in the European case, most of the transmission networks are interconnected². Then, it defines borders appearing in an integrated power system organization sharing an interconnected transmission network. More precisely, the relevant borders for the thesis study are key regulatory, technical and market borders. These definitions are useful to understand that each border is in fact an overlap of several kinds of borders. Based on this observation, the cross-border coordination of operation can be partly decomposed in a set of coordination arrangements corresponding to the various layers of border.

(a) A European transmission network

Figure I.1 is a map of the European electricity transmission network as in 2010. It shows clearly that there is already a European network inherited from the last century as described in appendix B.1. Only some islands such as Malta are isolated as in 2012. In fact, if a naive observer had to guess the political borders between European countries, then a map of the power transmission network would not help much.

The European interconnected network as seen by market participants can also be described with the bilateral Net Transfer Capacity (NTC)s. These values gives an idea of the cross-border capacities allocated by the TSOs to cross-border exchanges between market participants. Table I.1 shows NTC values between countries of the north western part of Europe as in 2011. Please note that an NTC value is only an approximation of the physical capacities and the role of this value shall be described with more details in section II.1.

²From a technical point of view, this interconnection may include circuit-breakers or power transformers.

³Data extracted from a document untitled NTC Values Winter 2010-2011, available at <https://www.entsoe.eu/publications/market-and-rd-reports/ntc-values/ntc-matrix/>, last visited November 2012. Final version of the document from 22 February 2011. Historical and updated values are accessible at the same url adress.

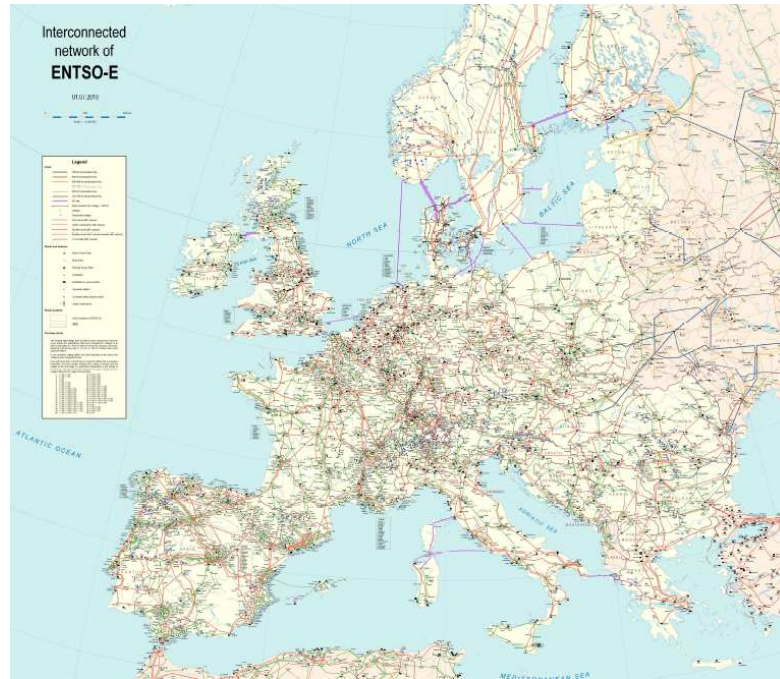


FIGURE I.1: European high voltage electricity network as in 2010 including existing high-voltage overhead lines and those under construction designed for voltages of 220 kV and higher and 110 kV to 150 kV if these line cross national frontiers. Source: ENTSO-E's website.

To \ From, in [MW]	BE	DE	FR	NE
Belgium (BE)	-	-	3400	2400
Germany (DE)	-	-	2700	3000
France (FR)	2300	3200	-	-
The Netherlands (NE)	2400	3850	-	-

TABLE I.1: Net Transfer Capacity (NTC) values on the internal borders of the CWE region for the winter of 2011, working day, peak hours (non-binding values). Source: ENTSO-E website³.

(b) Layers of regulatory, technical and market borders

From an administrative and organizational point of view, the network is divided up by at least three different kinds of borders. First there are regulatory borders as for instance between national regulations or because the EU law does not cover all European countries. Then there are more technical layers for operational issues defining for instance the control areas. Finally some traded products are attached to a geographical zone known as bidding zone which introduces market borders. This categorization is inspired from the work of Knops (2008b). In order to keep a global perspective, the analysis focuses on examples of these three kinds of borders rather than a comprehensive list.

Two key regulatory layers The political frontiers remain strong within Europe. In particular the national energy regulations can highly differ including fiscal issues or the renewable policy. Moreover, even when the EU law defines common rules on a specific issue, some European countries like Switzerland may have a different regulation because they are not part of the EU.

Control areas and synchronous areas According to the glossary of a Network Code proposal by the [ENTSO-E \(2012e\)](#),

Control area means a coherent part of the interconnected system, operated by a single system operator and shall include connected physical loads and/or generation units if any.

This layer is thus defined by the existence of a single system operator on the transmission network, which is in most cases a TSO⁴. Without entering into technical details at this stage, the control areas can be grouped for specific technical or legal purposes in larger areas, forming another layer of frontiers. For instance, as in 2012, the European transmission grid is divided in five wide synchronous areas⁵: Continental Europe, Nordic, Baltic, Great Britain and Ireland / Northern Ireland⁶. The left map in figure [I.2](#) shows the main control areas and synchronous areas which are called RG for Regional Group.

Additionally, other layers of control borders have been defined. For instance, as in 2004 in the synchronous area Continental Europe (formerly Union for the Co-ordination of Transmission of Electricity (UCTE)) the control areas were gathered in control blocks which were themselves gathered in two control centers (UCTE South and UCTE North) as shown in the Operation Handbook of the [UCTE \(2004\)](#).

⁴According to the glossary of ([EU, 2009b](#)), TSO refers to “a natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the transmission system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the transmission of electricity”.

⁵As defined in the glossary in appendix [A](#), a synchronous area is characterised by a common operating frequency over a network operated in an Alternative Current (AC) mode. Most of the European transmission network is operated in an AC mode as shown in figure [I.1](#). The common frequency can be used as a control parameter as described in section [I.2](#).

⁶Those areas were formerly named UCTE, UKTSOA, NORDEL, ATSOI, IPS/UPS as described by ENTSO-E. See website <https://www.entsoe.eu/system-operations/regional-groups/>, last visited in October 2012.

⁸Available at <https://www.entsoe.eu/about-entso-e/working-committees/system-operations/regional-groups/>, last visited November 2012.

⁸Available at <http://www.nordpoolspot.com/Market-data1/Maps/Power-System-Overview/Power-System-Map/>, last visited November 2012.

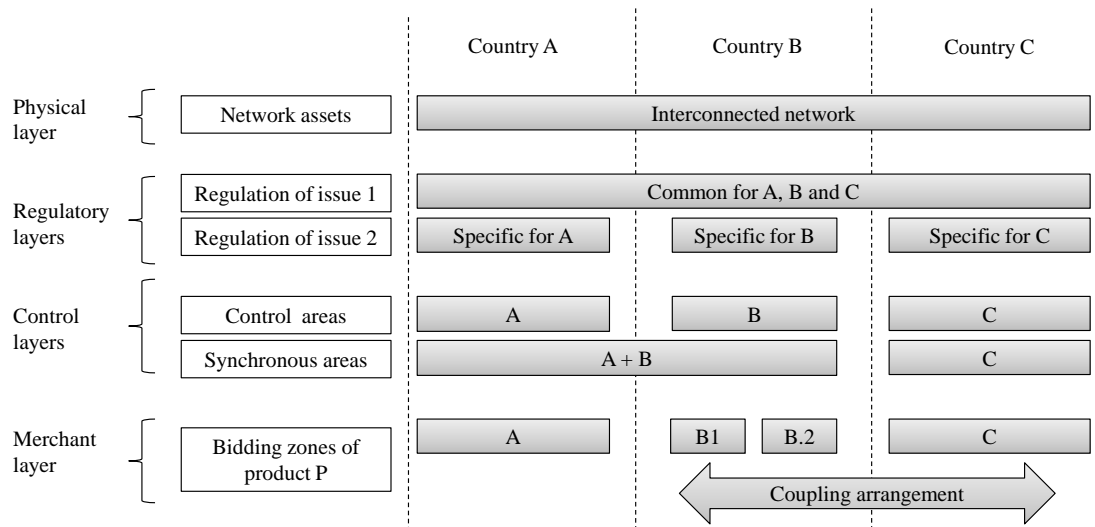


FIGURE I.3: Illustrative sample of regulatory, control and merchant layers of a power system organization over three countries A, B and C sharing a common network. The cross-border coordination between areas or zones is illustrated with a single coupling arrangement over several bidding zones.

Pilling up the layers of borders Figure I.3 illustrates a pilling up of layers illustrating on a few layers how a small number of country can generate a complex diversity of organizations. More particularly, the cross-border coordination between two countries can be complex to describe in a comprehensive way.

I.2 Relevant organization features in an isolated and homogeneous area

The term homogeneous area shall be used to refer to a geographical area with neither regulatory nor control borders. There is thus a common regulation, a common regulatory system and a single TSO which roles are introduced in this section. In this isolated area, it is assumed that market borders can be used for instance for congestion management. The term isolated shall be used to refer to the fact the electricity network of this area is not connected to any other area. The aim is to define what shall be coordinated by the cross-border coordination between two or more homogeneous areas that would not be isolated. Thus, this section shall define the key features of the internal organization of an area. Indeed, the analysis of the cross-border coordination solutions in this thesis requires a minimum level of details on the internal organization of the areas it is coordinating. In fact, the description focuses mainly on the wholesale market of electricity, the transportation network operation and more generally the system operation on this network since they are the most relevant parts to support the study of the cross-border coordination of operation⁹.

Based on the existing literature, the key relevant features of the organization are detailed in this section with reference to specific features of the electricity commodity they are related to. For the sake of clarity, it is made in two steps. Section [I.2.1](#) defines the organization of a power system as if they were no network issues and section [I.2.2](#) adds key network issues and their management.

The description requires the identification of four key sets of actors: (i) the market participants, including energy companies with power production assets, traders, consumers and the retailers that may represent them on the wholesale market, (ii) the market platform operators such as the Power eXchanges (PXs), (iii) actors of the regulatory system including for instance energy regulatory agencies, governments and courts, and

⁹According to the Energy Sector Inquiry from the [\(European Commission, 2007b\)](#), “[t]he electricity industry chain involves five main activities: (1) the production or generation of electricity, (2) the transport of electricity on high voltage levels (transmission), (3) its transportation on low voltage levels (distribution), (4) the marketing of electricity to final customers (supply), and (5) the selling and buying of electricity on wholesale markets (trading)”. Among them the thesis focuses on the second and the fifth activities plus the system operation as defined in the glossary (appendix [A](#)).

(iv) the actors in charge of the transmission network assets and the actors ensuring system operation at the level of the transmission network¹⁰. The term TSOs shall be used to refer the last set of actors in the thesis and section I.2.3 gives further insights on this actor role and governance, highlighting that it can take several institutional forms from a theoretical perspective.

Finally, section I.2.4 offers a graphical summary of the internal area organization and acknowledge the diversity among European areas beyond the common features.

I.2.1 Ensuring the generation adequacy without network issues

In this thesis, the term adequacy refers to the ability of an electric power system to supply the aggregated electric power and energy corresponding to the end-user demand “under steady-state conditions, with system component ratings not exceeded, bus voltages and system frequency maintained within tolerances, taking into account planned and unplanned system component outages” as defined by the International Electrotechnical Commission (IEC)¹¹. This definition is understood as including not only the long term infrastructure adequacy as meant in (ENTSO-E, 2012o) but also a short term ability to react¹². Based on this definition, the term generation adequacy is meant in this section as the restriction of the general adequacy to the assets connected to the grid as if they were no network issues.

Section (a) shows why maintaining the generation adequacy can be difficult and how it is ensured in a liberalized power system thanks to a sequence of forward arrangements and a real time module. Then, section (b) and (c) propose respectively a segmentation of the time horizons of exchange and a typology of the electricity products exchanged between actors that shall be used in the thesis.

¹⁰The system operation “covers the complete area of activities for operating an electric power network, including security, control and quality in terms of fixed technical standards, principles and procedures, but also the synchronous operation of interconnected power systems” (ACER, 2011d). This definition can also be found in the glossary (appendix A).

¹¹See website <http://www.electropedia.org/iev/iev.nsf/display?openform&ievref=191-21-01>, last visited December 2012.

¹²Please note that the The North American Electric Reliability Corporation (NERC) and academics such as Billinton et al. (1984) or Oren (2005) would use the term reliability for this broad definition while the term adequacy would be restricted to the existence of the infrastructure and security would be used to refer to the ability to react. For the exact definitions by the NERC, see website <http://www.nerc.com/page.php?cid=1|15|122>, last visited December 2012.

(a) Fundamental generation adequacy management principles

The limited foreseeability and controllability and a lack of energy storage capacities. The behaviour of each element connected to the grid, producing or consuming, can be characterized as more or less foreseeable, controllable or variable for the parameters that would not be controllable. Obviously these features are depending to the time-period considered with reference to a given period of delivery. For instance, the global domestic consumption is rather well forecasted one day ahead with daily weather forecasts and calendar parameters. On a longer time-scale, macroeconomic parameters such as economic growth can offer yearly load scenarios. If demand response devices are installed, this load can be to some extent controllable on a daily time-scale. With investments to improve building isolations, the load associated to indoor temperature management can be reduced on a longer time-scale. On the generation side, hydroelectric production sites with reservoirs are for instance rather controllable on a short term perspective but the yearly inflow of water can be difficult to forecast depending on the local climate yearly variability. These limited foreseeability and controllability of many assets connected to the network is a strong constraint on the ability to ensure a continuous supply.

In addition to that, storage is only a partial solution. Indeed, unlike many industries, it can be very expensive to build storage capacities for electricity products in comparison to the potential benefits they can generate¹³. In addition to that, the natural inertia of a power system, which is a form of short term storage of energy, is rather low. Therefore, in the European system as in 2012, the storage facilities have a limited ability to act as a buffer to compensate an inadequacy between production and consumption.

To sum up, the difficulty to maintain generation adequacy is related to the lack of storage as well as the limited foreseeability and controllability of many assets connected to the grid.

Generation adequacy management through anticipation and responsibilities.

In economic terms, the generation adequacy can be seen as a public good in the sense

¹³In fact one must store electrical energy in a different form, like in a chemical battery. The storage of energy in the form of potential energy of gravity of water in a dam is by far the cheapest solution, but its potential is limited by geographical constraints. See for example the descriptions of storage possibilities endorsed by the electricity storage association <http://www.electricitystorage.org/ESA/technologies/>.

that it is a non-excludable and non-rivalrous good¹⁴ for all assets connected to a common network. Indeed, everyone benefits from the system stability and continuity of supply. However a few assets can impede the generation adequacy and the cost to maintain it shall be shared between the beneficiaries. These externalities between actors require a form of agreement on their management. Therefore, through negotiation, with or without the intervention of a third entity with legitimate power, the beneficiaries shall find agreements.

To build this global set of agreements, anticipation and responsibilities are the main materials. Indeed, in addition to the technical limitation described previously, the transactions between actors are subject to frictions (Coase, 1960) and require time. Most of what happens in real time is thus agreed in advance and to handle the uncertainties, adjustments are possible when coming close to real time. In order to avoid free-riders about the short term generation adequacy, all actors should assume what is referred as the balance responsibility of their portfolio. This means that they are penalized if they produce or consume differently from what they have agreed to. An actor assuming this responsibility is called a Balance Responsible Party (BRP) and the responsibility can be transferred between actors¹⁵. The financial consequences are settled through imbalance settlement procedures. This responsibility is today handling the short term adequacy and a similar form of settlement may be required for long term generation adequacy in case long term responsibilities are given to some actors.

The anticipation implies to decide how long in advance the agreements shall be found. Indeed, there is a compromise between more information closer to real time and the fact that there are more decision variables further before the time of delivery, allowing to reach a better optimum as shown by classical microeconomic models of the production (Varian, 1992). The solution is to use a sequence of anticipation stages making the best of the two effects. Saguan (2007) shows and describes clearly the theoretical ideal solution as a sequence of optimizations. The idea is that each long term variable are fixed as close as possible to the period of delivery, based on all information available when it shall be fixed. In a liberalized system, Wilson (2002), Saguan (2007) describe how a discrete sequence of markets and mechanisms can be implemented. In this work, Saguan also emphasize the critical need of a real time operation module.

¹⁴See for instance (Varian, 1992) for an introduction on the definition public good.

¹⁵Due to the network issues described in the next section, this responsibility is in practice attached to a geographical area such as a bidding zone or a node of the transmission network.

A real time operation module to complete the anticipations. In addition to the sequence of decisions anticipating the real time operation, fast reactive mechanisms complete the organization. There is in practice a trading gate closure after which the TSOs of each control area becomes the single buyer of electricity products designed to ensure the generation adequacy¹⁶. This strong regulation of the system can be understood if one consider that a minimum set of guidance and control by the TSO as well as automatized mechanisms are necessary to ensure the short term generation adequacy (Wilson, 2002, Saguan, 2007). The following sections describe with more details a sequence of anticipation segmented in four periods and a typology of the product exchanged between actors.

(b) **Four time horizons for energy markets and balancing**

The organization of the European market design and power system operation as in 2012 combines a rather continuous sequence of markets and mechanisms from long term to short term time-horizons. For instance, Panciatici et al. (2012) describe the TSO practice as follow:

The decision-making process is no longer a two-step process (making day-ahead and then real-time decisions) but more and more a continuous, multistage process with a number of different time slots (i.e., intraday) available for deciding and/or applying different possible actions, depending on the market and on regulatory rules.

The theoretical aspects of this sequence, analyzed for instance by Saguan (2007), is adapted for this thesis. What shall be used is a segmentation of the sequence which has been adopted by many stakeholders of the current integration process in Europe (ACER, 2011e). This segmentation that fits to the European case study can be adapted to other power system organizations rather easily. It uses four time horizons with reference to a given period of delivery:

Long-Term (LT) covers all markets taking place before the Day-Ahead time horizon, trading mainly annual and monthly products,

¹⁶These products can also be used to manage network issues which are not considered in this section.

Day-Ahead (DA) refers to a daily market, also known as spot market, for the 24 hours of delivery during the next day,

Intra-Day (ID) covers the markets taking place between the DA gate closure and an ID gate closure before the balancing period,

Balancing (BA) covers all the actions and activities performed by a TSO close to real time in order to ensure frequency control of the isolated control area considered in this section.

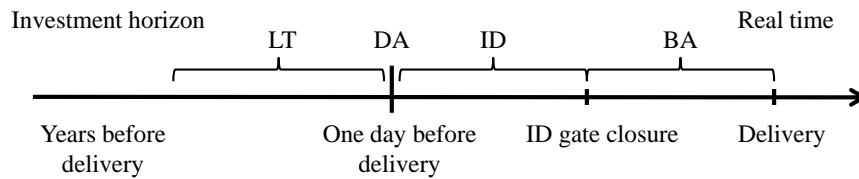


FIGURE I.4: Segmentation of the sequence of time horizons which can be used to describe the organization of a power system. The acronyms stand for Long-Term (LT), Day-Ahead (DA), Intra-Day (ID) and Balancing (BA).

A DA spot price ([Schweppe et al., 1988](#)) is often used as a reference price for electricity despite the fact that the underlying DA market is only one part of the wholesale market. It is indeed a meaningful arbitrage place between portfolios of productions and consumptions. It is taking place the day prior to delivery for the 24 hours of the day. Meanwhile, LT exchanges allows to secure a large share of the exchange long in advance. This time horizon also corresponds to hedging activities involving financial products with energy markets as underlying products.

This segmentation with four time horizons is rather resilient to evolutions of the organization. For instance, there are discussions about moving the DA market fixing or the ID gate closure closer to real time¹⁷. This evolution does not require to change the framework. Moreover, this segmentation can be extended by adding a specific time horizon for large investments and by showing explicitly the real-time operation out of the balancing time horizon as illustrated in figure I.4. The enlarged framework can then cover most actions in a power system from automated actions to large investments. If it is need in another study, the sequence could be extended with, for instance, the financial settlement post real-time which is not represented.

¹⁷One argument is that this would help manage intermittent renewable source like wind power which forecast are more accurate closer to real time.

(c) The products exchanged before the real time operation

The coordination between market participants and with their TSO for the generation adequacy is ensured by contracts or mandatory procurement often involving the exchange of several electricity products which can be assimilated to services. The ability to design products for trading is only limited by the traders imagination and regulatory boundaries. In this section the focus is placed on products that are rather directly related to energy or power capacity, involving a form of balance responsibility. Moreover, among these products, the description emphasizes the standard products exchanges on market platforms known as Power eXchanges (PXs) or exchanged with the TSOs. Beyond the diversity of products, it is important to keep in mind that all products influence each other and the global picture should be coherent for a functioning system. For instance, the ability of a large thermal power plant to deliver balancing products depends on its state of operation when the product is activated.

Standard energy products that can be exchanged on market platforms. Concerning the transactions between market participants, a wide diversity of market-based organizations is used. In practice, a distinction is made between Over The Counter (OTC) markets and Power eXchange (PX). The term PX refers to an operator of a rather centralized market platform trading standard products and offering financial services including a clearing house. They reveal public prices which can serve as reference prices. Concerning what is known as the spot prices, many European PXs use in practice a form of marginal pricing in a fixing for DA markets and continuous trading for ID markets. The term OTC refers to the transactions between market participants which do not involve a PX platform. For instance, there are bilateral contracts on standard products. There can also be market intermediates, known as brokers, which can have parts of the PX characteristics. Some PXs have been involved in the coupling of markets between their bidding zones. Their role and regulation have already been analysed by [Boisseleau \(2004\)](#), [Glachant \(2010\)](#), [Meeus \(2011b\)](#). In the thesis, their involvement in cross-border coordination arrangement is described in chapter II and their shareholding relation with TSOs is illustrated in figure V.1.

Concerning the energy market, a wide range of standard and non-standard products are exchanged or requested by regulation. This diversity of products can be described in

two dimensions. First, as described in the next section, the organization uses various time horizons of exchange. Since, for a given period of delivery, a guaranteed quantity of energy may not have the same value depending on when it is contracted, then the time horizon is a product parameter. Second, even at a single time horizon, the constraints of the production assets and demand side management are so diverse that one standard product might not fit for all. For instance, most hydroelectric plants using dams can increase their production rather fast but they can be limited by reservoir constraints, whereas large coal power plants can find coal in large quantities but they need hours to go from start to full power. This is why there are several sophisticated products defined in (ENTSO-E, 2012e) as “products with specific characteristics designed to reflect system operation practices or market needs”. As in 2012, the Nordic DA spot market allows for instance to bid with the two following standard products¹⁸:

A flexible hourly order is a single hour sales order where the members specify a fixed price and volume. The hour is not specified. The order will be accepted in the hour optimizing the overall socioeconomic welfare, given the price is above the asking price. This type of bid gives companies with power intensive consumption the ability to sell back power to the spot market by closing down industrial processes for the hour in question.

A block order consists of a specified volume and price for at least three consecutive hours. Block orders have an “All-or-Nothing” condition. The “All-or-Nothing” condition means that a block order must be accepted in its entirety, and if accepted the contract covers all hours and the volume specified. The block order is particularly useful in cases where the cost of starting and stopping power production is high. Furthermore, inflexible production, consumption and contracts can be handled efficiently with block orders.

Furthermore, Tirez et al. (2012) show with a simulation on historical data how the introduction of a new kind of sophisticated standard product on a Belgian market might have improved the global welfare. From a theoretical perspective, the impact of the standard product structuring on the global system organization can be seen from an

¹⁸Extract from NordPoolSpot website, <http://www.nordpoolspot.com/TAS/Day-ahead-market-Elspot/Order-types/>, last visited in November 2012.

optimization point of view. With this perspective, the products define the market interface between sub-optimizations the global system organization¹⁹ and an inadequate interface can lead to a suboptimal coupling of the subproblems. This principle is also true about the cross-border products.

Classical reserve products and their activation in real time. Concerning the balancing products, the [ENTSO-E \(2012i\)](#) gives a definition of three sets of reserves which is useful to describe some cross-border mechanisms in the following chapters. Over a synchronized area without network issues, the short term generation adequacy is performed through the control of the common frequency. Indeed, the dynamic of this parameter is linked to the global generation adequacy²⁰, it has in practice a unique value over a synchronized network and it can be measured easily. The principle of the reserve activation is that the system is controlled around a reference frequency, which is 50 Hz in Europe. In the following description of the three sets of products, the illustrative case considered is a single perturbation of the generation adequacy in a synchronized area due to a loss of generation. The correction to restore the generation adequacy in this case is called up-regulation while the reverse case of a positive net generation calls for down-regulation.

The first kind of reserve is Frequency Containment Reserve (FCR), also known as primary reserve. Its role is to react very quickly, in less than 30 seconds, to the frequency deviation in order to push the system toward a balanced state. Roughly speaking, in a case of up-regulation, these reserves are controlled to generate a positive additional generation proportionally to the spread of frequency observed around the reference value. In the case of up-regulation, the frequency decreases until the generation adequacy is restored, when the Frequency Containment Reserve (FCR) activation compensate exactly the perturbation. The second kind of reserve is called Frequency Restoration Reserve (FRR). Its function is to restore the reference frequency which happens to restore the Frequency Containment Reserve (FCR) capacities of reaction. The reserve activation follows the principles of an integral controller, *i.e.* in the case of up-regulation,

¹⁹For instance, under a perfect competition model, each wholesale electricity market participant performs an optimization of its portfolio with some market signals as exogenous inputs.

²⁰There is in fact a physical link between the generation adequacy and the frequency through the physical rotation speed of rotors in the classical synchronous power generators (the large majority of the production). In a simplified way, when there is an instantaneous positive net power consumption on the network, the rotors inertia decreases and reversely.

new reserves are activated as long as the frequency is not equal to the reference frequency. These reserves are not expected to start as fast as the Frequency Containment Reserve (FCR), but they may be expected to last over a more sensible period. The Frequency Restoration Reserves (FRRs) are also known as secondary and tertiary reserve. The distinction between these terms is usually made based on the fact that the activation is automatic or manual. Finally, the Replacement Reserves (RRs) are used to restore and support the required level of FRR to be prepared for further system imbalances. This category includes operating reserves with activation time up to hours.

All these reserves can be contracted in advance by a system operator in charge of the generation adequacy in its control area or requested by the regulatory system. It is not interesting to detail here further the existing standard products. Indeed, the principle of this section is to look at the common features rather than the differences. In practice there are about as many list of products as there are control areas as shown in an edifying manner by a survey on ancillary services procurement and balancing market design by the [ENTSO-E \(2012q\)](#).

Capacity markets or mechanisms. In addition, some capacity markets or mechanisms can be implemented to exchange a form of capacity available for long term generation adequacy. The product can be the maintenance in operation of a production capacity during a fixed period of time. Some economists such as [Joskow \(2007\)](#), [Batlle and Pérez-Arriaga \(2008\)](#), [Finon and Pignon \(2008\)](#) have raised the question if capacity obligations by a legitimate authorities could contribute to guide optimal generation investments. In the following chapters the capacity markets are excluded from the research scope. Indeed, as shown graphically in figure [I.6](#) in the coming section introducing the cross-border coordination of operation between areas, the research object focus on coordinating the energy and balancing modules whereas the capacity markets or mechanisms would be more closely related to the coordination on investments. This choice is supported by two arguments. First there are few forms of long term capacity markets designed for long term generation adequacy in European countries. Thus there are few objects for empirical observations. Second, even if long term generation adequacy responsibilities were more important in the power system organization as in 2012, it seems more related to the coordination of investments than to the coordination of operation according to the time horizon considered in both sets of arrangements.

I.2.2 Relevant network issues and congestion management

In addition to the generation adequacy related constraints, there are network related constraints. Among them, as selected by Pignon (2003), the focus is placed on two impacts of the power flows on a transmission network²¹. First, the power that can flow on a physical component of the network during a given period of time is limited (Kirschen and Strbac, 2004). Therefore, the transmission capacities on a network can be a scarce resource. In other words, bottlenecks for power flows, also known as congestions, can appear and congestion management is necessary to ensure the system adequacy. Then, the power flows on the transmission network generate losses. Thus, the cost of these losses must be distributed between the actors of the zone (Gomez Exposito et al., 2000).

One key physical property of electricity is that on a meshed interconnected network, the power commercially exchanged between two nodes of the network flows on all possible paths according to some well-known physical laws (Kirschen and Strbac, 2004). As a consequence, an action on one element of the integrated power system potentially impact the whole system. Thus, the network issues described above are global in the sense that a global coordination may be necessary to handle them.

This section gives further insight on the congestion management principles because it is an essential part of the cross-border coordination arrangements. Section (a) states first that the transmission network operator can influence the power flows by acting on network assets. Then, section (b) displays the congestion management principles within a single isolated bidding zone. Finally, section (c) discusses the use of multiple bidding zones for congestion management in a single isolated area.

(a) Possible actions on the transmission network assets

To handle network issues, the TSO in close relation with its regulatory system and the network users can act on the network assets at various times horizons.

On the long term, large investments can, for instance, add new network assets or increase the power transmission capacity of a high voltage line. The decision shall be prepared

²¹Note that additional network issues could be included in the analysis. For instance, voltage control issues are not explicitated for the sake of simplicity at this stage. A definition of the term is proposed in glossary (appendix A) and see for instance the work of (Rebours et al., 2007b) on voltage control ancillary services for a more in-depth perspective.

by a phase of network planning when anticipations are shared to allow an adequate coordination with the stakeholders.

Considering a shorter perspective from one or two years in advance up to the period of delivery, the large transmission infrastructures can be considered as fixed. At these time horizons, even without any control of the assets connected to the network, the transmission network still has some flexibility and smartness to partially control the flow paths. By flexibility is understood the ability to evolve on a short term basis. This ability depends on controllable devices²² able to modify the network topology. Therefore, it is possible to some extent to control the power flows on the grid in order to help reduce the burden on elements of the grid under critical conditions. In addition, the term smartness is used to describe the capacity of the network to collect and use data in an automated or partially-automated way in order to smartly use the network flexibility and more generally the power system controllability. The use of these control means by the TSO shall be called network operation.

(b) Congestion management within an isolated bidding zone

The congestion management can be seen as the allocation of a common-pool resource and it is an essential part of the global system adequacy which can to a large extent be considered as a public good requiring institutional arrangements ([Ostrom, 2010](#)). In practice, the congestion management is guided by incentives given to the TSO, producers and consumers with a careful attention given to the coordination between actions on the network assets and actions on the assets connected to the network ([Rious et al., 2008](#)). To this aim, the design of the network tariffs applied to the network users can provide adequate incentives to modify the operation of and investment in production and consumption assets ([Pignon, 2003](#), [Rious et al., 2008](#)).

In the European organization, the TSO has several role in the congestion management. First of all, it can use the network investments, network planning and network operation described in the previous paragraph. Then, within the framework of the network tariffs, it contributes to the definition of the adequate level of incentives. Additionally, to ensure the short term congestion management, the TSO responsible for the bidding

²²There are for instance Phase Shifting Transformer (PST)s over the AC network and power converter at the connections between AC and DC elements of the European transmission network.

zone is given some control over the assets connected to the network. Once a critical situation is identified²³, if the congestion is sufficiently anticipated, the TSO can use redispatching methods²⁴ as describe by [Lavoine et al. \(2006\)](#). If the aim is to relieve an emergency situation, then some redispatching is possible on short notice and more constraining decisions such as load shedding could be used as last resort options.

(c) **Role of multiple bidding zones for congestion management**

Within a control area, another way to manage a transmission corridor that may be congested is to translate this network constraint into limited exchange capacities on frontiers between two or more bidding zones. The main aim is to internalize the potential congestion in the market prices so that actors are incentivized to adapt themselves to the network constraint for their operation as well as investment ([Rious et al., 2008](#)). In practice, this principle of dividing up a control area in several bidding zones can take several forms. For instance, in Norway some zone boundaries can evolve with rather short notice ([ENTSO-E, 2012b](#), [Nordpool spot, 2012](#)). Meanwhile, the Control Area of Italy has several zones for producers which does not prevent the system from providing a national single price, also known as PUN, to many end-users ([AEEG, 2010](#)). Moreover, the allocation of rights for market participants to exchange electricity products across the borders between bidding zones can be more or less centralized ([Hogan, 1992](#), [Chao et al., 2000](#), [Pignon, 2003](#)). This last feature is further detailed in the European case with large bidding zones in section II.1 of the modular analysis of the cross-border coordination of operation.

I.2.3 **Focus on the TSOs**

As it appears in the previous paragraphs, the TSOs are given several responsibilities for the good functioning of the power system. [Rious et al. \(2008\)](#) has analysed the role of this actor from a modular perspective and argues that “at least three modules make the core of transmission design: the short run management of network externalities,

²³To guide the decision process, the TSO monitors the situation both in real time thanks to sensors and with anticipation thanks to knowledge about the planned power injections and sinks on the network.

²⁴In a simplified view, the common principles of these methods is to allow the TSO, under conditions, to buy and sell electricity products in a way that would relieve a network issue. The terms counter-trading and transmission loading relief refer to similar methods involving different bidding zones and implementation features.

the long run management of network investment, and the coordination of neighboring transmission system operators (TSOs) for cross-border trade". Thus [Rious et al. \(2008\)](#) has identified that this actor strongly involved in the internal area organization has also a key role for the cross-border exchanges.

Several research questions involving the TSOs have been studied both for the internal area organization and for cross-border issues between areas. First, a TSO interacts with the transmission network users in its control area through tariffs ([Pignon, 2003](#), [Rious, 2007](#)) for the access to the grid. Second, the TSO interacts with its regulatory system. In particular, a fundamental economic question is about the possibility to incentivize a TSO toward particular objectives ([Joskow, 2008b](#), [Glachant et al., 2012](#)) including an adequate legal liability of a TSO ([Philippe & Partners, 2010](#)). Third, the actors in charge of the system operation on the transmission network interact with their owners ([Rious, 2007](#), [Moselle, 2008](#), [Lévêque et al., 2009](#), [Supponen, 2011](#)). Fourth, some elements from this literature emphasize the organizational option of having a "light" actor in charge of the system operation on the transmission network under the form of an Independent System Operator (ISO). Based on five criteria²⁵, [Lévêque et al. \(2009\)](#) compare the ISO and the heavy form of TSO. According to this study, the heavy form has better results considering efficiency criteria than ISO, while the ISO design should limit conflicts of interest with AOs and offer brighter perspective for market integration with its neighbors than the heavy form for two reasons. First, "ISOs have no interest to distort coordination with one another because they have no incentive to reduce national transmission costs and because they follow some management protocols that can be changed more easily to integrate the regional perspective". Second, ISOs arrangements facilitate mergers of the transmission network system operators to reach for most of the regional coordination benefits, while the ownership of national transmission assets is more frequently blocked in the hands of national owners by their respective governments. In practice, the ISO institutional form is used in some large regions of North America²⁶, but it is seldom

²⁵These criteria are 1) Transaction cost savings, 2) the capacity to implement effective performance based regulation, 3) the conflicts of interest, including the one between the transmission ownership and system operation functions within a TSO, 4) non-discriminatory access, and 5) benefits from regional integration.

²⁶See the updated description of the ISOs in the United States on the Federal Energy Regulatory Commission webpage <http://www.ferc.gov/industries/electric/indus-act/rto.asp>, last visited April 2013.

applied in Europe where most TSOs are also the transmission network owners²⁷.

I.2.4 A summary of the organization and acknowledgement of the diversity among European areas

(a) A representation of a single area organization

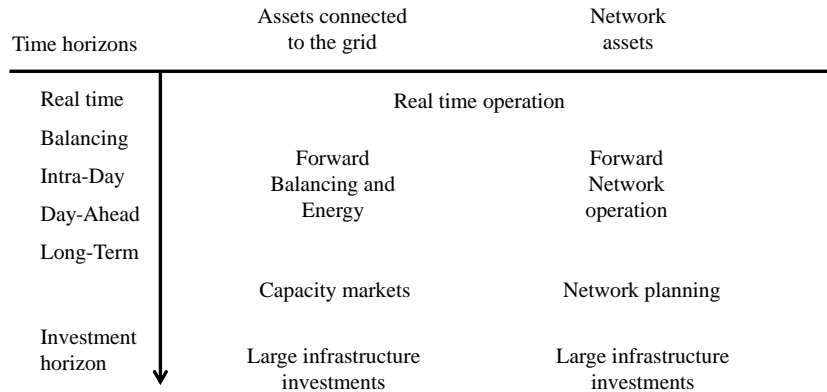


FIGURE I.5: Key features of European power system organization illustrated on an isolated control area.

Inspired from the work of [Saguan \(2007\)](#), figure I.5 summarizes a view of the organization in a control area. More precisely, the content of the graph is key modules of actions performed by stakeholders: real time operation, forward energy and reserve, forward network operation, generation capacity planning, network infrastructure planning and large infrastructure investments. The horizontal axis is a binary division of the power system physical layer between a set of network assets on one side and the elements connected to this first set on the other, including power stations and loads. The vertical axis is a continuous unscalled sequence of time horizons from real time operation (the financial settlement post real time is not represented) to the large infrastructure investments time horizon as illustrated in figure I.4. The interactions between these modules of action are not represented. Instead an empty space is left so that any model of these interactions could be represented depending on the research question or the empirical case considered.

²⁷An exception is the Scottish transmission network, operated by National Grid which is not the transmission network owner. See the company webpage <http://www.nationalgrid.com/corporate/Our+Businesses/transmission/>, last visited March 2013.

(b) The diversity beyond the common features

Beyond the simple graph introduced above, there is a wide diversity of organizations among the European countries²⁸. This diversity can be explained both by historical involvement of the national level as summarized in appendix B.1 and by the adaptation to local specificities. Indeed, [Newbery \(2009\)](#) states that the wholesale market design “should be tailored to the circumstances of each country (ownership structures, fuel sources and institutional/legal endowments and capabilities), but it should also facilitate a move towards a single EU-wide electricity market”. In other words, there may be in specific cases a tradeoff between the two objectives. This kind of interactions between an area organization and cross-border organization features is further discussed in section II.4.

²⁸See for instance the technical documents about DA market organization ([Comillas University et al., 2011](#)), about transmission tariffs ([ENTSO-E, 2012k](#)) or about ancillary services ([ENTSO-E, 2012q](#), [Rebours et al., 2007a](#)). The terms DA market and ancillary services are defined in the glossary of appendix A.

I.3 Definition and role of the cross-border coordination of operation

The previous sections have defined the internal borders and the organization principles within an homogeneous area of an integrated power system. Based on these elements, section [I.3.1](#) defines the research object as part of the cross-border coordination between homogeneous areas. More precisely, a short definition is first illustrated by a graphical representation of an integrated power system organization. Then, the research object is defined by the two fundamental economic functions it is expected to perform. This definition is to be further detailed in chapter [II](#) through a modular approach.

Then, section [I.3.2](#) shows why it is worth working on the improvement of the cross-border coordination of operation. Indeed, from a dynamic perspective, the evolution of the research object can be part of an integration process. In particular, the section shows through three complementary theoretical frameworks how an integration process can contribute to the objectives of an energy policy.

Finally, the interactions between improvements of the cross-border coordination of operation and large infrastructure investments in an integration process are formalized in section [I.3.3](#). Indeed, the two sets of actions interact through the common goals they serve. This formalization supports fundamental policy recommendations that should be followed when working on the two sets of actions separately as it is often done in practice and in this thesis.

I.3.1 Definition and role of the research object in an integrated power system

Let there be an internal border in a power system separating the power system in two areas with an imperfect coordination between them. Imperfect is simply understood as the fact that a modification of the coordination arrangements could improve the overall situation of the integrated system according to a set of policy objectives²⁹. To complete the identification of relevant power system organization principles, this section introduces the existence of a module called cross-border of operation between several control areas with differing regulations.

²⁹Appendix [B.2](#) is a brief summary of classical power system objectives.

(a) **Cross-border coordination versus extension of the internal area organization**

Across an internal border between different areas of an integrated power system, the solution to reduce the imperfection of a coordination lies somewhere between two theoretical modes: merging the areas with a deep harmonization of their area internal organization or improving the cross-border coordination between different internal organizations with different TSOs (Costello, 2001, Pignon, 2003). In the first mode the resulting system would be a larger area with an homogeneous internal organization. As introduced in the previous section, a light institutional form of TSO appears more adapted to the geographical extension of a control area (Lévêque et al., 2009). This principle has been promoted in the United States with the Regional Transmission Organization (RTO) model in a voluntary approach (FERC, 1999, Merrill, 2010, Costello, 2001, Joskow, 2005). The second mode can be seen as a module of coordination in addition to the internal area organization as proposed by Saguan (2007) according to a theoretical approach of the system organization based on its modularity³⁰. Within this perspective, the cross-border coordination becomes a core task of the TSO of each control area (Rious et al., 2008).

(b) **Rationale for focusing on the cross-border coordination**

The solutions studied in this thesis are the coordination arrangements across internal borders. This focus can be justified by three kinds of arguments. First, even in the United States where there are successful RTOs, several internal borders remain (Hogan, 2001) and it may be worth improving the coordination at these borders. Second, the European integration process as in 2012 is based on this mode. Third, in a neo-institutional framework where history matters (North, 1990, Williamson, 1993), the strength of the national level of organization in Europe can be assumed to be a strong limit to the possibility of applying the first mode with an extension of the control areas across national borders. This assumption is supported by the historical perspective given in appendix B.1 showing the strong involvement of the national level. Moreover, in the United States, the initiative by the Federal Energy Regulatory Commission (FERC) to

³⁰See section II for further insight on the modularity principles.

launch a standard market design has not been a full success³¹. For all these reasons, the thesis focuses on enriching the literature on the cross-border coordination.

(c) The research object as a subset of tasks of the cross-border coordination

As illustrated in figure I.6, the cross-border coordination arrangements take place between areas. In this set of coordination, a distinction can be made between two subsets which to some extent correspond to two ranges of time horizons. The term coordination of investments shall be used for large infrastructure investments and the term coordination of operation refers to coordination on short term arrangements up to three years maximum. Beyond this first division, the research object is further detailed in chapter II.

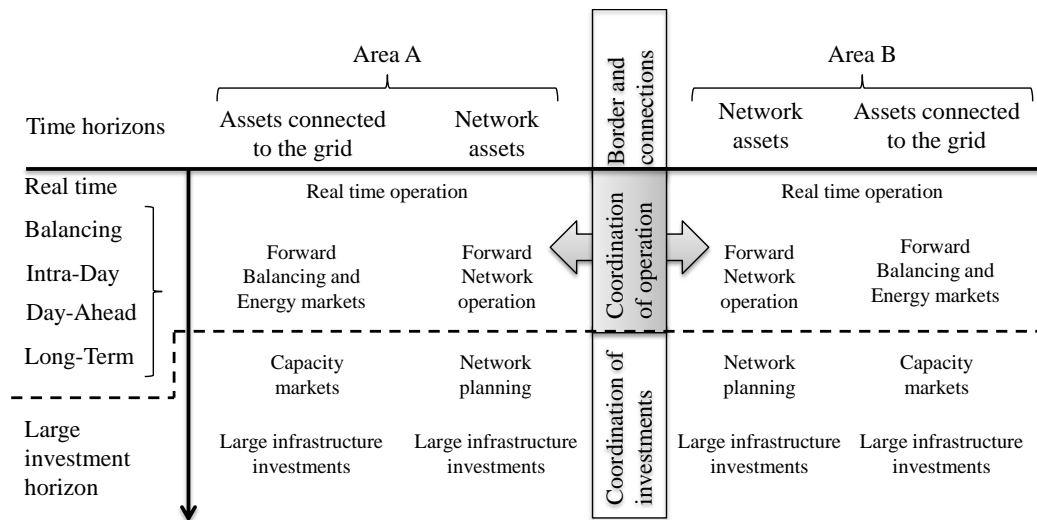


FIGURE I.6: Coordination of operation and coordination of investment between two control areas sharing an interconnected network. The description of each area organization is based on the graphical summary in figure I.5.

(d) The two core economic problems the cross-border coordination of operation shall solve

The principle of third party access to the interconnected transmission network has been agreed among several European countries and settled for instance in the EU law (EU, 2009b). The cross-border coordination of operation shall use it to the benefits of the whole integrated power system. To this aim, the cross-border arrangements shall handle

³¹See the Order Terminating Proceeding of the initiative in the Federal Register at the webpage <http://www.gpo.gov/fdsys/pkg/FR-2005-07-26/html/05-14710.htm>. Besides, there have been many critical comments on the initial proposal (Chao, 2006).

various cross-border issues finding their roots in two core economic problems: determine and allocate a scarce resource and handle the market failures related to cross-border effects requiring a regulation³².

With a simplified view, the benefits of an existing interconnection include the possibility of a mutual support between control areas and the possibility to exchange products defined in section I.2.1 for the benefits of both actors exchanging the product³³. In both case, there is a limited space of possibility for cross-border exchange of energy in real time due for instance to the congestions defined in section I.2.2. Thus, a first fundamental economic problem is to determine and allocate the scarce resource available for cross-border exchanges at each period of delivery. More precisely, this space of possibilities shall be determined at several time horizons before the period of delivery and allocated in advance in order to be used by the actors during the forward modules of the internal area organization as described in section I.2.1.

The cross-border coordination of operation shall also handle several forms of externalities that may appear due to an interconnection and due to its use for cross-border exchanges (Knops, 2008b, de Jong, 2009), which are not solved by the first set of cross-border arrangements for the determination and allocation. The description and classification of these necessary arrangements is proposed in section II.2 of the modular analysis of the cross-border coordination of operation. Moreover, chapter IV about the role of the EU shows with more detail how supranational institutions can solve or prevent several market failures related to the externalities.

I.3.2 Rationale for improving the cross-border coordination of operation

The historical analyses summarized in appendix B.1 shows that the cross-border integration process is a fundamental trend in Europe since the electrification. This section shows that it may be worth investing in further improvement of the cross-border coordination of operation. Indeed, the improvement can be part of an integration process as described in section (a) and the potential benefits of such process are described in

³²The terms market failure and regulation are understood as defined by Baldwin et al. (2011).

³³See for instance (Joskow and Schmalensee, 1983) or the historical perspective on the European electrification in appendix B.1.

subsection (b). This section also selects a combination of three complementary theoretical frameworks to analyse the potential benefits of an improvement in an integration process.

(a) **The coordination improvements as a part of an integration process**

In a dynamic perspective, an integration process of a power system with internal borders can consist in reinforcing the physical layer or improving the coordination over the internal borders. In this first distinction, the physical layer refers to all physical assets impacting the electrical power that can be transmitted between two parts of the system. For example, it includes, among other infrastructures, conductors, transformers, switchers, sensors and generating units. To illustrate the actions on this layer, (Rebours et al., 2010b) shows through bottom-up modeling that investments in the physical level to increase sensibly cross-border capacities can generate a net social surplus for Western Europe, assuming a strong renewable penetration level. Depending on the initial network, the increase of cross-border capacities can be obtained by investments on cross-border lines as well as internal lines in case of internal congestions limiting cross-border exchanges. In both cases, the work on any line often requires to update surrounding infrastructures, such as neighboring lines, so that it can cope with the additional power flows.

The second set of actions can be divided into those concerning the coordination of operation and those concerning the coordination on investments. The decision to invest on the physical layer could indeed benefit from an improved coordination³⁴ (Rious, 2007) and it is shown in the next chapter that there are several perspectives of improvement of the cross-border coordination of operation in the European case. Moreover, section IV.2 shows how some EU non-binding initiatives can foster new agreements and innovations supporting the improvement of the cross-border coordination.

With the two distinctions described above, there are three sets of actions for further integration corresponding to the three blocks at the center of figure I.6 illustrating an integrated power system from a static perspective. The next sections show how further improvement of the cross-border coordination of operation can contribute to the final objectives of an energy policy.

³⁴This set of action is introduced in (Janssen and Rebours, 2012b).

(b) How an integration process can serve an energy policy

Appendix B.2 defines an energy policy³⁵ as a compromise between objectives such as the physical ability to deliver energy in an adequate form, the acceptable costs of delivery and the coherence with other economic and environmental policies linked to the energy system. For instance, the priorities can be to maintain the security of supply and to integrate a large share of intermittent renewable energy at a minimum cost for the society (European Commission, 2007a).

The objective of this section is to support with a theoretical perspective the general intuition acknowledged by economists and engineers (Joskow and Schmalensee, 1983) that a minimum level of coordination over the internal borders of an integrated power system can potentially serve any energy policy. More precisely, it shows through three complementary theoretical frameworks that the cross-border coordination can improve the ability of the system to efficiently reach an objective. The first theoretical framework is an optimization point of view with a fix level of competitiveness concerning the market participants behavior. The second framework adds the potential benefits from an increase competition over the coordinated areas and the coupled markets. The third theoretical framework underlines potential side benefits from further cooperation between non-competitive actors such as sharing good practices on internal area organization features.

This section is a qualitative argumentation and later in this thesis, chapter III supports with some quantitative results that it seems worth studying the improvement cross-border coordination of operation in particular. Besides, these theoretical framework would also be valid to analyse the impact of infrastructure investments in an integration process.

Better operation and investments: the optimization point of view

With a given market competitiveness, an integration process as defined in the previous section can result in a better operation and better investments with reference to a set of objectives. For instance, the objective can be a social surplus maximization under

³⁵In this thesis, unless stated otherwise, the term energy policy shall be used to refer to the policy selected by the energy regulatory system.

security of supply requirements. To describe this, an adequate model of the system is an optimization with objectives that can be quantified in a common unit such as monetary units. Indeed, many parts of power system operation can be seen as optimization processes subject to constraints, such as transmission capacities on the network. Within such optimization problems, increasing the integration between two power systems can be equivalent to relaxing some constraints. Within the resulting enlarged space of possibilities, a new optimum may be found. This is illustrated in figure I.7 on a simple two-area system, considering fully controllable generation capacities with a maximum value in both areas for a given period of delivery. The space of possibilities considered is the total consumption in each area. It is a meaningful set of two homogeneous variables which is adequate for a graphical representation. First the consumptions are assumed positive by definition, and without Available Transfer Capacity (ATC) between the two zones, the constraints are the maximum production capacity $P_{max,i}$ in each area $i \in \{1; 2\}$ in capacity unit (for instance in MW). Because these constraints are horizontal and vertical, the space of possibility is a rectangle. If there is a strictly positive ATC of value ΔP in capacity unit in both directions, then the maximum consumption in each area become $(P_{max,i} + \Delta P)$. In addition, there is a constraint for the total consumption in both areas which shall be below $\sum_i P_{max,i}$. This last constraint would be represented as a 45 degree decreasing line on the graph which explain why the enlarged space of possibilities is not a rectangular anymore. In this simple case, the graph shows clearly how a higher ATC between the two areas can provide additional opportunities for power consumption in both areas. Depending on the production costs, the utility function of the demand in both areas or any other parameters defining considered in the two-area system optimization, the optimum mix of consumption can be among these additional opportunities.

In practice, in a system with several price zones, a common day-ahead market objective can be the maximization of the social surplus from the exchanges under network constraints, as performed by the day-ahead market coupling algorithm³⁶. Let us consider an action relaxing network constraints which increases the cross-border capacities between zones. This action offers the possibility to reach a better optimum, i.e., a situation with an additional gross social surplus rising above the implementation cost of the action.

³⁶See for instance the case-study on tight volume coupling in section C.

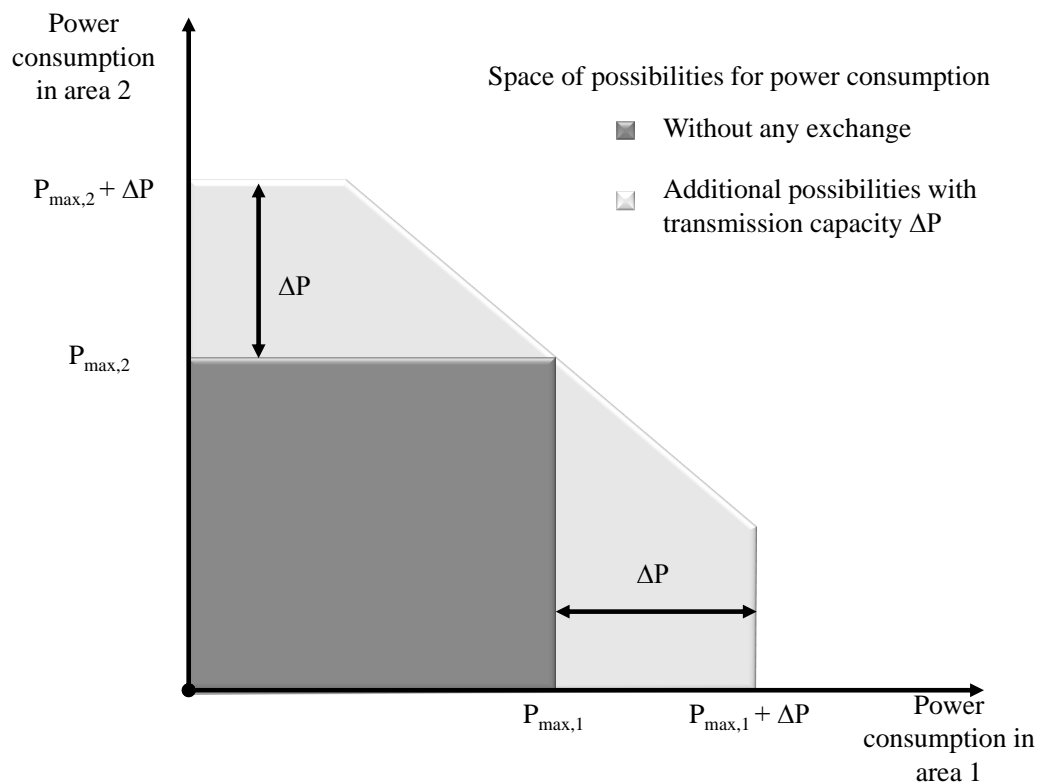


FIGURE I.7: Considering two areas with controllable generation capacities with maximum values for a given period of delivery, the space of possibilities for the power consumption mix can be increased with a higher Available Transmission Capacity. $P_{\max,i}$ is the maximum production capacity in each area $i \in \{1;2\}$ and ΔP is an ATC in capacity unit.

Another example of application of this theoretical framework is the minimization of intermittency management costs in an integrated power system with a high share of intermittent power sources. In this case, the coordination of balancing strategies of neighboring control areas is expected to be able to offer a better optimum (Vandezande et al., 2010). Similarly, the association Eurelectric (2010) concludes more generally that several cross-border coordination of operation arrangements can “optimize the response from flexible sources to compensate for the effect of intermittent [Renewable energy] sources”.

Additional benefits from an increased competition

The first theoretical perspective includes the classical benefits of international trade under fix market competitiveness levels. This second framework takes into account that the integration is likely to increase competition for many actors on the wholesale

markets. An indicator of this effect is for instance the enlargement of the market base for energy and balancing products (Perrot-Voisard and Zachmann, 2009). As a result, the increased competition is expected to bring various additional benefits including more efficient wholesale market suppliers, through innovation, for instance, or incentives given by new perspectives of business opportunities (Krugman and Obstfeld, 2008).

Additional benefits from further cooperation

There is at least another theoretical set of benefits that cannot be found in the two first sets: the positive impacts of further cooperation between non-competitive actors. For instance, the cooperation between TSOs described in chapter V and between regulators as described in section IV.2.1 offers perspectives for sharing good practice. This cooperation is encouraged and stimulated by an integration process.

I.3.3 Formalization of the interactions between improvements of the coordination of operation and infrastructure investments

This section is adapted from (Janssen and Rebours, 2012b).

In an integration process, the improvement of the cross-border coordination of operation interacts with the investment process in infrastructures, including the coordination on these investments. More precisely, they interact through their common objectives given to the integration process as introduced in the previous section. Thus, the question can be raised whether it is adequate to study only the cross-border coordination of operation and the answer depends in practice on the objectives of the study. Concerning the four next chapters, it is justified to focus on the research object because the two sets of actions are to a large extent distinct according to the classification made in the previous section.

Therefore, this section uses a simple mathematical model to formalize how the two sets of actions interact. To formalize the distinction, section (a) defines a hardware and a software level of integration in an integrated power system reduced to a two-node power system. The objective of the integration process is defined as maximizing a social surplus. This modeling shapes a resource allocation problem between the two sets of actions and the mathematical results are presented in section (b). These results

show how the two sets of actions interact through their common final objective. In addition, section (c) draws from the results some pragmatic policy recommendations on the integration process.

(a) Modeling of the interactions with two variables

Topology of the considered power system The illustrative system is made of two nodes and one interconnector (see figure I.8). At each node, the wholesale market is made of one market with only one period of time and one traded product. The two system operators manage mechanisms dedicated to interconnector capacity calculation and allocation, which present some inefficiencies. For example, an imperfection can be a lack of coordination while calculating the exchange capacities offered to allocation mechanisms.

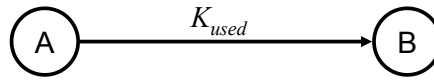


FIGURE I.8: Representation of a two-node system with a single interconnection.

Variables of the hardware and software level of an integration process An integrated power system can be described with a physical layer and an organizational layer. Sometimes, these two parts are referred as the hardware and software layers, highlighting with this metaphor that they complement each another (Eurelectric, 2010). In this section, the software layer shall be reduced to the cross-border coordination of operation, all other elements of the organizational layer being fixed.

Based on these definitions, the model considers two variables. The software level variable $s \in [0, 1]$ is the ratio between the capacity used K_{used} with a given organization and the capacity that could have been used with a perfect organization, i.e., the interconnector physical capacity K_{phy} . The hardware level variable $h \in [0, +\infty[$ is the ratio between the interconnector physical capacity K_{phy} , and a reference capacity K_{ref} defined below.

From these two variables, the integration variable $I = hs$ is the ratio between the capacity used K_{used} and K_{ref} , where K_{ref} is chosen as the lower value of K_{used} so that there is no congestion perceived by the users in the system. With this reference, $I = 1$ represent the minimum value without apparent congestion. In other words, considering the initial software integration s_0 in place, $\frac{K_{ref}}{s_0}$ corresponds to the minimal physical capacity K_{phy} of a system with no congestion. This third variable I is useful to interpret the model developed in this section.

Gross social surplus The gross surplus function G corresponds to the reduction of the deadweight cost associated to a situation with no exchange, as shown in figure I.9 (Krugman and Obstfeld, 2008, CRE, 2009), so $G(I)$ is a concave function. Furthermore, a fair representation of the reality can include the following constraints:

- $G(0) = 0$;
- $G(1) = k_{surplus}$, which represents the maximal value for G because of the definition of K_{ref} ;
- $G'(1) = 0$ to model a saturation when I is close to 1.

A function fulfilling these conditions is given in (I.1), which also equals the total surface of the three grey areas in figure I.9.

$$\begin{cases} G(I) = k_{surplus} (2I - I^2), \forall I \in [0; 1] \\ G(I) = G(1), \forall I > 1 \end{cases} \quad (\text{I.1})$$

Figure I.10 shows the behavior of the function for $I \in [0, 1]$. Cases for $I > 1$ are not represented because such integration levels do not bring higher gross benefits than $G(1) = k_{surplus}$.

Integration costs The integration cost function is based on two assumptions. First, $C(h, s) = C_h(h) + C_s(s)$, corresponding to the general case where hardware and software costs can be accounted separately. Second, each of these two cost functions is strictly growing, which corresponds to the general case where better results lead to higher costs.

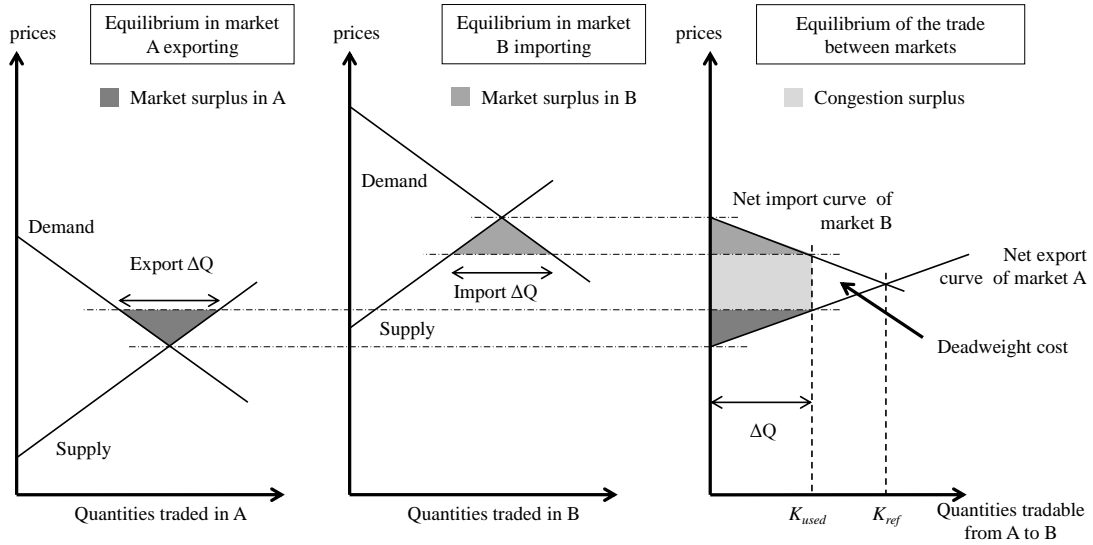


FIGURE I.9: Illustration of the gross surplus as a function of the quantities of capacity used K_{used} . It is assumed that the trade export energy form zone A to zone B. The total gross surplus is the sum of three grey areas on the third graph: the market surplus in A, the market surplus in B and the congestion surplus. When K_{used} is below K_{ref} , the surplus which cannot be reached due to the congestion is sometimes called the deadweight cost.

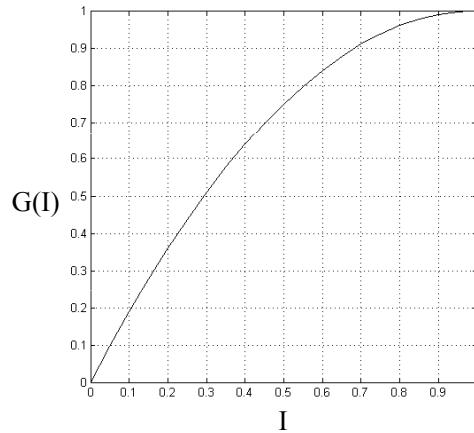


FIGURE I.10: Gross surplus G as a function of the integration variable I representing the ratio between the capacity used and a reference capacity

General results given in section (b) are a priori not sensitive to the choice amongst classical cost functions. Therefore, cost functions are defined to allow an analytical study. In fact, the integration cost is defined as a simple quadratic function as in (I.2), where $x \in \{h, s\}$ and $k_{cost,x}$ is a constant cost parameter. Besides, an initial cost $k_{ini,x} > 0$ can be added without impacting the general results as highlighted in section (b).

$$C_x(x) = k_{cost,x}x^2 \tag{I.2}$$

Net social surplus and similarities with a resource allocation model The common net social surplus N is defined as the difference between the gross surplus $G(hs)$ and the integration costs $C(h)$ and $C(s)$. By using (I.1) and (I.2), the resulting net social surplus can be expressed as in (I.3).

$$N(h, s) = k_{surplus} (2hs - (hs)^2) - k_{cost,h}h^2 - k_{cost,s}s^2 \quad (\text{I.3})$$

The resulting function is similar to the objective function in a resource allocation problem with a Cobb-Douglas production function of two goods considering strong saturation effects (Cobb and Douglas, 1928). Therefore, some elements from the microeconomics toolbox, including a classic two-dimensional graphic representation, can be used to analyze the results.

(b) Results from the modeling

From the model proposed in section (a), this section analyzes how the two variables measuring the impact of the two sets of actions interact while serving their common objective.

Variations of the net social surplus and partial optima First, since the net social surplus N is a strictly concave function over $(h, s) \in [0, +\infty[\times [0, 1]$ with $\lim_{h \rightarrow +\infty} N(h, s) = -\infty$, this surplus has a maximum value illustrated graphically in section (b). Hence, at least one optimal integration (h_{opt}, s_{opt}) exists corresponding to the maximum of N .

Second, the formal expression of the partial deviative (I.4) brings more interesting results.

$$\frac{\partial N}{\partial s}(h, s) = 2k_{surplus}h(1 - sh) - 2k_{cost,s}s \quad (\text{I.4})$$

N is strictly concave and if $\frac{\partial N}{\partial s}$ is extended over $[0, +\infty[^2$, then a unique function $s_e^*(h)$ from $[0, +\infty[$ to $[0, +\infty[$ exists such as:

$$\frac{\partial N}{\partial s}(h, s_e^*(h)) = 0 \Leftrightarrow s_e^*(h) = \frac{k_{surplus}h}{k_{surplus}h^2 + k_{cost,s}} \quad (\text{I.5})$$

Therefore, the partial optimum s^* as a function of h can be build within $[0, 1]$:

$$s^*(h) = \begin{cases} s_e^*(h) & \text{if } s_e^*(h) \leq 1 \\ 1 & \text{if } s_e^*(h) > 1 \end{cases} \quad (\text{I.6})$$

Naturally, the optimal level s^* of s at fixed h increases when the software integration cost $k_{cost,s}$ decreases or when the maximal possible gross social surplus $k_{surplus}$ increases.

Third, two interesting results come from the observation of key values of $s^*(h)$. $s^*(0) = 0$ means that if h is close to 0, then it may be sub-optimal to implement a “high” s . Therefore, policy makers should concentrate on software integration only if the hardware integration is already sufficient. $s^*(h)h < 1$ means that the optimum $(h_{opt}, s^*(h_{opt}))$ is a situation with $I < 1$. Therefore, the “copper plate” target, i.e., looking for no congestion, is inefficient in this model, except if costs are null, i.e., investments have been already paid back.

Last, if s is fixed, then the results are symmetrical in this simple model for h with only $k_{cost,h}$ replacing $k_{cost,s}$.

Graphic illustration and discussion on the parameters Figure I.11 and I.12 give a graphic representation of the case described in section (a). They represent in plain line a selection of isocurves of the net social surplus N as a function of the hardware h and the software s integrations. Furthermore, the locations of the partial optima $(h^*(s), s)$ for h at fixed s are represented by the crossed lines, while the locations of the partial optima $(h, s^*(h))$ for s at fixed h are represented by a line with circles. The global optimum is where the two lines cross, i.e., the extreme value where both partial derivatives of the concave function $N(h, s)$ equal zero.

Regarding parameters related to benefits and costs, $k_{surplus}$ is fixed at 1 as a meaningful reference value, since it represents the maximum gross social surplus. The ratio between the two integration cost parameters as well as their values relative to $k_{surplus}$ have a strong impact on the shape of the graphs. Figure I.11 illustrates a case with symmetric costs parameters $k_{cost,h} = k_{cost,s} = 0.25$, i.e., the costs $C_h(1)$ and $C_s(1)$ equal 25% of the maximal gross surplus. The graph is restricted to $(h, s) \in [0, 1]^2$ because this space contains the optimum according to the findings of section (b);

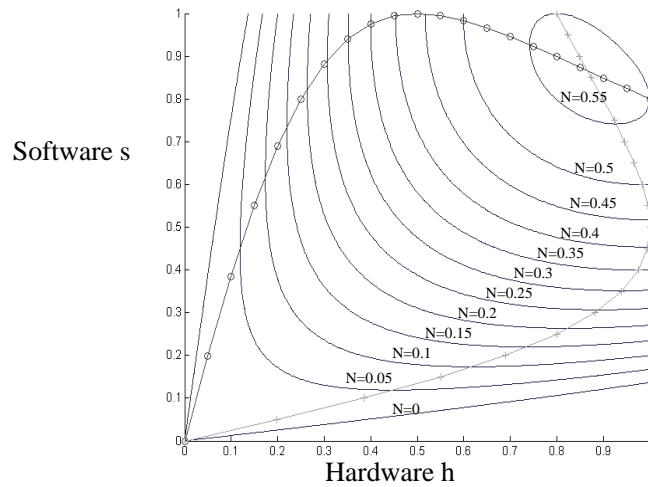


FIGURE I.11: Isocurves of the net social surplus $N(h, s)$ with symmetrical costs functions for the hardware h and software s levels

Figure I.12 displays another case with asymmetric costs parameters fixed at $k_{cost,s} = 0.25$ and $k_{cost,h} = 0.5$, i.e., the hardware is twice more costly than in the previous situation. Compared to the first illustration, the increase infrastructure costs results in lower values for $h^*(s)$ and the optimum (h_{opt}, s_{opt}) is shifted.

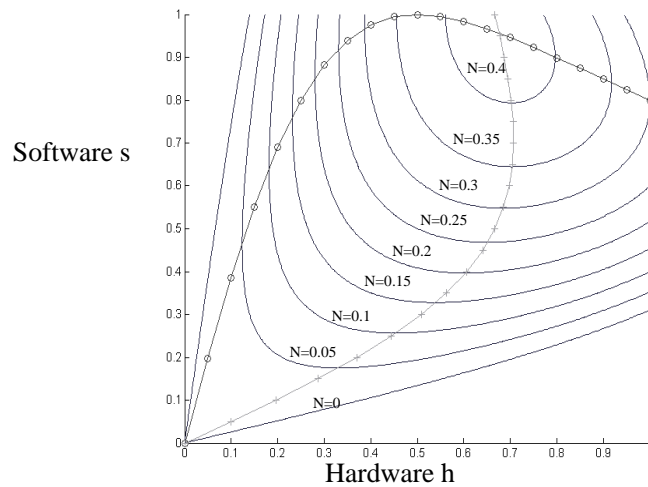


FIGURE I.12: Isocurves of the net social surplus $N(h, s)$ with asymmetrical costs functions for the hardware h and software s levels

Besides, if the integration cost functions were under the form $C(x) = k_{cost,x}x^2 + k_{ini,x}$ with $k_{ini,x} > 0$, then the graphs would have the same shape. The difference would lie in the value N in each isocurve. For instance if $k_{ini}^x = 0.1$, then the isocurve corresponding

to $N = 0.1$ on the graph would become the break-even line for a project with a positive net social surplus.

(c) Policy recommendations for a power system integration process

Chapter III highlights the difficulties of a global quantitative analysis of an integration process such as the European one. This is why this qualitative model with two variables has been developed instead. The result interpretation is similar to a resource allocation problem with complementary goods (Varian, 1992). More precisely, the fundamental interactions described in the simple example (see section (b)) offer an opportunity to strengthen three key policy recommendations to the stakeholders of the integration process.

First, indicators based on congestion effects can be misleading for the integration process. For instance, the fall of an indicator based on congestion occurrence can be associated to a decrease of social surplus if it results from overinvestments. Figure I.13 shows where the area without congestion would be on the illustrative model described above. The optimum is clearly outside of the area without congestion.

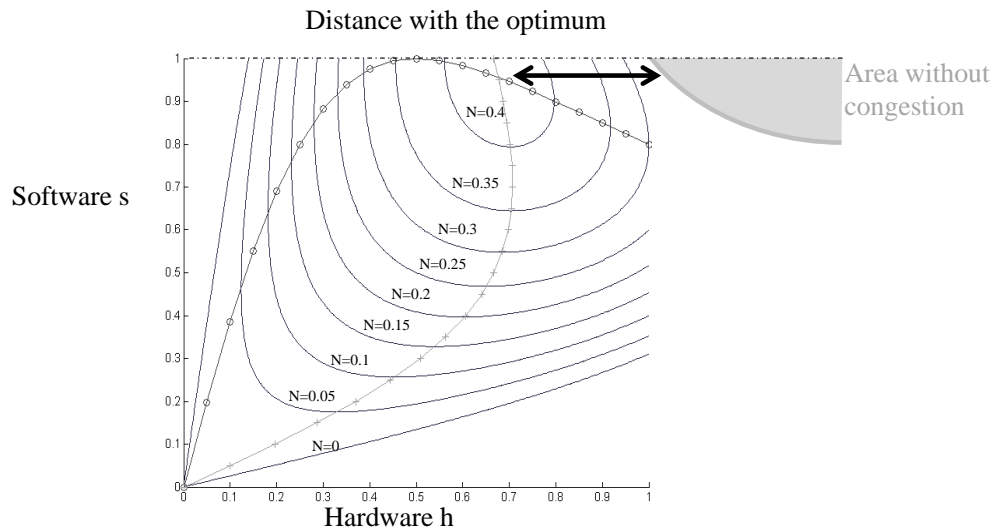


FIGURE I.13: Isocurves of the net social surplus $N(h, s)$ and partial optima as described in figure I.12. The optimum situation is outside of the area without congestion on the top-right corner of the figure.

Second, in order to optimize the large investments in new infrastructures, the impact assessment supporting the investment decision could take into account at least one scenario

of foreseeable improvement of the coordination of operation. Indeed, if the infrastructures can be used in a better way, then the optimum level of investment for the coming period can be more affordable or the investment resources can be better allocated in the case of underinvestment. This is shown in figure I.14 in a case of the illustrative model.

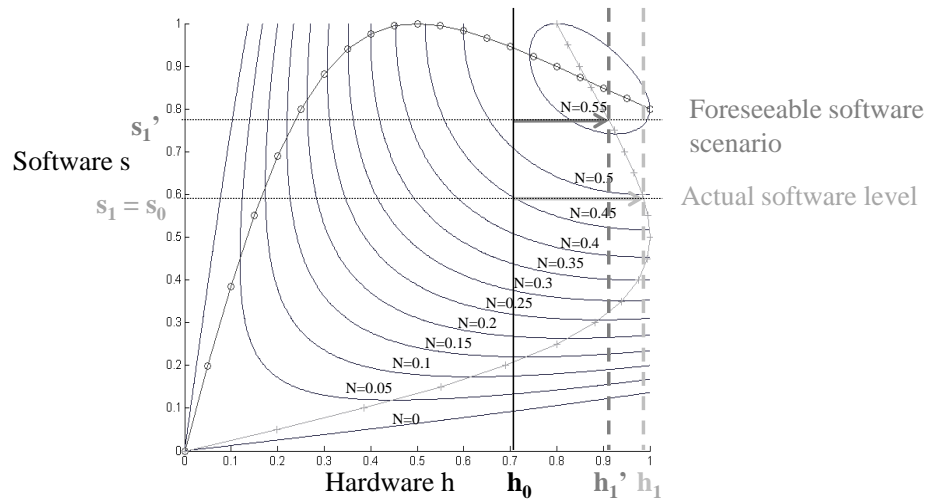


FIGURE I.14: Isocurves of the net social surplus $N(h, s)$ and partial optima as described in figure I.11. Based on initial hardware and software levels (h_0, s_0) , the optimal investment in the hardware level h_1 differs depending on the assumed future software level s_1 , i.e. the level of coordination in the illustrative model. In the case represented, with $s_1' > s_1$, the optimal investment is $h_1' < h_1$, i.e. less investments are needed.

Third, reciprocally, depending on the level of interconnection on the hardware side, the optimal level of investment in the coordination of operation may not be the same over all borders as illustrated in figure I.15. For instance, the software integration may require costly adaptations of local market designs and the drawbacks may be greater than the benefits of a better use of a small interconnection capacity.

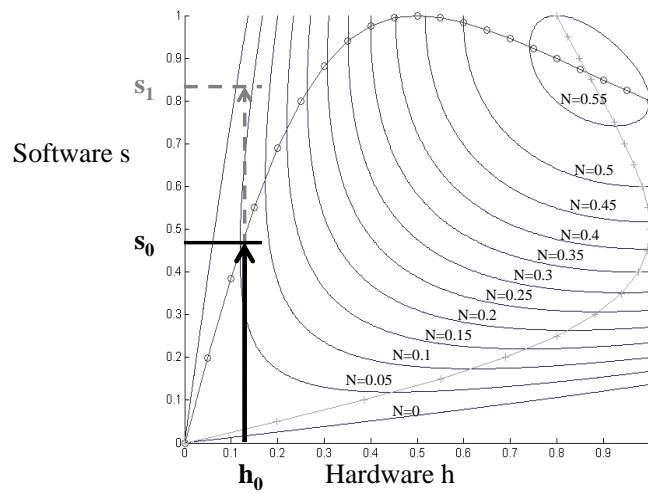


FIGURE I.15: Isocurves of the net social surplus $N(h, s)$ and partial optima as described in figure I.11. Based on an initial hardware level (h_0), if s_0 is the partial optimum level for s , then any investment to reach $s_1 > s_0$ would be at a loss in the illustrative model.

I.4 Chapter Summary

The concept of integrated power system is adequate to describe the European case where most European countries share a large interconnected electricity transmission network and where the organization of the electrical industry over this network is divided by several layers of regulatory, technical and market borders. In this conceptual framework, the cross-border coordination of operation is defined as a set of cross-border arrangements over the technical and regulatory borders³⁷. In particular, the cross-border coordination of operation shall allow the cross-border exchange of energy or reserve products over a sequence of markets and mechanisms segmented in four time horizons called LT, DA, ID and Balancing. It shall also handle the impact of the cross-border power flows on the congestion managements and the network losses.

These arrangements aim at handling two core economic problems : (1) determine and allocate a scarce resource for cross-border exchanges between areas of an integrated power system considering a given set of infrastructures; and (2) handle the cross-border externalities that may appear due to the interconnections between areas and due to their use for cross-border exchanges. The detailed analysis of the cross-border arrangements is performed in the next chapter and to connect these arrangements to the internal area organizations, some relevant features have been selected and introduced in this chapter.

This chapter also introduces the benefits of the improvement of the cross-border coordination through a combination of three frameworks. First, from an optimization point of view and with fixed assumptions about the actors behaviors, the cross-border arrangements can improve the coupling between two sub-problems allowing the integrated power system to reach a better optimum, e.g. an increase of social welfare. Second, with an enlarged microeconomic perspective, the coupling of markets can increase the competitive pressure on each bidding zones. As a consequence, assuming common rules ensure a fair competition across the market borders, the system can benefits from the impact on the actors behaviors in term of efficiency, innovation and relevance of the price signals. Third, positive side products can emerge from the coordination between regulated actors such as the TSOs and members of the regulatory systems cooperating

³⁷See also a graphical definition of the cross-border coordination of operation in an integrated power system organization in figure I.6.

for the implementation of cross-border coordination arrangements, for instance through the exchange of good practices about an internal area organization.

To assess the impact of cross-border coordination in an integration process, this introductory chapter formalizes the interactions between improvements of the coordination of operation and infrastructure investments. Three general policy recommendations can be drawn from the analysis. First, indicators based on congestion effects can be misleading in an integration process. Second, the scenario used for transmission network investment planning could anticipate the impact of the improvement of the cross-border coordination of operation to provide an accurate guidance. Third, depending on the potential benefits of further integration and the level of interconnection on the hardware side, the optimal level of investment in the coordination of operation may not be the same over all borders.

**Part 1: Solutions for the
cross-border coordination of
operation and the tools to assess
their impact**

In the current European integration process, stakeholders are invited to express their view on various arrangements which together form the coordination of operation. Following this thesis objectives, the aim of this first part is to help understand the role and the potential consequences of each one of these arrangements. Chapter II builds a modular framework of the cross-border coordination of operation that should help to go through the complex set of arrangements and chapter III analyses how the impact of a new set of arrangements can be measured. This chapter also gathers a few figures from the literature to give order of magnitude for the process taking place in Europe as in 2012.

Chapter II

Modularity of the cross-border coordination of operation

II.1 Four modules to determine and allocate a scarce resource	58
II.2 Four modules to handle cross-border externalities	93
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“Divide each of the difficulties under examination into as many parts as possible, and as might be necessary for its adequate solution.”

René Descartes¹

¹In Discours de la méthode (1637) (translation by Veitch (Descartes, 2008)).

The first chapter has defined the cross-border coordination of operation in the European integrated power system as a set of coordination arrangements between control areas with differing organizations answering two economic tasks at the benefits of the integrated system. This second chapter goes further into the details of the research object through a modular analysis². The global perspective shows that there is much more than market coupling to efficiently couple markets. This analysis should strengthen the common understanding among stakeholders, it could guide further study on the integration process and it can be used to shape a monitoring board of an integration process as illustrated in the next chapter. Moreover, the description of the modules offers a rather comprehensive view on the current organization in the Central Western Europe (CWE) regions and several perspectives of improvement that could inspire other integration processes.

As described by (Baldwin and Clark, 2000), the underlying principle of a modular analysis is that when the complexity and volume of a task is evaluated above a certain level, the implemented solution can split it in several subtasks that can be performed independently. A good decomposition of the global function should verify that the division between the subtasks are clear, that all subtasks are more simple than the global task, that the remaining interactions between the subtasks can be performed through common well defined interfaces and that the resulting system takes care of the additional externalities between the subtasks. To sum in a few words, a modular framework in economics is a theoretical framework making smart frontiers between parts of a complex system. Ideally, the modules should be defined with no or a very limited overlapping, the set of modules should cover the whole global task and the interactions between the modules and with the rest of the world take place through interfaces that can be defined.

Section II.1 shapes four modules to determine and allocate spaces of possibilities for cross-border exchanges and section II.2 shapes four additional modules to handle the cross-border issues generated by the interconnection or the cross-border exchanges. Each module is described with the following perspectives. First, the role of the module reminds in a few words the place of the module within the global cross-border coordination of operation function. Then, a paragraph called implementation choices describes what

²A first version of the modular framework has been presented in (Janssen and Rebours, 2012c).

has to be decided to perform the task from a theoretical perspective. It also introduced key sets of solutions discussed in the European debate. Finally, the paragraph called implemented solutions points at key arrangement already in place in the CWE region as in 2012. The aim is to complete the theoretical point of view with a concrete picture and a few references are given for more details on the implemented solutions. Altogether, the descriptions build a picture of the whole coordination of operation in a single geographical area. The economic organization of the TSO involvement in these implemented solutions is analyzed in chapter V. In addition, some focuses are added to some modules. The aim is to describe with more details some foreseeable evolutions or hot topics that have been discussed during the current European debate.

To complete the modular framework, section II.3 analyses two key interactions between cross-border modules and section II.3 focuses on the interactions with area internal organization features.

II.1 Four modules to determine and allocate a scarce resource

The fundamental economic task of determination and allocation of a scarce resource can here be decomposed in the two logical steps: (A) Determination of spaces of possibilities for cross-border exchanges, (B) Allocation over the time horizons of the sequence of markets and mechanisms of a power system organization. Each step is itself decomposed in two modules and the structuration of the four modules is inspired by previous works from regulators and TSOs ([CIGRE Working Group C5.04, 2006](#)).

The determination process translates some physical constraints of the system, anticipations of the future system operation and security requirements into constraints on cross-border exchanges. For a given time horizon, the interface between this function and the next is a space of possibilities. For given period of delivery, there can be as many spaces as the number of time horizons of allocation. The process is divided in two parts. **Module A.1** gathers relevant inputs centralized by the TSOs and **module A.2** determines the spaces of possibilities for a secure operation within the limits and rules defined to handle cross-border externalities. The description includes focuses about the possibility to add a new determination time horizon and about a particular form of output of the determination process known as Flow Based (FB).

Concerning the allocation, since the spaces of possibilities for cross-border exchanges are limited resources for the coordinated system, its used shall be optimized and the optimization is decomposed in two steps. **Module B.1** describes a first segmentation fixing the nature of the cross-border capacity right allocated and the time horizon when it is allocated. Then **Module B.2** is the allocation to potential users for a given product at a given time horizon. Concerning the first segmentation, four focuses analyses the reservation of capacity for shorter time horizon, the duration of a base ‘market time period’ for cross-border products, the choice of LT cross-border products and the impact of PTR UIoSI nature on the space of possibilities selection for a given time horizon. Three additional focuses enrich the description of the second module about the success of implicit allocation over explicit allocation, about a common ID implicit allocation and about intuitiveness constraints that may be added to an allocation process.

II.1.1 Module A.1 Information sharing between TSOs

(a) Role.

The expected output of this module A.1 is a common set of database about the power system characteristics which shall feed software used to calculate the space of possibilities for cross-border exchanges in module A.2. This module can also be shared with the software used by TSO to produce coordinated security assessment and to coordinate their actions as described in section II.2. The description of module A.1 focuses on TSO data but it could be enlarged to include the market orders that may be used in module A.2 and market information for market monitoring by regulatory authorities which are included in module D.2 ensuring the good functioning of the wholesale market. With this focus, the output typically includes parameters of the system operation such as network characteristics which can be real time measures, reference cases, network equivalents or forecasts. The reference cases can for instance help to make adequate approximations or guide parameter settings in a calculation process.

(b) Implementation choices.

The first step is to identify the adequate data to be shared based on their potential availability and their expected use. Conventions are necessary on these data definition, measurement and accuracy as well as numerical format. Part of the database can be dynamic since most of the system characteristics depend on variable factors. For instance, temperature and wind impact thermal dissipation, and thus the conductors power capacity (Gaudry and Bousquet, 1997). Similarly, wind can reduce exchange capacities because of the increased risk of short circuit with neighboring items (Kirschen and Jayaweera, 2007). Then, transparency can be useful for the system functioning as long as there is no legitimate reason to restrict access to some data for some time. On this topic, the ERGEG (2010b) advises to establish “a minimum common level of fundamental data transparency that is a precondition for the efficient functioning of wholesale electricity markets”. Finally, there are more practical choices to ensure the operational reliability of the database concerning for instance the security level for the confidential data and the capacity to access the data. Therefore, the responsibilities shall be clearly defined in the agreements.

(c) Implemented solutions.

TSOs of the European Network of Transmission System Operators for Electricity (ENTSO-E) Continental Europe Regional Group currently share files including some elements of a common system database. In particular, the current agreement on data sharing defining Day-Ahead Congestion Forecasts (DACFs) files ([ENTSO-E, 2011c](#)) allows each SO to perform a load flow forecast with a certain amount of details over a larger region than its control area. These files are for instance used in module C.1. Furthermore, the [ENTSO-E \(2009\)](#) offers an overview of its Common Information Model (CIM) Model Exchange Profile. It defines standards for the exchange of data about the state variables, TSO topology features and TSO equipments.

II.1.2 Module A.2 Determination of spaces of possibilities for cross-border exchanges**(a) Role.**

The expected outputs are secure spaces of possibilities for cross-border exchanges between bidding zones determined at various time horizons. The aim is to find the adequate balance between offering as much opportunities as possible for cross-border exchange and maintaining the risk of system failure below a satisfactory level.

The data of the first module include a complex representation of the physical limits of the system and some commonly agreed anticipations on its future behavior among other useful information. This second module transforms these data into a more practical output for a given period of delivery taking into account security rules. More precisely, this module can be divided in sub-modules corresponding to the time horizons for which the calculation is performed. Indeed, the space of possibility for a given period of delivery may be different depending on the time-horizon when it is performed.

(b) Implementation choices.

The determination process cannot be reduced to a simple software issue. Far from it, this process involves at least three fundamental economic choices.

First, there is an arbitrage between external and internal congestion management within a control area. This issue is developed with a more global perspective in section II.4, summarizing a very clear work by [Willems and Sadowska \(2012\)](#) about the Swedish bidding zone definitions.

Second, the choice of security criteria and security levels is an arbitrage between increasing the spaces of possibilities for cross-border exchanges or increasing the reliability. Indeed, given the inherent uncertainties of power system operation planning, it would not be optimal to ensure at all costs that the system is unlikely to break its physical limits. In practice, two different kinds of uncertainties drive the determination of a space of possibilities ([ACER, 2011d](#)) from the common system data: the uncertainties about a contingency and the uncertainties associated to approximations in the cross-border coordination process.

Third, the shape of the output space of possibility for the cross-border exchanges is a fundamental choice of market design. Given the interdependence between flows on all borders of an AC interconnected network, it would seem interesting to keep these relations into the space of possibilities. Methods based on this principle are called Flow Based (FB) and are described in a long focus of this module. If the allocation process is performed through separate bilateral allocation on each border, then the space of possibility shall be reduced to fit within this additional organizational constraint.

(c) Implemented solutions.

Concerning the security rules, the prevention of contingency includes, for instance, the application of rules known as “N-x” criteria (read “N minus x”). In a few words, the “N-1” criteria states that the system should be able to cope with the unexpected loss of one major element such as a transmission line or a large power plant. In addition, security margins are taken to handle uncertainties associated to approximations made in the determination process such as those described in the focus on FB methods below.

Concerning the shape of the space of possibilities for the Long-Term (LT), Day-Ahead (DA) and Intra-Day (ID) time horizons in the CWE region in early 2012, it is a set of vectors of maximum bilateral capacity at each physical border in each direction. For a given period of delivery, the so-called Net Transfer Capacity (NTC) are calculated

at each border for each direction of the flow according to equation (II.2) as defined in (ENTSO-E, 2011c). *BCE* refers to the Base Case Exchange or physical flows without cross-border exchanges. ΔE is a maximum shift of generation that can be assigned to control areas involved in the interconnection preventing any violation of the N-1 security principles. The Total Transfer Capacity (TTC) is sometimes used to refer to the sum of *BCE* and ΔE . From this sum is subtracted a Transmission Reliability Margin (TRM) determined in a bilateral process as described in (ETSO, 2001a).

$$TTC = BCE + \Delta E \quad (\text{II.1})$$

$$NTC = TTC - TRM \quad (\text{II.2})$$

(d) Focus on the possibility to add a new determination time horizon

Let it be assumed that the TSOs of a coordinated area determine spaces of possibilities for cross-border exchanges at the DA time-horizons and use the same result for the ID allocation processes. This focus argues that a new determination of the space of possibilities closer to real time for part of the ID markets could generate a net social surplus. Indeed, on the cost side, the additional cost for this new task can be moderated if it uses parts of a process already developed and tested for the initial DA determination. On the plus side, benefits can come from a reduction of uncertainties if the data are actualized closer to real time. Indeed, there are for instance new information such as DA market results, better forecasts of whether conditions for load as well as wind and solar power generation. Thus some security margins may be reduced while keeping the same level of security for the system operation for DA and ID time horizons. In other words, the new task may end up offering a different space of possibilities with additional opportunities to reach a better optimum.

(e) Focus on Flow Based (FB) methods

The bilateral NTC as described above are only one of many possible shapes that could be used in an allocation process. The CWE region plans to implement in the near future another method under the term Flow Based (FB) which is under experimentation (ACER and AESAG, 2012b). It is one of many implementation solutions that could be

referred with this term and their common principle is to make less assumptions on the future flows in order to produce a better output of function A, *ceteris paribus*.

Since this new method shall impact several aspect of the system organizations, it appeared necessary to dedicate a long and didactic focus on it. After an introduction to the general principle, the following paragraphs offer a formal description of the determination starting from a linear model of the physical constraints. Then, the output is illustrated graphically for a three-node system. Finally, the FB output is compared with potential NTC outputs. Thanks to the understanding of the FB determination process, the last paragraphs show why the new method is expected to perform better than the previous one.

FB general principle. As introduced above, the aim of the FB solution for module A.2 is to link the commercial transactions to the physical limits of the network in a reasonably simple way. In both cases it needs, as inputs, a network model and a commonly agreed base case of the power system operation for the period of delivery considered. The general model introduced below is similar to the one used in official reports such as (CWE, 2011b). In a zonal organization, the output of the process, a space of possibilities for cross-border exchanges, can be defined for the net export $(E_z)_{z \in Z}$ where Z is the set of zones considered. They can be listed in a vector \mathbf{E} .

In addition, a set C shall lists the relevant physical constraints on the interconnected network of the coordinated areas. In this representation, for each constraint $c \in C$ only one mathematical boundary is represented. Given that the power flow is limited in both directions on each network element, the model includes potentially two constraints for each element: one for each direction. For each $c \in C$ the impact of \mathbf{E} on the power flow limited by c shall be referred as F_c . The impact can be modeled by a function f_c as follow:

$$F_c = f_c(\mathbf{E}) \tag{II.3}$$

For each $c \in C$, a Remaining Available Margin (RAM) shall be determined as a maximum acceptable value for F_c according to the formula in equation II.4. This formula is similar to equation (II.2) describing the NTC. Indeed, the parameter F_c^{max} is defined

as the difference between the maximum positive power flow on the line and a reference flow corresponding to the base case, similarly to the TTC while a Flow Reliability Margin (FRM) is subtracted from it to manage some uncertainties similarly to the TRM.

$$\forall c \in C, \quad RAM_c = F_c^{max} - FRM_c \quad (\text{II.4})$$

With these upper boundaries, equation (II.5) defines a space of possibilities for vector \mathbf{E} as follow:

$$\forall c \in C, \quad F_c \leq RAM_c \iff f_c(\mathbf{E}) \leq RAM_c \quad (\text{II.5})$$

The choice of the set of constraints C and the determination of the related RAM_c are key regulatory choices. As highlighted in section II.4, this choice includes arbitrages between intra-zone and cross-border congestion management methods. For instance an increase of the term F_c^{max} for a given constraint can increase the opportunities for cross-border exchanges at the expense of those who may have to pay for congestion alleviation methods for this constraint.

Power Transfer Distribution Factors (PTDFs) in a linear system of constraints. As described in (CWE, 2011b), the output of the implemented solution in the CWE region is planned to be a linear system of equation. This feature is useful for the next modules since for instance it allows to use mixed integer linear optimization solver for the allocation process. Therefore the functions $(f_c)_{c \in C}$ shall be replaced by a single linear function between two multidimensional spaces. The resulting multilinear function can itself be modeled by a matrix \mathbf{M}_{PTDF} which elements are called Power Transfer Distribution Factor (PTDF). In the resulting equation (II.6), the parameters $(RAM_c)_{c \in C}$ are listed in a vector \mathbf{RAM} in a coherent order with the matrix construction and the operator \leq is used to represent the comparison of two vectors ‘line by line’.

$$\mathbf{M}_{PTDF} \times \mathbf{E} \leq \mathbf{RAM} \quad (\text{II.6})$$

The output linear system of constraints represented by equation (II.6) defines a convex space of possibilities. The proof of this statement is rather intuitive. Each constraint

$c \in C$ defines space of possibilities as half-space (a half-plan in two dimension) which is a convex space. Then, since the global space of possibilities shall meet all requirements, the result is the intersection of convex spaces which is itself convex.

In this model, each PTDF links the variation of net export E_z in a zone $z \in Z$ to the variation of power flow F_c limited by the constraint $c \in C$. In practice, there are different methods to estimate them. Two intuitive ways to feel what the PTDFs represent are to imagine them as the result of a regression analysis over the net export variables or as the result of partial derivatives around a base case, hereinafter BC in the following equations. The derivative definition is formalized in equation (II.7) similarly to a definition used by Kurzidem (2010). With this approach the PTDF matrix can be seen as the Jacobian matrix of the vector of functions made of $(f_c)_{c \in C}$ calculated at the base case.

$$\forall z \in Z, \forall c \in C, \quad PTDF_{c,z} = \left. \frac{\partial F_c}{\partial E_z} \right|_{BC} \quad (\text{II.7})$$

Obviously, this coefficient cannot be calculated without the information on where the net export is flowing if the zone is exporting or on where the power is produced if the zone imports. In fact, the selection of an arbitrary reference zone is sufficient, *i.e.* a zone receiving the net export injected by all other zones. The choice of this reference zone has no impact as long as the same reference is used for all the coefficients of the matrix M_{PTDF} . The validity of this method can be explained by the additivity of the power flows in the network model and the generation adequacy constraint on the total net export³ over all zones $\sum_{z \in Z} E_z = 0$ which is added to the network constraints in a way or another during the allocation process to select acceptable outcomes for the vector E . Indeed, since the sum of the net exports over the integrated power system has to be zero for the generation adequacy, then the virtual net export on the reference node that does not correspond to a real variation of generation shall be zero for a possible outcome. Thanks to the additivity of the power flows, the virtual power flows going to and from the reference zone from each zone adds up to form the power flows corresponding to the global outcome.

Insights on the determination of the PTDF matrix in practice. In a system with large bidding zones, the determination of a PTDF matrix can be decomposed in

³The losses generated by cross-border transactions on the regulated network are handled by the organization of each control area.

three complementary processes. One produces a network model based on assumptions about the network assets. A second produces assumptions on the localization of the variation of net export within each zone. The third is a selection of the most relevant constraints to reduce the size of the output matrix. This selection can improve operational efficiency by reducing computing durations for instance. The principle of these three processes is described in the following paragraphs.

First, the network can be modeled by PTDF coefficients in a nodal view of the network. At this level of detail, the calculation depends mainly on network assumptions. For each node $n \in N$ the coefficient links a variation of the net export E_n at this node to the variation of power flow on a critical element $c \in C$ as shown in equation (II.8) with a derivative definition to be coherent with equation (II.7). Similarly to the zonal PTDF, the calculation of the nodal PTDFs over an interconnected system to build the PTDF matrix requires a common reference node.

$$\forall n \in N, \forall c \in C, \quad PTDF_{c,n} = \left. \frac{\partial F_c}{\partial E_n} \right|_{BC} \quad (\text{II.8})$$

Then, since Europe has a zonal organization, it is necessary to make assumptions about how a net export in a large zone is distributed between the nodes of the zone. These assumptions are gathered in coefficients known as Generation Shift Keys (GSKs) linking the variation of net export in a node to the variation of net export in a zone as defined in equation (II.9). It can involve a market model since it intends to anticipate at which nodes the cross-border exchanges would have an impact. Please note that the underlying assumptions behind the GSKs can be expressed in other forms.

$$\forall n \in N, \forall z \in Z, \quad GSK_{n,z} = \left. \frac{\partial E_n}{\partial E_z} \right|_{BC} \quad (\text{II.9})$$

With this two sets of coefficients, the zonal PTDF coefficients of equation (II.7) can then be built mathematically as a sum over the nodes as shown in equation (II.10) because the net exports over these nodes form an adequate set of variables to replace the zonal net export variables. Moreover, this equation can be written under the form of a matrix multiplication as in equation (II.11) where matrix $\mathbf{M}_{PTDF,zonal}$ is defined by the coefficients $(PTDF_{c,z})_{c \in C, z \in Z}$, matrix $\mathbf{M}_{PTDF,nodal}$ is defined by $(PTDF_{c,n})_{c \in C, n \in N}$

and matrix \mathbf{M}_{GSK} is defined by $(GSK_{n,z})_{n \in N, z \in Z}$.

$$\forall z \in Z, \forall c \in C, \quad \begin{aligned} PTDF_{c,z} &= \sum_{n \in N} \left. \frac{\partial F_c}{\partial E_n} \right|_{BC} \times \left. \frac{\partial E_n}{\partial E_z} \right|_{BC} \\ PTDF_{c,z} &= \sum_{n \in N} PTDF_{c,n} \times GSK_{n,z} \end{aligned} \quad (\text{II.10})$$

$$\mathbf{M}_{PTDF,zonal} = \mathbf{M}_{PTDF,nodal} \times \mathbf{GSK} \quad (\text{II.11})$$

In addition to that, the set C is reduced at several stages of the process, so that only the most relevant constraints are kept and transmitted as output of module A.2 (CWE, 2011b). For instance, in a deterministic view of the system, some constraints may be neglected without any consequences on the model security indicators if they are covered by stronger constraints. In a stochastic approach, the selection is more subtle but follows the same spirit. The selected elements are often referred as critical branch in official reports and in the literature. Among other definitions, the term flowgate is also used by Kurzidem (2010) to refer to the constraints defined in a simplified transmission system model.

To sum up, in the FB solution that shall be implemented in the CWE region as described for instance by Aguado et al. (2012), key implementation choices includes nodal PTDfS, GSKs and a selection of critical branches, all based on reference cases. On this topic, several actors such as (Statkraft, 2012) remind that “complexity requires transparency”.

Alternative expression of the space of possibilities. In the previous paragraphs, the variables defining the space of possibilities have been only expressed as the net exports listed in a vector \mathbf{E} because it what the CWE project reports displays. In practice, other sets of variables can be used. For instance, it is possible to use the commercial cross-border transaction flows $(T_b)_{b \in B}$ where B is the set of directly connected borders and for each transaction flow a positive direction is fixed by convention. \mathbf{T} is the vector listing these variables. This set of variable is often used in the literature because it allows an easy graphical comparison with NTCs. For other applications, B can also represent the set of all couples of bidding zones with the same theoretical framework.

The two mathematical representations of the space of possibilities have many similarities. Among the differences, there may not be as many zones as borders, therefore B and Z may have different dimensions. More precisely, B has a higher dimension than Z as

soon as the interconnected network is meshed. \mathbf{E} can easily be determined in a unique manner from a given \mathbf{T} since the net export of each zone can be calculated as the sum of the cross-border transactions involving this zone. For a given system, the conversion matrix $\mathbf{M}_{\mathbf{T} \rightarrow \mathbf{E}}$ has coefficients $(I_{z,b})_{z \in Z, b \in B}$ as defined in the following equation:

$$\forall z \in Z, \forall b \in B, \quad I_{z,b} = \begin{cases} +1 & \text{if zone } z \text{ is exporting when } T_b > 0 \\ -1 & \text{if zone } z \text{ is importing when } T_b > 0 \\ 0 & \text{in any other cases} \end{cases} \quad (\text{II.12})$$

Let $\mathbf{M}_{PTDF,\mathbf{E}}$ be the PTDF matrix of equation (II.6) described in the previous section for \mathbf{E} . Let $\mathbf{M}_{PTDF,\mathbf{T}}$ be the PTDF matrix representing the same system with the same assumptions, but expressed for \mathbf{T} . These two matrices are related by the matrix $\mathbf{M}_{\mathbf{T} \rightarrow \mathbf{E}}$ whose coefficients have been explicated above:

$$\mathbf{M}_{PTDF,\mathbf{T}} = \mathbf{M}_{PTDF,\mathbf{E}} \times \mathbf{M}_{\mathbf{T} \rightarrow \mathbf{E}} \quad (\text{II.13})$$

The output of the FB method is then a set of constraint for \mathbf{T} :

$$\mathbf{M}_{PTDF,\mathbf{T}} \times \mathbf{T} \leq \mathbf{RAM} \quad (\text{II.14})$$

Graphical illustration on a three-node system The system studied has three zones (A, B and C) connected by three lines as shown in figure II.1 and each zone is a single node. The variables shall be the net cross-border transactions in order to prepare the comparison with NTC methods. Moreover, the output is reduced to a two dimensional space in order to produce a clear graphical representation. The two variables shall be $T_{A \rightarrow B}$ and $T_{A \rightarrow C}$ whereas $T_{B \rightarrow C}$ is fixed at zero⁴. Three lines with a maximum power flow in each direction generate six constraints which are upper boundaries for the respective power flows $F_{A \rightarrow B}$, $F_{B \rightarrow A}$, $F_{A \rightarrow C}$, $F_{C \rightarrow A}$, $F_{B \rightarrow C}$ and $F_{C \rightarrow B}$. The linear model uses transaction PTDFs to link the six power flows and the two variables. For instance the power flow $F_{A \rightarrow B}$ is calculated as:

$$F_{A \rightarrow B} = PTDF_{F_{A \rightarrow B}, T_{A \rightarrow B}} \times T_{A \rightarrow B} + PTDF_{F_{A \rightarrow B}, T_{A \rightarrow C}} \times T_{A \rightarrow C} \quad (\text{II.15})$$

⁴This arbitrary constraint $T_{B \rightarrow C} = K$ with K constant is necessary to have a two-dimensional representation of a three-zone system. The value zero is chosen because it offers lighter equations.

For a numerical application of the PTDF, the system is taken symmetric with the same electrical impedance on the three lines. There are no control device on the cross-border power flows resulting from commercial transactions between zones. Moreover, since there is no bidding zone larger than one node, there are no need of GSKs. Thus, the calculation of the PTDF coefficients can be made using the basic Kirchhoff's and Ohm's circuit laws. For a commercial transactions between two nodes, two thirds of the power flow follow the short direct path while one third flows through the long path through the third node. In this simple case, the power flows resulting from the two sets of transactions simply add up on the lines and the equations are directly linear. Thus no additional linearization is necessary and the result is given for $F_{A \rightarrow B}$:

$$F_{A \rightarrow B} = \frac{2}{3} \times T_{A \rightarrow B} + \frac{1}{3} \times T_{A \rightarrow C} \quad (\text{II.16})$$

The resulting system of equation representing the six constraints is listed in equation (II.17). For the graphical representation, all RAMs are given the same value RAM in capacity unit and they correspond to a base case without cross-border flows. The resulting space of possibilities and the borders of the constraints are displayed in figure II.1.

$$\left\{ \begin{array}{l} (C_1) \quad \frac{2}{3} \times T_{A \rightarrow B} + \frac{1}{3} \times T_{A \rightarrow C} \leq RAM_{A \rightarrow B} \\ (C_2) \quad -\frac{2}{3} \times T_{A \rightarrow B} - \frac{1}{3} \times T_{A \rightarrow C} \leq RAM_{B \rightarrow A} \\ (C_3) \quad \frac{1}{3} \times T_{A \rightarrow B} + \frac{2}{3} \times T_{A \rightarrow C} \leq RAM_{A \rightarrow C} \\ (C_4) \quad -\frac{1}{3} \times T_{A \rightarrow B} - \frac{2}{3} \times T_{A \rightarrow C} \leq RAM_{C \rightarrow A} \\ (C_5) \quad -\frac{1}{3} \times T_{A \rightarrow B} + \frac{1}{3} \times T_{A \rightarrow C} \leq RAM_{B \rightarrow C} \\ (C_6) \quad \frac{1}{3} \times T_{A \rightarrow B} - \frac{1}{3} \times T_{A \rightarrow C} \leq RAM_{C \rightarrow B} \end{array} \right. \quad (\text{II.17})$$

Graphical comparison between FB and NTC The expected benefits of using a FB solution rather than NTCs in a meshed interconnected network could be measured in at least two sets of dimensions: how large and adequate is the space of possibilities and what are the security levels. In the following graphical illustration, the security of supply is fixed at the same levels for both NTC and FB solutions. With this assumption, the NTC space, also known as NTC domain, is necessarily included into the FB space, or domain, and the expected benefits shall be illustrated as additional space of possibilities.

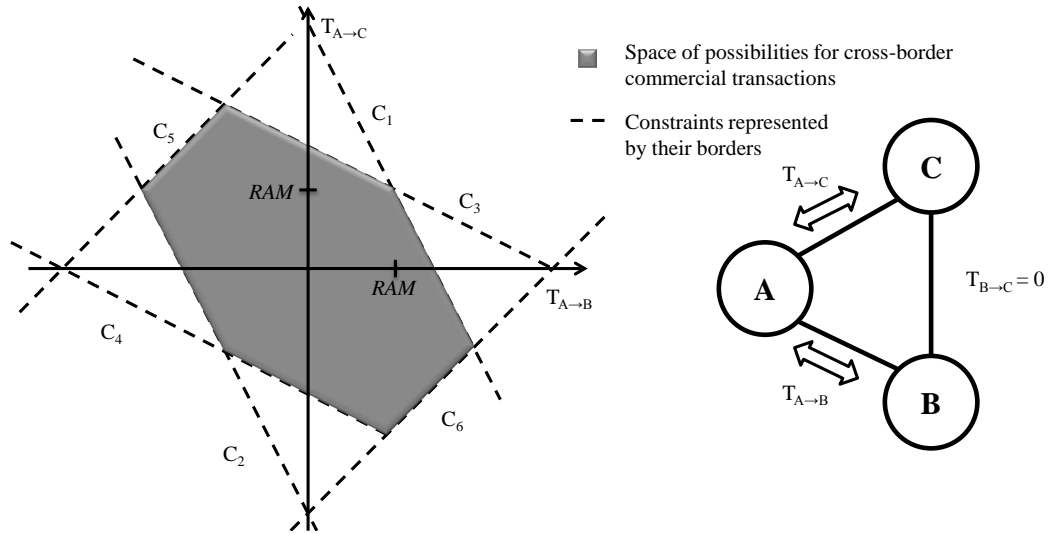


FIGURE II.1: Two dimensional representation of the Flow Based output for a three-zone system represented on the right side with commercial transactions between zones. The dotted lines illustrate the constraints with the reference numbers given in equation (II.17) where the six RAMs are given the same value RAM .

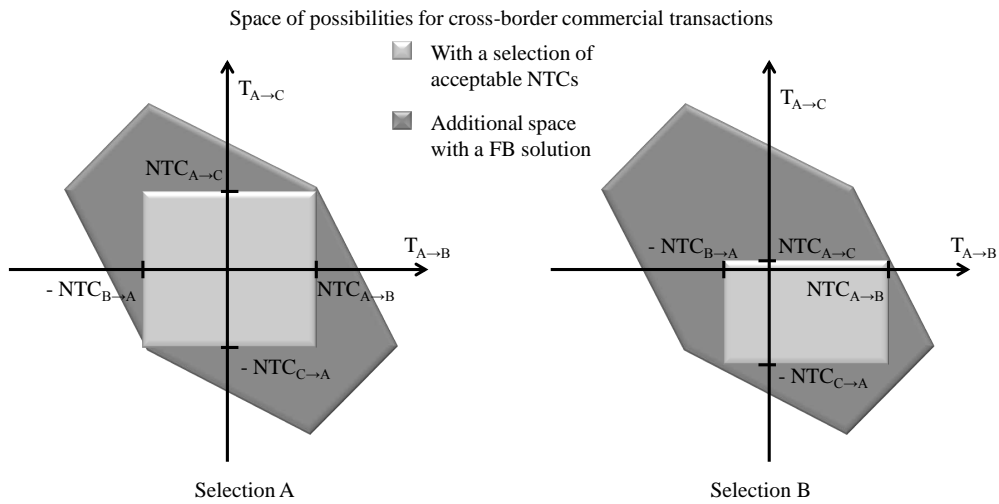


FIGURE II.2: Two dimensional representation of the difference between Flow Based and Net Transfer Capacity spaces of possibilities for cross-border exchanges on a three nodes example. Two possible selection of NTCs are displayed. See figure II.1 for the construction of the FB space of possibilities and the definition of the variables $T_{A \to B}$ and $T_{A \to C}$.

The NTC method gives a fix boundary for each bilateral cross-border transaction. Therefore the resulting space of possibilities is a rectangle in two dimensions and a hyperrectangle (also called more simply a box) if there are more dimensions. Figure II.2 gives two selections of acceptable NTCs for the case described in the previous paragraph. They show that, to a certain extent, the NTC selection requires additional parameter than the secure domain defined here by the FB solution. Moreover, the progression from NTC

to FB solutions underlines that the notion of secure space of possibilities is to a large extent the result of conventions in addition to the physical properties of the system.

Comparing the two concepts is a very limited exercise because there is an infinite set of options to choose from for each kind of method. An impact assessment supporting a decision process should thus focus on two precise implementation solutions.

II.1.3 Module B.1 Allocation between products and time horizons

(a) Role.

For a given delivery period and time horizon, the physical space of possibilities for cross-border exchange can be allocated under various forms of products and reduced to take into account the allocation at other time horizons. The module B.1 splits up general spaces of possibilities for cross-border exchange, determined in module A.2, between several time horizons and kinds of product that shall be allocated through the module B.2. The decision to consider B.1 separately from these two other modules has been taken to level down the complexity of each module.

(b) Implementation choices.

For each time horizon, transmission capacities can allow exchanges for various markets and mechanisms between different geographical areas. In order to make the best use of the spaces of possibilities, it appears adequate to decide *ex ante* of some fixed conventions about the kinds of products allocated and the distribution between time-horizon. This choice is in a way supported by [Chao et al. \(2000\)](#) when stating that “[t]ransmission rights are so fundamental to efficient design that their definition must be an integral part of market rules”.

The products related to cross-border exchange capacities are often classified either as Physical Transmission Right (PTR) or as Financial Transmission Right (FTR) ([Booz&co et al., 2011](#)) and both can be measured in capacity units such as MW. To a certain extent, a physical and a financial products can be allocated for the same underlying capacity as illustrated in the FTR line of figure [II.3](#). When TSOs allocate a financial product, it allocates in advance a form of future congestion revenue rights as described

by [Duthaler and Finger \(2009\)](#). These products can serve as hedging elements for market participants. Since the congestion revenue are limited structurally and the TSO is not expected to take financial risk in the allocation process, the amount of FTR than can be allocated is related to the amount of possible cross-border physical exchanges. Two examples of FTR are described in the focus on LT products. Besides, among the PTRs, two theoretical categories can be made depending on the fact that the right is associated to an obligation or not concerning the use of the physical capacity. In the following thesis, if it is not specified otherwise, the term PTR shall be associated with a form of balance responsibility. For instance, the owner of a PTR between two control areas becomes a Balance Responsible Party (BRP) for the amount of power it shall export or import according to the definition of the PTR. The other case shall be referred as a reserved cross-border capacity, when the PTR is only a right to use the capacity without any obligation.

Note that, at a given time horizon, if module A.2 uses a FB method rather than bilateral NTC for the LT explicit auctions, then the capacity can still be allocated as bilateral capacity rights. Some have also proposed that the rights could be allocated with reference to a limiting element of the network with concepts such as the “Flowgate Rights” described for instance in ([Chao et al., 2000](#)). This point of view corresponds to an organization where the output of the determination of the space of possibilities for cross-border exchange would be the critical branch rather than the FB variables described in the focus of module A.2.

In addition there are key contractual features such as the firmness of the physical products, *i.e.* under which conditions the capacities may be withdrawn from its holder with a compensation, which has its own chapter in the network codes proposed by the [ENTSO-E \(2012e\)](#) on Capacity Allocation and Congestion Management (CACM). The term ‘force majeure’ in the glossary is an example of legal term for the special cases reminding that extreme cases may have a special treatment in common rules.

(c) **Implemented solutions.**

First of all, in a simplified vision of the CWE region, a form of reserved cross-border capacity could be used to handle the cross-border flows resulting from the frequency control reserve activations which is *de facto* coordinated over a synchronous area. Indeed,

the Frequency Containment Reserve (FCR) and Frequency Restoration Reserve (FRR) of a synchronous area are activated by the same frequency and it generates unscheduled cross-border flows between control areas⁵. In practice, this reservation is in fact rather made in module A.2 when margins are taken for various security reasons in the determination of the space of possibilities (ETSO, 2001b, ACER, 2011d). Nevertheless, the result is qualitatively similar to a specific reservation of capacities in priority to any other time horizon.

Then at the LT time horizon, only a chunk of the remaining space of possibilities in each direction is offered for LT allocation because the other part is reserved for shorter time horizons. There are in particular annual and monthly allocations for respectively the next full calendar year and one of the coming calendar months ahead. The product used is the PTR with Use It or Sell It (UIoSI) conditions. It is a hybrid product in the sense that it can be seen as a PTR with an option to become a FTR⁶ or reversely. In practice, it shall be converted definitely in a FTR or a PTR before a so-called nomination deadline which takes place a day before the DA time horizon. The principles are illustrated on a simple case in figure II.3.

Finally, the physical capacities offered for allocation at the DA time horizon are all the remaining physical capacities after the various security margins and the PTR UIoSI which have been nominated as PTR with balance responsibility for the owner. For the shorter time horizons, ID and Balancing, the capacity that can be allocated are the capacities not allocated in the DA allocation process. In practice, additional capacities could appear from a new determination of the space of possibilities for cross-border exchanges at a shorter time horizon, with new conditions or less uncertainties as introduced in the first focus of module A.2.

At each time horizon, the bilateral Available Transfer Capacity (ATC) for one direction at a border between two bidding zones is calculated with reference to the NTC calculated in module A.2. The ATC is determined by withdrawing the Already Allocated Capacity (AAC) corresponding to the previously allocated capacities as shown in equation II.18

⁵See the definition of FCR and FRR in section I.2.1.

⁶The financial right is similar to a FTR option with, in a simplified view, the DA spot prices as price references in each bidding zones. The term FTR option is briefly described in the following paragraph on LT product choices.

⁷In this illustration, the two allocation time horizons correspond to the same period of delivery. Please note that in practice, different time horizons cover periods with different durations as described in section II.3.

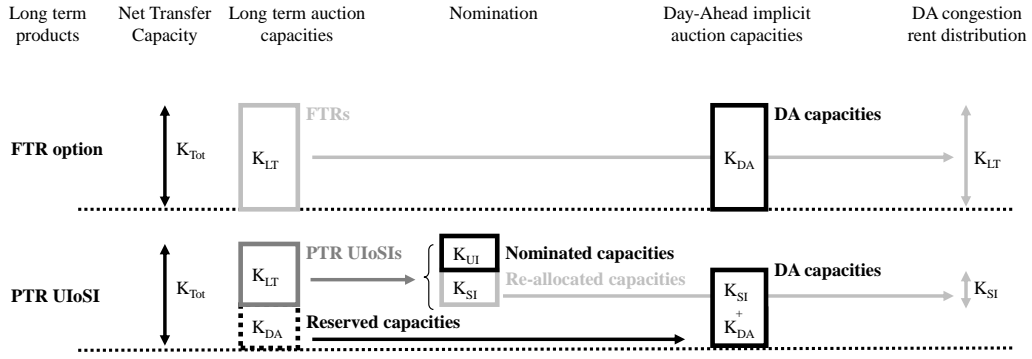


FIGURE II.3: Illustration of the products FTR and PTR UIoSI principles. The simple case is a deterministic model with a fixed NTC K_{tot} from one bidding zone to another which is fully used at the end of the allocation process. There are two time horizons of allocation for a given period of delivery⁷, LT and DA, and there is an allocation of physical products at DA. The other element of the sequence of time horizons are not represented. In the first line, a FTR product is introduced in the LT. There is no direct competition between LT and DA capacity allocation and both can in principle reach the NTC level. After the DA allocation, the DA congestion rent, if there is any, is transmitted to the FTR holders. For instance, if there is a fixed spot price spread ΔP between the two bidding zones, then they shall receive $\Delta P * K_{LT}$. The second line describes the functioning of the PTR UIoSI. Between its LT allocation and the DA, there is a nomination time-horizon when the PTR UIoSI holders have to decide if the capacities shall be used as PTR, to the amount K_{UI} on the graph, or if the product shall be sold, *i.e.* used as a FTR, to the amount K_{SI} on the graph. The physical capacities $K_{SI} + K_{DA}$ are then available for DA allocation.

(ENTSO-E, 2011c). Behind the simplicity of this formula lies the complexity of the AAC calculation. One interesting feature is that since netting is taken into account to a certain extent, the ATC can be above the NTC. Indeed, when the net AAC is in the opposite direction of the ATC calculated, then the term is in principle negative.

$$ATC = NTC - AAC \quad (\text{II.18})$$

(d) Focus on the reservation of capacity for shorter time horizon

The ENTSO-E (2012a) has published a position paper on the allocation of cross border capacities to reserve markets to facilitate the exchange of ancillary services. It concludes that “[t]he cross border exchange and possibly (subject to case-by-case security analyses) sharing of reserves can increase social welfare and availability of sufficient transfer capacity is necessary to share/procure cross border reserves” and that for these cross-border services “the availability of transfer capacity can be ensured in different ways ranging from ex ante allocations to market based mechanisms”. This document illustrate, among

other methods, the classical economic theory stating that an arbitrage between different uses can be made based on the marginal social surplus generated by these uses.

This issue can be included in a more general context of reservation of capacity for shorter time horizon beyond the DA. In this context, a distinction can be made between the allocation of DA capacities to the exchange of reserve products on the one hand and the reservation of capacities for exchange of products at ID and balancing time horizons on the other. In the first case, the reserve market or mechanism could generate a DA value for the cross-border transmission capacities allocated to them which would make it conceivable to do an arbitrage between the allocation to a DA energy market and to a DA reserve market. The difficulty is that the two kinds of market do not use the same cross-border product. Indeed, the energy market uses a PTR with balance responsibility obligations while the reserve market would require a cross-border reserved capacity without obligation to use it. The principle of the impact of the second product on the space of possibilities is introduced in the last focus on this module describing the impact of a product of an option nature with the example of the PTR UIoSI. In the second case, since the ID and balancing products have not been exchanged at the DA time horizon, it is harder to estimate a value for the reservation of capacities for these shorter time horizons. In fact, there may well be a high variability combined with high uncertainties on the distribution function. Nevertheless, this does not mean that prospective studies should not consider the possibility to reserve capacities for ID and balancing markets in an efficient manner.

To conclude, if it is proven through rigorous studies that the social welfare can be enhanced by a reservation of capacity, then one difficulty in this kind of arrangement would be to find an acceptable common estimator of the social surplus potentially generated by the reserved capacity for future markets and mechanisms. In this case and if there are conservative positions, in order to find a consensus, the agreement could use a conservative estimator of the expected social surplus and a upper cap on reserved capacity. However, [Vandezande \(2011\)](#) argues that the opportunity costs of reserving cross-border capacity for balancing would be too high.

(e) Focus on a base market time period for cross-border products

In the organization features for generation adequacy management, the power injections and loads of the BRPs is integrated over a contractual period. Similarly, a key parameter of the energy products is a market time period which is defined as “the time resolution for the delivery of energy” in the network codes on CACM by the [ENTSO-E \(2012e\)](#). To be coherent, the corresponding period for cross-border products can be adapted to the features of the coordinated bidding zone.

The decision in the choice of this market time period includes at least the following tradeoff. A shorter time period than the current usual one may offer more market signals of the system constraints in the sense that there would be more market time periods per unit of time. It can also reduce the artificial inflection points that may appear when passing from a market time period to the next in some load and generation profiles. On this topic, [Eurelectric \(2012a\)](#) stresses that “this time resolution could become lower than the current usual setting of 1 hour” and it is added later in the same document “even lower than 15 minutes”. On the other side of the balance, having a shorter time period may increase the optimization complexity in the software tools used by various actors and this additional complexity may negatively impact the system functioning⁸.

(f) Focus on the choice of LT cross-border products

The product currently allocated by TSOs in the CWE region, the PTR UIoSI, is described in figure [II.3](#). The current debate in Europe is to propose a choice between this product and two kinds of FTR. The financial rights are in principle associated to bidding zones reference prices such as the DA spot prices in the CWE region. The first kind of financial right discussed is known as FTR obligation, also called two-sided. In this case, the FTR holder receive a positive revenue when there is a congestion rent in the direction of the product, while it is expected to give money to the TSO if the congestion is in the other direction. The second kind is FTR option, also called one-sided. In

⁸The optimization algorithm issues for Power eXchange (PX) operators are for instance introduced in appendix [C](#) describing a particular market coupling. In a few words, the duration allocated to the numerical solver for the calculation process is limited in the system organization. In practice, this limitation is a regulatory parameter as shown for instance by the public consultation about the future DA market coupling over the north western part of Europe <http://www.statnett.no/no/Nyheter-og-media/Nyhetsarkiv/Nyhetsarkiv---2013/Konsultasjon-knyttet-til-priskopling-i-North-West-Europe/>, last visited May 2013.

this case, the FTR holder receive a positive revenue when there is a congestion rent in the direction of the product, while there is no monetary transfer in the other direction. More exactly, the basic financial products behavior can be defined by a simple equation in the following case. There are two bidding zones A and B, a given period of delivery and a unique price spread, expressed for instance in €/MW, $\Delta P_{A \rightarrow B} \in \mathbb{R}$, which can be positive, negative or zero. It can basically be calculated as the difference between reference prices in each zone $\Delta P_{A \rightarrow B} = P_B - P_A$. An actor holds a quantity $K_{FTR,A \rightarrow B}$, expressed in MW, of FTR from bidding zone A to bidding zone B for the period of delivery considered. The FTR holder shall receive a revenue $R_{FTR,obl}$ for a FTR obligation or $R_{FTR,opt}$ for a FTR option in €, determined by the following equations:

$$R_{FTR,obl} = K_{FTR,A \rightarrow B} * \Delta P_{A \rightarrow B} \quad (\text{II.19})$$

$$R_{FTR,opt} = \begin{cases} \text{if } \Delta P_{A \rightarrow B} > 0, & K_{FTR,A \rightarrow B} * \Delta P_{A \rightarrow B} \\ \text{else} & 0 \end{cases} \quad (\text{II.20})$$

In practice, TSOs only auction a limited amount of FTR, determined with reference to the ATC possibly taking into account some netting. Indeed, when TSOs sell a FTR to another party, they are exposed to a financial risk. For instance with a FTR option as described above, TSOs guarantee the formula in equation II.20 and thus are exposed to the spread between some reference prices. This financial risk is covered by a congestion revenue associated to the price spread as long as the amount of FTR sold in MW is below the amount of commercial transactions generating the price spread, *i.e.* below the physical capacity used in the DA market for instance. Since it is not in the TSO responsibilities to bear financial risks, it is not supposed, in principle, to sell an amount of FTR above the forecasted NTC.

The benefits to allocate PTR UIoSI or one of the two kinds of FTR depends on the expected usefulness of long term capacities. Among the objectives often expressed, LT allocation can allow financial risk hedging and it can favor cross-border competition between producers (ENTSO-E, 2012d, Booz&co et al., 2011). To support the decision process, the ENTSO-E (2012d) offers a rather comprehensive comparison study. Among the result, it is pointed that FTR obligation are more easily netted and FTR options are expected to have in practice a similar effect than PTR UIoSI with the benefit that they are simpler to handle, with for instance no nomination phase. As an illustration of the

complexity of such comparison study, the ENTSO-E cannot conclude on the potential impact of a future EU financial regulation on the use of FTR whereas it does not affect the PTR UIoSI. Among other actors, [Eurelectric \(2012b\)](#) expresses a preference for FTR rather than PTR. Nevertheless, some actors suggest to keep PTR UIoSI at some borders depending on the functioning of the DA allocation process ([ACER, 2011a](#)). Furthermore, the [ACER \(2011a\)](#) “agrees with stakeholders that moving to FTRs is not the highest priority”.

This choice between three general options is an example where integration process has required to reduce the diversity of choices excluding, for instance, the following combination. If PTR UIoSI are to be kept, there could be, on paper, a possibility to offer PTR UIoSI as well as one kind of FTR at the same time, at the same border and in the same direction. Figure II.4 illustrates that the benefits compared to PTR UIoSI alone would be to allocate the “reserved capacity” for DA as FTR products with the drawback of a more complex allocation with two products instead of one. As in 2012, this possibility is excluded from the debate by the [ACER \(2011e\)](#) since “hybrid solutions, mixing PTR and FTR on the same border, shall not be permitted.” This principle is transposed by the [ENTSO-E \(2012g\)](#) in Article 28(2) of the draft network code on forward capacity allocation. The reason is probably to be found in Article 3 which requires the “optimisation between the highest overall efficiency and lowest total cost for all involved parties”. Indeed, the multiplication of products in the primary market may be seen as increasing the transaction costs and complexity without a sufficient benefit.

Nevertheless, another kind of diversity may be offered with the introduction of so-called peak and off-peak products in addition to the base products in the primary markets ([ENTSO-E, 2012g](#)). Similarly the long term products may be allocated further ahead or over several years as asked in a public consultation by the ([ACER, 2012a](#)). Besides, there are products which are neither allocated by the TSOs nor based on TSO allocated products but which apparently fulfill LT hedging objectives. The Contract for Difference (CfD)⁹ are for instance currently used in the Nordic region and these financial products are included in the [ENTSO-E \(2012d\)](#) comparison table.

⁹These contracts are based on the spread between a Nordic bidding zone price and a Nordic system price for the DA spot market.

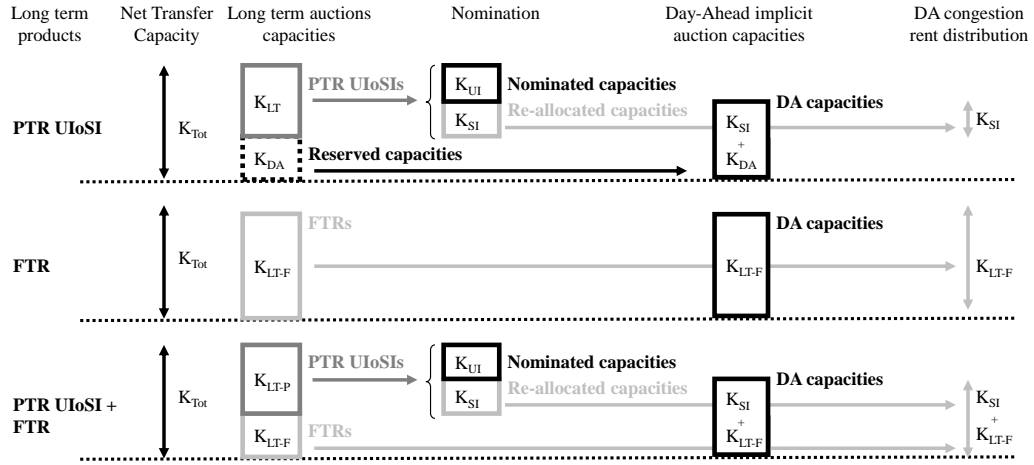


FIGURE II.4: Illustration of the potential coexistence of PTR and FTR at the same time-horizon, based on the case described in figure II.3. The third line shows a hybrid solution which has been excluded from the current European debate. Please note that in practice, the amount of FTR that could reasonably be allocated could be lower than shown in this simple case with a perfectly forecasted NTC.

(g) Impact of the nature of PTR UIoSI on the space of possibilities selection for a given time horizon

This focus highlights how the nature of the product allocated can put a constraint on the sub-space of possibilities allocated. More particularly, the allocation of PTR UIoSI, and more generally a product which is an option on physical capacities, may require to add constraints on the space of possible outcome. This effect has already been described graphically for instance by [Perekhodtsev and Cervigni \(2011\)](#) in the literature. In addition to that, this focus offers a short mathematical formalization.

Let S be the space of possibilities for a firm product defined by the set of constraint C as described in the focus on a FB solution in the CWE region. Let the vector $\mathbf{T} \in S$ be a possible outcome listing a combination of cross-border commercial transactions $(T_b)_{b \in B}$ for the set of borders B . In some cases, for a given border $i \in B$, the cross-border transactions $T_i \neq 0$ requires that the transactions on another border $j \in B$ ($i \neq j$) are different from zero. If the space S is reduced to the two dimensions corresponding to borders i and j , then we consider a case where $(T_i, T_j) \in S$ while $(T_i, 0) \notin S$. In this case, if the product allocated is an option, then (T_i, T_j) is not possible. Indeed, if all PTR UIoSIs on the border i are nominated and PTR UIoSIs at the border j are not nominated at all, then the realized transactions shall be $(T_i, 0)$ which is not part of the

space of possible outcome S . To avoid that, the space of possibilities shall be reduced, so that such cases are excluded. Therefore, the space of possible allocation for an option S' may end up strictly smaller than the space for a firm product S .

From a theoretical perspective, the option set S' can be modeled based on the total set S as follows. The new conditions are that, for a given outcome of the allocation T , the set of possible results of option nomination S^T , explicited in equation (II.21), should be included in S .

$$\begin{aligned} \forall \mathbf{T} \in S, S^T &= \{\mathbf{U} \in S \mid \forall b \in B, U_b \in [0, T_b]\} \\ \mathbf{T} \in S' &\Leftrightarrow S^T \subset S \end{aligned} \quad (\text{II.21})$$

In practice, it is not conceivable to test the infinite set S^T . Since S is a convex space in the CWE solution, then it is sufficient to test that the corners of the hyperrectangle S^T are included in S to show that $S^T \subset S$ which means that $\mathbf{T} \in S'$. This simplified set of corners $S^{T,c}$ is explicited in equation (II.22).

$$\begin{aligned} \forall \mathbf{T} \in S, S^{T,c} &= \{\mathbf{U} \in S \mid \forall b \in B, U_b \in \{0, T_b\}\} \\ \mathbf{T} \in S' &\Leftrightarrow S^{T,c} \subset S, \quad \text{if } S \text{ is convex} \end{aligned} \quad (\text{II.22})$$

However if n_B is the dimension of the space including S , then there are 2^{n_B} corners to be tested on their inclusion in S . This means that with this method the number of constraints would be roughly multiplied by 2^{n_B} . This is why it would be best to define explicitly the set S' or a subset of it.

The impact of these additional constraints on the space of possibilities is illustrated on the graphical representation of a FB solution introduced in the description of module A.2 and illustrated in figure II.1. In this theoretical simple case, it is easy to express explicitly S' with the help of extremum values Min_b and Max_b for each $b \in B$ as defined in equation (II.23).

$$\forall b \in B, \begin{cases} Min_b = \min T_b \text{ subject to } \mathbf{T} \in S' \\ Max_b = \max T_b \text{ subject to } \mathbf{T} \in S' \end{cases} \quad (\text{II.23})$$

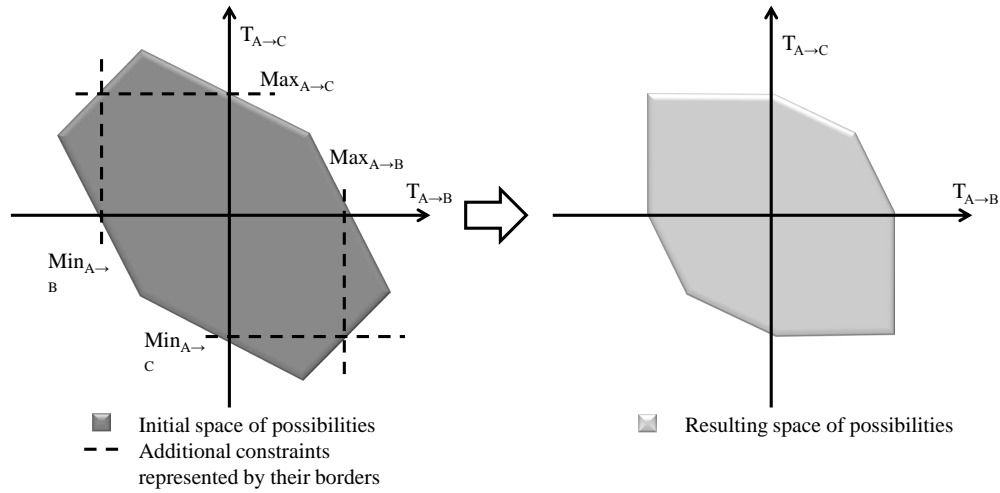


FIGURE II.5: Based on the case of figure II.1 describe in the focus on FB methods, the figure shows the reduction of the space of possible allocation for product such as PTR UIoSI which is an option of physical capacities. The new constraints are formalized in equation (II.23).

Based on these values, the explicit conditions to define S' can be summarized under the form of equation (II.24).

$$\mathbf{T} \in S' \Leftrightarrow \begin{cases} \mathbf{0} \in S \\ \mathbf{T} \in S \\ \forall b \in B, T_b \in [Min_b, Max_b] \end{cases} \quad (\text{II.24})$$

The proof of the equivalence is summarized in a few words. The implication from left to right is straightforward, if $\mathbf{T} \in S'$ then the conditions are verified by definition of S' , Min_b and Max_b . In the reverse direction, one proof consists in showing that if \mathbf{T} meets the conditions, than the four corner of the rectangle S^T are necessary in S . Therefore $S^T \subset S$ and $\mathbf{T} \in S'$.

II.1.4 Module B.2 Allocation of a given product at a given time horizon

(a) Role.

This module allocates the share of the space of possibilities made available for a given product and a given time-horizon. Each allocation mechanism can be considered as a sub-module.

(b) Implementation choices.

First of all, it is necessary to agree on the selection principles between the potential users. In Europe, the market-based or a surplus maximizing mechanism should be first choice as agreed in the CACM Framework Guidelines (FG) by the ACER (2011e). Nevertheless, in specific cases such as a continuous allocation process, there can be a form of first-come-first-serve allocation *de facto* as described in the focus on ID implicit allocation below. In other cases, the surplus maximizing principle can be limited by constraints related to other consideration such as the “intuitiveness” issue described in a focus of this module.

Then, for a market based allocation, a fundamental distinction is made between explicit and implicit allocation. In an explicit arrangement, the product is allocated through a dedicated auction with direct access for potential users. There is a diversity of auction parameters to chose from and, for instance, marginal pricing can be preferred to pay-as-bid pricing. The graph on the left of figure II.6 illustrates an explicit allocation with a central auction operator auctioning for market participants spaces of possibilities for cross-border exchange between two zones. If a market participant intends to exchange wholesale products between the two zones, it has to get a share of the space of possibilities for cross-border exchange which makes it balance responsible in the two zones.

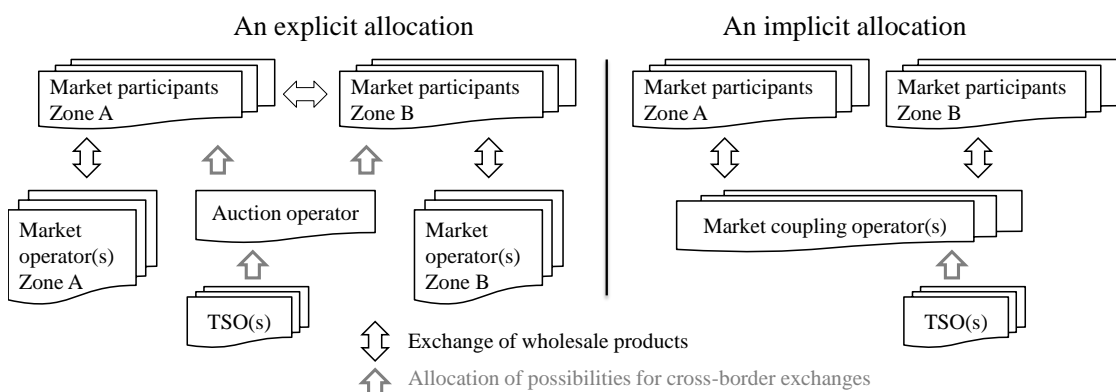


FIGURE II.6: Examples of explicit and implicit allocation organization. In the implicit case, the market coupling operator(s) act(s) both as market operator(s) and allocating body for the spaces of possibilities for cross-border exchange between zones.

Implicit allocation refers to a more subtle market based solution where a firm physical product is embedded in the coupling of, for instance, energy product markets or a balancing reserve activation mechanisms. As a result, the auctions of power and capacity are coordinated into a single process. The graph on the right side of figure II.6

illustrates an implicit allocation through one or more market coupling operators. These operators perform the function of market operator(s) in the coupled bidding zones and allocating body of a space of possibilities for cross-border exchange. Among the implicit allocation through the coupling of energy market platforms, a first distinction is made in practice between market coupling and market splitting. The term market coupling is used if more than one PXs are coupling their market platforms to perform the implicit allocation and the term market splitting is used if only one PX is involved (ETSO and EuroPEX, 2008, Everis and Mercados EMI, 2010)¹⁰. Additionally, another distinction is often made between price coupling and volume coupling with the following definitions (NordPoolSpot, 2012). In a price coupling, the matching of orders from market platforms and the implicit allocation are solved in the same algorithm. In a volume coupling, a first algorithm uses some energy market data to perform the implicit allocation and its output, the “volumes”, are then used as input of the market platform matching solvers as described in appendix C about a volume coupling solution.

Last, implicit and explicit allocation can coexist if the access to spaces of possibilities for cross-border exchanges is open both to Over The Counter (OTC) trading and to market coupling operators at the same time.

(c) **Implemented solutions.**

The three following allocation arrangements take place, among others, in the CWE region as in 2012. On the LT time horizon, the product PTR UIoSI is explicitly allocated on monthly and annual auctions through a common platform operated by Capacity Allocating Service Company (CASC)¹¹. The DA physical capacities are implicitly allocated through a price coupling over the CWE internal borders under the form of market coupling involving two market platforms operated by the PXs APX-Belpex and Epexspot. For more technical details, the common algorithm used is described in (APXendex et al., 2010). In real time, the implicit allocation of the remaining capacities is embedded in a FRR activation coordination mechanism between the four German TSOs. As summarized by Zolotarev et al. (2012), the principle is to avoid counteracting FRR activations by TSOs in neighboring control areas if there are enough cross-border capacities to agree

¹⁰Please note that the terms market splitting and market coupling can be used with a narrower definition taking into account additional features. For instance, (Booz&co et al., 2011) states that market splitting would use a more detailed model of the coupled power system than market coupling.

¹¹For more details, the explicit auction rules are detailed in (Amprion et al., 2012).

on the mutual compensation of imbalance without impacting the system security level. Indeed, a surplus of power can be offset by a lack of power in a neighboring area, as shown with a numerical example in table II.1, reducing the global costs of reserve activation. In practice, it is one element of a larger Grid Control Coordination, performed through a software integrating agreements about limits of the mechanisms. The international extension to neighboring countries is introduced in chapter V about TSO coordination.

Numbers in [MW]	Without allocation	With allocation
FRR activation in area A	down regulation of 20	No activation
Available capacity from A to B	100	80
FRR activation in area B	up regulation of 40	up regulation of 20

TABLE II.1: Illustration of a cross-border allocation arrangement in real time. In a case without allocation, first column, there would be a downward regulation of 20 MW in area A, *i.e.* the area should have net production 20 MW lower according to what has been planned, while at the same period there would be an upward regulation of 40 MW in area B, *i.e.* the area should have net production 40 MW higher according to what has been planned. Since there are 100 MW of available capacities from A to B, it is possible to agree that a 20 MW power flow can be allocated in this direction to reduce the amount of FRR products activated in both areas.

Additionally, another example of implicit allocation is given at the border of the CWE region with the capacity auction of the Britned HVDC cable connecting Great Britain and the Netherlands. The capacity auction arrangements in place as in late 2012 have some exotic features because the cable is partially exempted from the EU regulation on power transmission infrastructure and because there is no meaningful DA market platform in England. For instance at the DA time horizon, the company operating the cable organizes a form of implicit allocation integrated within the CWE DA market coupling as described in (APXendex, 2011). With a simplified view, orders are collected by APXendex on a market platform in England and they are transformed into Dutch bids in CWE DA market coupling. After the Dutch DA market clearing, the results are transmitted to the bidders in England. In the transformation process a fee is added as authorized by the exemption scheme.

(d) **The success of implicit allocation over explicit allocation**

As described by ETSO (2004), explicit allocation pose a “chicken and egg” problem in the global system organization. Market participant would better optimize their asset operation if the cross-border allocation is known, whereas the allocation would be more accurate with good information on assets operation. The implicit auction at the DA

horizon partly solve this issue for this time horizon because it optimizes both decision variables in the same problem. In practice, it consists in embedding the capacity allocation within a larger optimization involving, for instance, energy products. The same principle can apply at other products and other time horizons. Figure II.7 illustrate graphically what would an optimal allocation process look like and figure II.8 shows results of explicit and implicit allocation methods at the border between Belgium and the Netherlands. Similar graphs are displayed in (CRE, 2009) for other borders as in 2008. Based on these graphs, implicit allocation appear clearly more successful than explicit allocation. This graphical argument is confirmed by studies providing a quantitative estimation of the benefits of implementing an implicit allocation such as market coupling instead of explicit auctions as described in the next chapter about a measure of the potential benefits.

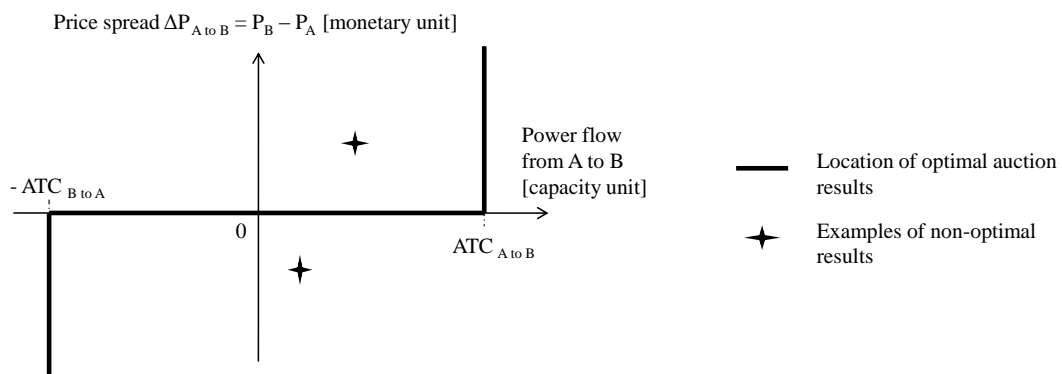


FIGURE II.7: On this graph, a point can represent the result of a single allocation process in a system with two bidding zones A and B and ATCs in both directions. The x axis represents the power flow while the y axis corresponds to a difference between reference prices P_A in zone A and P_B in zone B. The black thick lines represent the location of optimal allocations: if the price spread is non-zero, then the capacity is expected to have been fully used. The two stars on the graph represent possible wrong outputs of an allocation. In the case of the top-right quadrant of the graph, the star represents a case where the price in zone B is strictly higher than the price in zone A and the capacity is not fully used. It means that additional cross-border transactions could have generated a social surplus. In other word, some cross-border capacity have been wasted. In the case of the second star, the power flows goes from the zone with the highest price to the zone with the cheapest spot price. In this case, the exchange would generate in theory a negative welfare in the two-zone system.

Please note that this intuitive graphical indicator described for NTC-based spaces of possibilities cannot be applied as simply on a FB space of possibilities, as described for instance in (CWE Flow-Based Validation Task Force, 2012). An equivalent rule of thumb would be that when there are no congestion on the critical branches of the FB

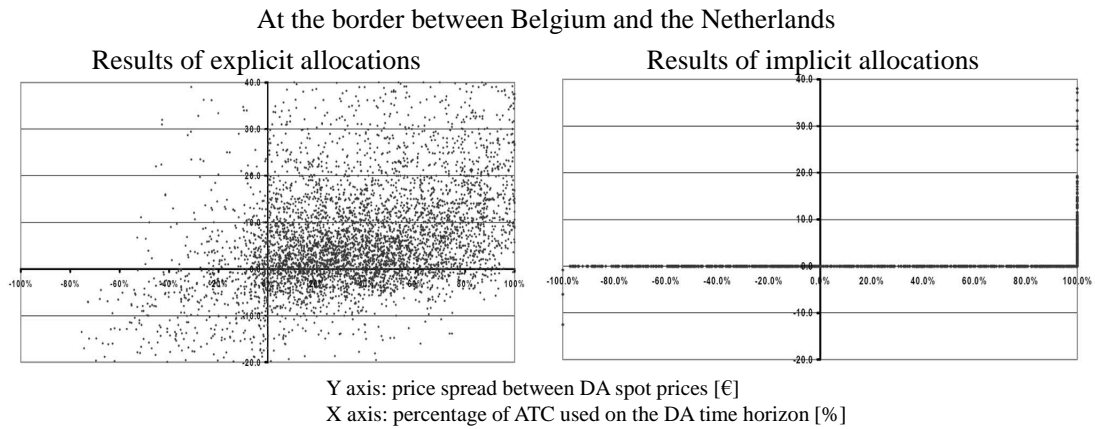


FIGURE II.8: Empirical observation of explicit and implicit allocation process results at the border between Belgium and the Netherlands at the DA time horizon. The observation has been made around 2006, year of the implementation of a market coupling between Belgium, France and the Netherlands, formerly known as the TLC. According to the principle described in figure II.7, the implicit auction method appears clearly more efficient than the explicit auction. Sources: [EpexSpot \(2009\)](#).

process, then all prices should be equal to the extent that it is allowed by the constraints defined by the product exchanged.

(e) Focus on features of a common ID implicit allocation

Figure II.9 gives an overview of a set of arrangements for cross-border ID implicit allocation proposed in the 2012 version of the network code on CACM ([ENTSO-E, 2012e](#)). This focus highlights three interesting features.

First, the distribution of responsibilities between TSOs and PXs may differ from what is currently applied for DA market coupling in the CWE region ([ACER and AESAG, 2011b](#)). For instance, while TSOs are rather naturally in charge of the Capacity management module (CMM) and PXs could agree on a form of Shared Order Book (SOB, also referred as Shared Order Book Function, SOBF, or Common Order Book, COB) and a matching algorithm. PXs faced at one point some disagreements between themselves and “[r]egulators emphasised willingness to move on a possible solution as soon as possible without waiting for PXs to solve the problems” ([ACER and AESAG, 2011c](#)). Similar concerns about the PXs involvement have been expressed in 2012 by Mr Cailliau from Eurelectric: “[w]hy do we not stop and ask another party (ENTSO-E) to take over the tender process, to create SOBF + CM and ask anyone to connect?” ([ACER and AESAG, 2012a](#)).

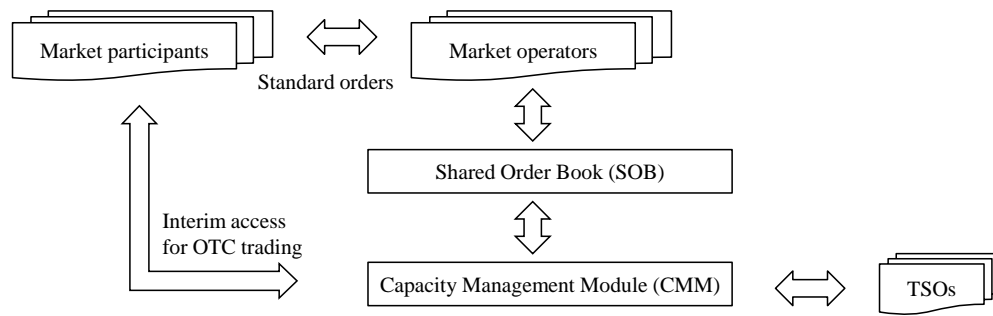


FIGURE II.9: Overview of the cross-border intraday market coupling principles as described in the network codes on CACM (ENTSO-E, 2012e). A Capacity management module (CMM) shall contain up-to-date ATC in real time in order to allocate them in a continuous manner, based on TSO data for instance. A Shared Order Book (SOB) shall collect all matchable orders from the participating market operators such as PXs and perform continuous matching of those orders. Additionally, an interim solution gives market participants an access to the CMM for cross-border OTC transactions.

The second feature shows how some of the conservative arguments against what is deemed as an improvement can be answered with a temporary transition period. In principle, with a classical implicit allocation of all the space of possibilities available for a given time horizon, there is no form of cross-border access for market participants outside of the SOB associated to the coupled market platforms. On the borders where cross-border OTC transaction were taking place at the ID time horizon, some actors, including traders, have asked for a smooth transition from explicit to implicit allocation. This explains partially why the network code (ENTSO-E, 2012e) includes transitional arrangements which preserve a form of explicit allocation. This interim solution is an OTC access to the Capacity management module (CMM) until 2016 as settled in the 2012 version of the network codes on CACM.

The third interesting feature is the choice of a continuous allocation. It means that a first come first serve principle is applied (ERGEG, 2010a) which goes against the requirement to use market-based solutions (Everis and Mercados EMI, 2010). For instance, for a given cross-border capacity between two ID bidding zones, a cross-border transaction with a social surplus of S_1 in monetary units can have access to the capacity in priority before another one with a social surplus of S_2 taking place a few minutes after, even if $S_2 \gg S_1$. An alternative with multiple fixings, *i.e.* discrete auctions, instead of continuous trading may reduce some of these inefficient effects. Indeed the fixings would put, in the allocation process, more weight on market based parameters such as

prices rather than the time of entrance in the allocation process, *i.e.* the first come first serve principle. Moreover, the fixing solution could benefit from the experience of implementation solutions already tested for DA market coupling in order to reduce the implementation costs. The comparison is not obvious¹² and on the other hand, the continuous trading could match transactions faster for market participants. The nature and impact of the revealed information may also differ. More generally, there is an infinite set of solutions depending on the adequate number of fixings, their position in the time sequence and how these figures could be adapted before the auctions, based on predefined rules. Furthermore, a continuous trading in each ID bidding zone can be compatible with scheduled releases of the ATC, creating fixing conditions. This solution is mentioned by the ACER (2011e), and proposed with limiting conditions in the corresponding network code from 2012 (ENTSO-E, 2012e). Such cross-border arrangement could also be compatible with the particular ID rules functioning in the Iberian peninsula which does not use continuous trading in 2012 (OMEL, 2012). Concerning the implementation details, it is difficult to state with qualitative arguments how to split the total ATC over the ID time horizon. Nevertheless, a quantitative simulation¹³ based on real or realistic ID order books could be used to adjust various parameters.

(f) Focus on intuitiveness constraints that may be added to an allocation process

Let us consider an implicit market coupling for a given time horizon, with a FB space of possibilities using the zone net exports as variables as described in the focus of module A.2. According to CWE Flow-Based Validation Task Force (2012), “[a] situation is intuitive if and only if there exists a decomposition of [the net exports of the zones] into intuitive exchanges”¹⁴, *i.e.* “exchanges on each interconnector occur from the low price area to the high price area”. More precisely, the task force report uses by default a definition called “bilateral intuitiveness” which consider only the exchanges between

¹²There is a literature in financial economics studying the comparative advantage of continuous trading and call auctions. Nevertheless, it appears of little help because the markets considered are very different from energy markets.

¹³The limits of quantitative simulations are discussed in the next chapter.

¹⁴As stated before, it is easy to calculate the net exports from the bilateral transactions. Nevertheless, the reverse operation may have an infinite set of solutions. Indeed, since there are more links than zones, then the dimension of the space of bilateral transaction is higher than the dimension of the space of net exports.

directly interconnected zones. This report offers an enlightening description of the issue on the CWE system, including simulations based on historical system data and a mathematical formalization of the intuitiveness issue in its appendix. They observe that some simulated outcomes of allocations based on FB spaces are indeed not “intuitive” with reference to the description above. For instance, there are cases where the cheapest bidding zone of the coupled system is importing.

In order to offer insights on the issue, this focus describes a simple example based on the previous three-zone case illustrated in figure II.1. In this model, the variables considered are the cross-border commercial transactions $(T_b)_{b \in B}$ in capacity units and the transactions between B and C are fixed at zero¹⁵. These commercial transactions generate social surpluses. At each border $b \in B$, this surplus is noted S_b and it is measured in monetary unit. Concerning the implicit allocation objective, the total surplus shall be maximized as shown in the following equation under the FB constraints explicated in equation (II.17).

$$\max_{(T_{A \rightarrow B}, T_{A \rightarrow C})} S_{A \rightarrow B}(T_{A \rightarrow B}) + S_{A \rightarrow C}(T_{A \rightarrow C}) \quad (\text{II.25})$$

In practice, the marginal surpluses, noted S' could be a price spread between spot markets as described in section III.1 about the expected benefits. It is assumed that they are constant and strictly positive if A is exporting:

$$\begin{cases} S'_{A \rightarrow B} = \frac{dS_{A \rightarrow B}}{dT_{A \rightarrow B}} > 0 \\ S'_{A \rightarrow C} = \frac{dS_{A \rightarrow C}}{dT_{A \rightarrow C}} > 0 \end{cases} \quad (\text{II.26})$$

According to these marginal surpluses and the “bilateral intuitiveness”, commercial exchanged are to go in the direction generating a positive value. As a result, zone A should not be importing because it would generate a negative surplus. The “intuitive” space of possibilities is thus reduced to the upper-right quarter of the graph as shown in figure II.10 and defined by the following constraints:

$$\begin{cases} T_{A \rightarrow B} \times S'_{A \rightarrow B} \geq 0 \\ T_{A \rightarrow C} \times S'_{A \rightarrow C} \geq 0 \end{cases} \quad (\text{II.27})$$

¹⁵This could happen in a theoretical model if the link between B and C pass through zone A without connecting any producer or consumer. In this case there are no direct bilateral trade between B and C.

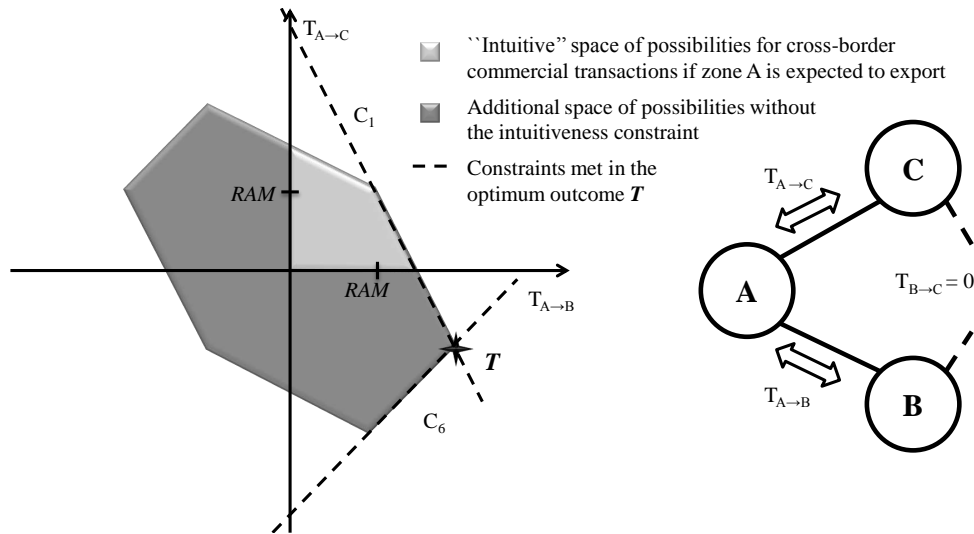


FIGURE II.10: Two dimensional representation of the Flow Based (FB) output for a three-zone system represented on the right side with commercial transactions between zones as described for figure II.1 and defined by equation (II.17). An “intuitive” subspace is represented according to the constraints in equation (II.27). The point called T is the optimum solution in the full FB space under the assumption that $S'_{A \rightarrow B} > 2 \times S'_{A \rightarrow C}$.

However, these constraints can exclude an outcome which would be otherwise optimal as described in the following example. Let it be assumed that $S'_{A \rightarrow B} > 2 \times S'_{A \rightarrow C}$. In this theoretical case, without intuitiveness constraints it is worth generating a negative surplus in zones A and C in order to allow more exchanges between zones A and B. Under these conditions, the optimal outcome maximizing the total surplus without intuitiveness constraints is a particular vector T , represented by a point on figure II.10. It is exactly at the border of two constraints (C_1) and (C_6) explicated previously in equation (II.17) and this point is well outside the intuitive space of possibilities.

More generally, if these additional constraints reduce the allocation space of possibilities, then from a simple theoretical point of view it would only produce equal or worse outcomes. However in practice, such arrangements could be implemented despite this negative impact. In fact, as stated in 2011, “Whether or not to enforce intuitiveness is still under discussion” (Pentalateral Energy Forum, 2011) Indeed, the negative impact can be balanced by additional considerations in a real political decision and the CWE Flow-Based Validation Task Force (2012) lists elements of an impact assessment.

On the cost side, the negative impact of adding intuitiveness constraints may be reasonable. For instance, the CWE Flow-Based Validation Task Force (2012) gave an estimation of the losses resulting from the enforcement of a form of intuitiveness called

“source-to-sink” in the CWE DA market coupling simulated with FB spaces of possibilities. The simulated impact amounts to about 1% of the market surplus generated from switching from ATC to FB methods for the DA market coupling in the CWE region. Another interesting result is that “the observed frequency of bilateral non-intuitive situations with FB [method] is low: 24 hours, i.e. 15.7% of congested hours and 1.6% of the 1512 simulated hours”.

On the other side of the balance, the [CWE Flow-Based Validation Task Force \(2012\)](#) describes three categories of arguments that might be used to justify a form of intuitive constraint in the CWE region. First, a form of fairness could be taken into account to limit a strong distributive effect between zones. In the example, zone C is in a way sacrificed in favor of zone B. During a negotiation process to switch from ATC to FB methods, if a similar situation is expected to be repeated over time at the expense of one zone, it may appear unacceptable for some stakeholders. In this case, “intuitiveness” constraints can be necessary for the agreement between zones. In the CWE region, “smaller area decision makers may consider that they are more likely to ‘help’ the larger ones than to be ‘helped’ by them”.

Second, given the numerous assumptions used in a FB method for zonal markets, “it is evident that shifting generation in a bidding [zone] is not the most efficient way to reduce the physical flow on a specific [critical branch]”. Indeed, allowing non-intuitive flows is not the only way to relax the constraint on a critical branch in order to maximize a social surplus over the whole allocation process. Agreements on local forms of counter trade measures might be a more efficient solution. Nevertheless, there are no clear cost sharing agreements for such coordinated actions as in 2012.

Third, “it is also usually felt that electricity markets should ‘look like’ as much as possible to ordinary commodity market in order to function well”. This statement is supported by two examples. First, the “bilateral intuitiveness” tends to increase the partial convergence¹⁶ which according to the task force would have some usefulness as a price signal. Second, it would prevent any actor from interpreting the allocation outcome as a “dumping for obscure grid management reasons” as written between quotation marks in the report.

¹⁶“partial convergence is reached when at least 2 countries have approximately the same price” ([CWE, 2011b](#)).

To sum up, if “intuitiveness” constraints are implemented, there is a potentially reasonable negative impact in term of market surplus and there are qualitative benefits that could hardly be quantified or highly depend on the existence of other arrangements. With this perspective, a reasonable negotiation cost on this debate would be welcomed. Nevertheless, given the complexity of the issue, a long and serious negotiation should at least improve the stakeholder awareness about the market coupling functioning.

II.2 Four modules to handle cross-border externalities

This second fundamental economic problem covers a large set of cross-border issues generated by the interconnection or by the cross-border exchanges which are not fully handled by the four modules described in the previous section. The related coordination arrangements concern more the coordination of area internal organizations arrangements rather than the cross-border exchanges themselves. The analysis cuts off the tasks directly under TSO responsibilities (function C) from a wider set of tasks involving the legitimate authorities and other stakeholders (function D).

Two modules address a diversity of system operator tasks that could be coordinated with benefits. **Module C.1** provides coordinated system assessments that may complete the perspective of each TSO in order to identify and anticipate the potentially stressed situations. **Module C.2** ensures a minimum coordination of TSO actions to maintain a reasonable system security level or to improve the efficiency of the network operation or congestion management for instance.

The arrangements of the previous modules are mainly based on agreements between TSOs in the coordinated zones. In addition to them, surrounding agreements are required in practice for the good functioning of the coordination. **Module D.1** covers the income and cost sharing agreements that may be required for the acceptability of the cross-border coordination. The description of the module includes a focus on the existing so-called Inter-TSO Compensation (ITC) agreements. **Module D.2** is designed to ensure all surrounding issues which could impede the global coordination of operation if they were not handled. For instance, it is necessary to ensure the fairness of the common markets created by the coordination arrangements with a common competition law and a common arbitrage authority among other institutional elements.

II.2.1 Module C.1 Coordinated system security assessment

(a) Role.

In each control area of an integrated system, a TSO performs security assessment studies. The same competences can be applied to a larger area offering an overview on the global network security completing the national vision. This task can use module A.1 as well as

other inputs. In addition, this module can provide a security “redundancy” and feedback to module A.2 about the determination of the space of possibilities. Depending on the time horizon of the security assessment, this module could be divided in sub-modules.

(b) Implementation choices.

This task requires that a minimum of updated data are shared between TSOs. This requirement can be considered as part of module A.1 about data availability. It is also necessary to agree on the outputs and on technical definitions of the stressed situations that may require coordinated actions. Moreover, as an example of economic organization choice discussed in chapter V, the security assessment can be performed by all TSOs in parallel or by one entity with the necessary common agreements.

(c) Implemented solutions.

In the CWE region as in 2012, three TSO subsidiaries act as service providers to assess global security: Coreso, Security Service Centre (SSC), TSO Security Cooperation (TSC). The ownership structure of these three companies is detailed in chapter V. One example of service offered by Coreso is a security analysis for the DA time horizon¹⁷. The first step is to merge the Day-Ahead Congestion Forecast (DCAF) files provided by TSOs as defined in module A.1. Then the multi-area system is simulated under various conditions to test its reliability during the next day. The constraints identified are analyzed and communicated to Coreso clients. Finally, Coreso also contribute to the next module C.2.

As described by (Arrivé et al., 2012), current developments as in 2012 include a coordination procedure for further information exchanges such as ID Congestion Forecast (IDCF) files.

¹⁷The process is described on the following webpage: <http://www.coreso.eu/day-ahead.php>, visited last in October 2012.

II.2.2 Module C.2 Coordination of TSO actions

(a) Role.

This module refers to coordination arrangements on TSO actions on the system. Indeed, in addition to the allocation process which can be seen as a passive congestion management method, each TSO acts in its control area to handle network issues as described in section I.2.2. Some actions could be coordinated with benefits, including active congestion management for instance. Similarly to the previous module, some exchanges of necessary data could be considered as part of module A.1 in the system organization. Besides, if an action has sensible costs or generate sensible negative impacts, some cost sharing agreement may be required. These agreements are included in a wider perspective through module D.1.

(b) Implementation choices.

The first task is to identify the goals that could be best served by coordinated actions. Among the good candidates¹⁸ lies an efficient active congestion alleviation. Indeed, a congestion in one area can be sensible impacted by actions in another. Coordinated action can also help to minimize negative effects of maintenance outages. The outage of a large network element can for instance reduce the capacity to maintain N-1 security rules over an interconnected meshed network. The effects can become unbearable if several uncoordinated outages are programmed at the same time in neighboring areas.

Then, in practice, the coordination can be supported by general agreements and routines that can be adapted to each time horizon depending on the time available to foster an validate a coordinated response. An adequate definition of the responsibilities of each actor is key to ensure the proper functioning of the system (Knops, 2008b). For instance,

¹⁸In addition to the example given in this section, several technical issues which are not included in this thesis scope would be best handled by coordinated actions such as voltage control. As described by Phulpin et al. (2009), it is possible for each TSO to use network equivalents of the neighboring areas for a coordinated decentralized optimization taking into account voltage issues. Indeed, voltage issues are rather local issues unlike the frequency issue which is global over a synchronous interconnected AC network. Another technical example would be the circling power flows. Janssens and Kamagate (2003) describe power flows going in circle around a ring on the transmission network. According to their sources, “large circulating power flows of about 1000 MW were recorded in the ring power systems around the lake Erie and around the Rocky mountains in North America”. These flows are completely useless but they generate losses and they can cause congestions. These unwanted phenomenon could appear if there is a synchronous ring around the Mediterranean sea and it is necessary to avoid them by a coordinated control.

a clear option is that each TSO keeps full responsibility over its control area. In this case the delegation of responsibility involved in cross-border agreement is de facto limited.

(c) Implemented solutions.

In Europe neighboring TSOs sharing a meshed network have a long tradition of formal and informal cooperation while each TSO remain fully responsible in its control area. The practice is briefly illustrated by the coordination of some actions for the three first goals introduced above. These examples are displayed from the most occasional to the most systematic coordination.

There are occasional coordination on active congestion alleviation. If a stressed situation is anticipated, then there are various decision variables that could be optimized over several areas. More precisely, there are network controllable devices such as Phase Shifting Transformer (PST) ([Arrivé et al., 2012](#)) and possibilities to activate counter trading or redispatch. In the future, even if each TSO keeps responsibility over its control area, common service providers such as Coreso can greatly help coordination. Indeed, they can provide global analysis and centralized expertise on stressed situations that would be best answered with a coordinated remedial action. In the end, as reminded by Coreso on its website¹⁸ “the decision to implement these remedial actions remains the responsibility of the TSOs”.

There is also a coordination on outages of large network elements for maintenance or reinforcement of the network. “Together, TSOs determine the most suitable dates of outages for the maintenance or the reinforcement of the following network elements” ([ENTSO-E, 2011c](#)). In practice the coordination starts one year ahead, and is reinforced on a monthly basis. In addition, weekly updates take into account the changes occurring on a short term perspective. This practice is expected to be continued through the outage planning proposed in a draft network code ([ENTSO-E, 2012h](#)).

The third example is generation adequacy management over a synchronous area concerning automatic activations based on frequency control such as the FCRs and FRRs described in section [I.2.1](#). If two TSOs of a synchronized interconnected network can settle their control parameters independently, then they may be tempted to act as free rider by letting the other area bears all the burden. This lack of coordination would

be particularly embarrassing in an extreme emergency situation. Indeed, load shedding can be used as a means of last resort for adequacy management. The activation of load shedding only in some control areas of a synchronous area, without acceptable reasons for the citizen, would not be acceptable for TSOs and their legitimate authorities. Thus, the current agreements between TSOs in each European synchronous area include co-ordinated frequency control parameters (ENTSO-E, 2010). These agreements shall also be part of the draft network code on the topic (ENTSO-E, 2012).

II.2.3 Module D.1 Monetary transfer agreements

(a) Role.

The coordination arrangements described in the previous sections can generate common revenues, costs that shall be split as well as negative externalities. For instance, since physical flows differ from commercial flows in a meshed electricity network, a trade between France and Germany may generate extra flows on the Belgian grid which may generate extra costs for Belgian stakeholders. In this context, cost or income sharing agreements may be useful to handle cross-border externalities on some actors that could impede the acceptability of coordination arrangements and the good will to cooperate. This module is thus introduced in support of the previous ones and it is considered separately because the externalities could be handled in a global way rather than for each specific arrangements.

(b) Implementation choices.

If the most significant costs and benefits can be evaluated with a well-established method, if the aggregated net benefit is positive and if the parties involved do not try to get more than their share according to the evaluation, then there are possible agreements from a theoretical perspective. However, due to the complexity of a power system, a well-established method can lack. In this case, there may be a tradeoff between simplicity and accuracy. In a few words, without a minimum level of accuracy, the monetary transfer would not play their role for the acceptability of the cross-border coordination consequences, whereas above a certain level of accuracy, the complexity may increase vainly the negotiation and transaction costs. Additionally, it might be interesting to

allocate some common incomes to some common costs in order to save some monetary transfers to and from the relevant actors.

(c) Implemented solutions.

The congestion revenue rights on regulated interconnections are an example of income sharing. As in 2012, they are split equally between the two TSOs involved at each bilateral borders.

Concerning the costs generated by the common tasks, there are no general agreements. For instance, the work of Coreso for the function C is financed by TSOs, *i.e.* by the network users. Similarly, the role of common market operator assumed by some PXs is financed in the CWE region through the fees paid by market participants on the coupled markets. Moreover, it does not seem to exist any predefined monetary agreements to share the costs of a coordinated action in module C.2. Instead, “The TSC initiative includes a pilot phase of cross-border coordinated redispatch among TSOs, where the ‘requester’ principle is used, *i.e.* the one TSO requesting for redispatch measures, will pay the costs for these measures” ([Arrivé et al., 2012](#)).

Concerning the management of network externalities generated by cross-border exchanges, there are Inter-TSO Compensations (ITCs) agreements as described in the following focus.

(d) Focus on the ITC agreements.

This overview of the debate starts with a short historical perspective on the ITCs since the year 2000. Then it points briefly at two studies reflecting part of the debate until 2010. Finally, rather than entering into the details of the possible solutions, it summarizes the rather precise directions given by a commission regulation from 2010 and points at a key implementation feature which is still under discussion as in December 2012.

As introduced above, an agreement is deemed necessary between TSOs to compensate each other for the costs generated by cross-border physical flows that may be negative externalities. A common agreement was discussed publicly as soon as 2000 ([ETSO](#),

2000). The associated monetary transfers were then called cross-border tariffs, but it shall not be confused with classical trade tariffs to restrict cross-border exchanges which would not be allowed under EU law on the frontiers between countries. According to (ETSO, 2000), the cost components include the infrastructure investment and maintenance costs plus the losses, constraints and ancillary services costs as well as taxes and insurances. The report assumes that constraint costs are recovered by the congestion management process and that local ancillary service costs are recovered separately from local network users. Moreover, it states that “[i]n practice, the largest part of the costs is those related to transmission investment”. Since 2002, a voluntary agreement, sometimes referred as ‘CBT’ standing for cross-border tariffs, is used to compensate for infrastructure and losses costs. This agreement used a key of distribution to collect the funds and another to distribute them. As summarized in (ETSO, 2008) the total amount collected has increased from about 200 M€/year in 2002 to almost 400 M€/year in 2006 and 2007. This document also displays the former keys of distribution and the resulting net monetary flow for each country. Among them, France has been a net contributor whereas Switzerland is a net beneficiary.

The debate on the adequate key of allocation has involved various consultants and academics. For instance, a report commissioned by the EC (Consentec and Frontier Economics, 2006) analyses six candidate allocation methods for ITC between countries. On the same topic, an academic study of four methods by Olmos and Perez-Arriaga (2007) shows that “the choice of one method or another would have a significant impact on the compensation to be received by each country”. Besides, an official working document from the (European Commission, 2008) summarizes the various options and objectives as in 2008.

Since 2010, the future multiyear agreements are framed by the a Commission regulation (EU, 2010a) supported by article 13 of regulation (EC) 714/2009 (EU, 2009d) and structured around a dedicated ITC fund. This fund is fed by TSOs and the contribution, calculated at a national level, shall be “in proportion to the absolute value of net flows onto and from their national transmission system as a share of the sum of the absolute value of net flows onto and from all national transmission systems”. Besides, special conditions apply for exchanges with countries which are not subject to EU law or to a particular agreement concerning the ITC arrangements. In particular, a transmission

system use fee is applied and for 2011 this “perimeter fee” has been determined to be 0,8 €/MWh [ENTSO-E \(2012j\)](#).

As stated in [\(EU, 2010a\)](#), this ITC fund shall provide compensation for two kinds of costs. The “costs of losses incurred [by] national transmission systems as a result of hosting cross-border flows of electricity” are evaluated in two steps: the amount of losses per country and the value of these losses. The ENTSO-E is responsible for the estimation of the variation of losses induced by the existence of cross-border physical flows. In accordance with this responsibility, the [ENTSO-E \(2012j\)](#) released an overview of the method applied and monthly results for the year 2011. Then the monetary value of these extra-losses (or lower losses) shall be coherent with the value of losses estimated by regulatory authorities for national purpose if there is any. These values per country for 2011 are summarized by the [ACER \(2012e\)](#).

Besides, the “costs of making infrastructure available to host cross-border flows of electricity” [\(EU, 2010a\)](#) are handled with two separated decisions: a total sum and a key of distribution. The distribution is rather precisely defined. It shall be in proportion to two weighted factors. A transit factor weighted 75% refers to “transits on that national transmission system state as a proportion of total transits on all national transmission systems”. A load factor weighted 25% refers to “the square of transits of electricity, in proportion to load plus transits on that national transmission system relative to the square of transits of electricity in proportion to load plus transit for all national transmission systems”. The total sum is to be decided by the European Commission (EC) following a proposal from the Agency for the Cooperation of Energy Regulators (ACER). Until a decision on the total sum, a default value has been settled at 100 M€/per year [\(EU, 2010a\)](#). To favor a sound proposal, the agency was given two years to undertake a technical and economic assessment with the support of the ENTSO-E. Within this context, the ACER has commissioned an impact assessment of the infrastructure component of the ITCs [\(Consentec, 2012\)](#). Following this report, a public consultation on its results has been released [\(ACER, 2012d\)](#) and the consensus is still to be found as in December 2012.

The [\(ACER, 2012e\)](#) summarizes the ITC settlement for the year 2011 as well as the input data. The amount of money collected this year is about 204 M€ between the ITC parties and 20M€ from the perimeter fee introduced previously. The distribution

corresponding to the losses compensation amounts to 124 M€ and the compensation for the infrastructure costs is at 100 M€ as planned in the regulation.

II.2.4 Module D.2 Surrounding public agreements concerning the internal area organizations

Module D.2 is a set of surrounding public agreements to ensure a minimum level of compatibility between internal area organizations and fairness between coupled markets over the integrated power system.

Several implemented solutions of this last module are described all along chapter [IV](#) about the role of the European Union (EU). In particular, section [IV.1.1](#) shows why public agreements are needed between areas and section [IV.1.3](#) describes pieces of EU law supporting the good functioning of the internal market, the security of electricity supply and a common environmental policy.

II.3 Additional interactions between cross-border modules

This complementary perspective focuses on key interactions between modules of the functions A, B and C. The analysis of the interactions between these modules and the surrounding necessary agreements function D requires to introduce several institutional perspective which is partly done in the following chapters. The description is structured around two topics: some information flows and the compatibility between sub-modules of differing time-horizons.

II.3.1 Information flows for the cross-border congestion management

Figure II.11 represents with arrows the key data flows between the modules of functions A, B and C for the cross-border congestion management. The information are shared at predefined steps of the sequence of time horizons. The next paragraph gives some depth to this overview with a perspective on the time dimension. Besides, interactions with the rest of the world, including market players, are not explicitly represented in this figure.

II.3.2 Compatibility between time horizons

For the functions A, B and C, the modules can often be decomposed in submodules for each time horizon. This may raise compability issues between sub-modules over the sequence of time horizons. For instance, the [ACER \(2011e\)](#) warns that “[l]ong-term capacity calculation methodologies shall be fully compatible with the adopted short term capacity calculation”. The following paragraphs uses this example to illustrate how the framework isolates to a large extent this issue in the module B.1. First it is illustrated that it is conceivable to have a diversity of arrangements over the LT and DA time horizons. Then, it is shown that the coherence of the cross-border coordination of operation is ensured by a careful design of module B.1.

The opportunity to have different arrangements at various time horizons is simply illustrated by a selection of arrangements for the LT and DA time horizons which are allowed by the guidelines from the [ACER \(2011e\)](#).

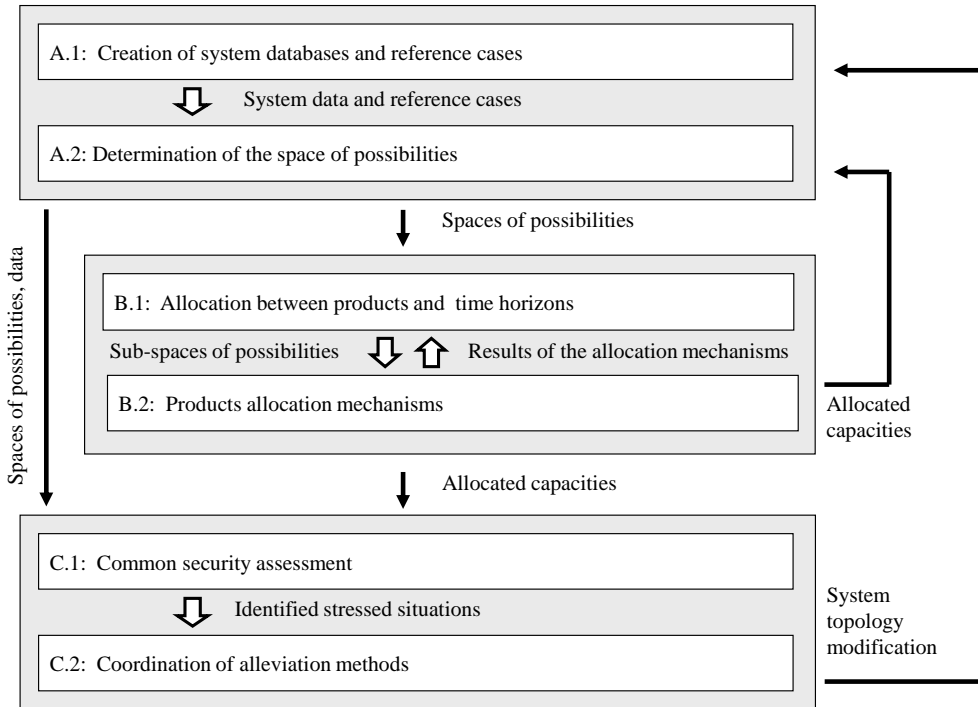


FIGURE II.11: Simplified representation of the information flows for the cross-border congestion management between the modules of functions A - determination of the space of possibilities for cross-border exchanges, B - allocation and C - coordinated congestion alleviation.

Module	Parameter	LT arrangement	DA arrangement
A.2	Shape of the output	bilateral NTC	FB
B.1	Product allocated	PTR UIoSI	PTR
B.2	Mode of allocation	Explicit	Implicit
C.1	Coordinated assessment	No	Yes

TABLE II.2: Selection of cross-border arrangements for Long-Term (LT) and Day-Ahead (DA) time horizons. The aim of this table is to illustrate that differing arrangements can be selected for the a given task at differing time horizons. The arrangements, the choices and the module, referred with a code, are designed by key words described in the previous sections.

Over the sequence of time horizons, module B.1 can be seen as the central coordinator for a given period of delivery. Through this module, a large share of the result of previous actions can be adequately integrated into the decision process. An illustration is given based on the three-node system described in the focus on FB methods for module A.2 in section II.1.2. The cross-border arrangements include the features given on table II.2. If TSOs have acted on the network between the LT and DA determination of the space of possibilities, it can be included in a new output of module A.2. It is assumed in this illustrative case that the output of A.2 is the same. In addition, the result of the

long term allocations of physical capacities, after the nomination of the PTR UIoSI, are centralised in a vector \mathbf{T} representing the long term bilateral commercial transactions. If full netting is allowed for the resulting long term cross-border flows, then this vector is sufficient to determine in module B.1 the capacities for the DA implicit allocation. As described in (CWE Flow-Based Validation Task Force, 2012) it is in theory a simple translation of the space of possibilities with reference to the origin of the graph, as shown in figure II.12.

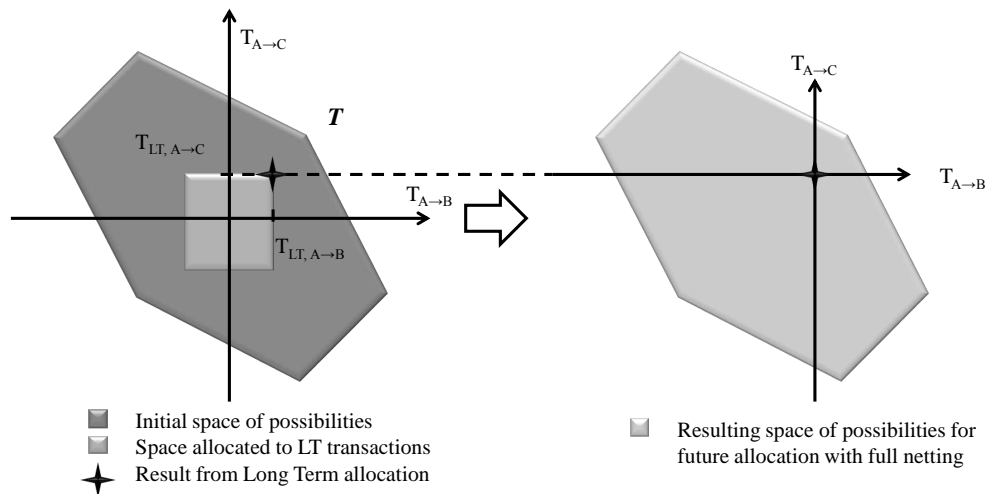


FIGURE II.12: Illustration of the impact of a previous allocation of physical cross-border capacities on the space of possibilities with full netting.

II.4 Interactions with area internal organization features

The coordination of operation at a border between two areas is a coordination between the internal organization of each area. Therefore, there are inherent interactions between the internal and cross-border arrangements.

The following paragraph highlights first the strong relation between internal and cross-border congestion management within a meshed network. Then, it appears that, in the current integration process, several options of improvement require to put a higher constraint on the area internal design flexibility. This second kind of interactions can put limits on an integration process.

II.4.1 Interactions between internal and cross-border congestion management

According to the physical laws on a meshed grid¹⁹, the physical flows resulting from internal and cross-border transactions tend to add up on the physical network. Therefore, when an element of the network is identified as potentially congested because too much power could be flowing, it can be due to a sum of internal and cross-border transactions. However, the congestion management may not be fully homogenous over the meshed grid. In particular, the internal congestion management methods can be different from the cross-border ones. Moreover, there may be an arbitrage between the two sets of methods to manage the congestion. In practice, this arbitrage can be suboptimal from a social surplus maximizing point of view. This arbitrage is an important research topic because it can impact the economic surplus of many actors.

For instance, with reference to an optimal arbitrage, cross-border congestion management methods such as a reduction of the space of possibilities for cross-border exchange can be overused to make up for underused internal congestion management methods such as counter trading. In this case, the congestion issue would be “shifted” at the border more than it would have been with the optimal arbitrage. [Bjørndal et al. \(2003\)](#), [Glachant and Pignon \(2005\)](#) have indentified conditions that could give incentives²⁰ to a TSO to implement a suboptimal arbitrage. For instance, it is assumed the internal congestion management is a cost for TSO A in a country A and cross-border congestion management is a reduction of social surplus in country B across the border. Under these conditions, TSO A might end up with an incentive to favor cross-border congestion management rather than internal actions.

This arbitrage possibility has been more recently broadly described by [Willems and Sadowska \(2012\)](#) with a very instructive numerical example. This study shows not only once more how the cross-border congestion management can be overused in comparison with an optimal situation, but also how it could be underused. For instance, under EU law, the pressure to increase the spaces of possibilities for cross-border exchange and

¹⁹Including for instance the famous Kirchhoff’s law or the superposition principle with a linear model of an electricity grid.

²⁰Note that the very complex issues of TSO regulation and TSO incentives is a complex research object that has not been fully studied, but it is too large to be included in the thesis scope.

to avoid congestion shifting at the border could result in neglecting the contribution of cross-border exchange on internal line congestions.

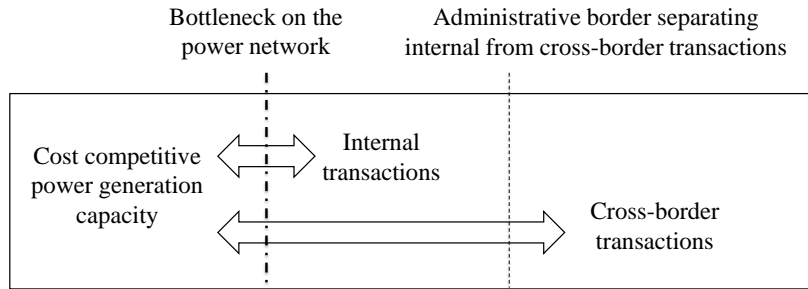


FIGURE II.13: Internal and external transactions can add up on the same transmission capacity over an internal bottleneck.

To complete the analysis of the arbitrage, a more formal description is given with the following notations. In this example, a power system is composed of several control areas and everything is optimally operated with fixed infrastructures during a single time period. One of these areas has a generation source which is cost competitive either within the area or for the neighboring areas. In other words, this production is the cheapest over the system considered and should be used as much as possible. The quantity produced by the cost competitive generation source is $q_P = q_I + q_E$ with q_I the power capacity associated to internal transactions and q_E the power capacity associated to cross-border transactions as illustrated in Figure II.13. q_P can take any value between 0 and $q_{P,max}$. The social surplus generated by internal transactions within the area is $S_I(q_I)$ while the surplus associated to external use would be $S_E(q_E)$ ²¹. These surplus functions are assumed concave because the additional power is allocated in order of merit²². Moreover these surplus functions are assumed to be strictly growing between 0 and $q_{P,max}$.

However, the use of this generation sources is limited by a single internal bottleneck. The maximum power flow on this bottleneck is a capacity $T_I < q_{P,max}$. It is assumed the total flow is a strictly growing as a function of q_I and q_E . For the simplicity of the example, it is more precisely assumed that the quantities q_I and q_E adds up linearly at this internal bottleneck and there are no other source of power flow. With this simple

²¹The argumentation is independent from the definition of the social surplus function. It can include for instance the transaction costs and losses.

²²This assumption has also been made and described in the model of section (a).

model, the total flow on the bottleneck is equal to q_p . Therefore, the social surplus maximization problem can be summarized as in the following equation:

$$\begin{aligned} \max_{q_I, q_E} S_I(q_I) + S_E(q_E), \\ \text{subject to } q_I + q_E \leq T_I; 0 \leq q_I; 0 \leq q_E \end{aligned} \quad (\text{II.28})$$

In this context, since the surplus functions are strictly growing, the solution will obviously correspond to a full use of the limited capacity at the internal bottleneck, *i.e.* $q_I + q_E = T_I$. Therefore the optimization problem can be written in (II.29) as a maximization depending on a single variable q_E , the power exported outside the area.

$$\begin{aligned} \max_{q_E} S_I(T_I - q_E) + S_E(q_E), \\ \text{subject to } q_E \leq T_I; 0 \leq q_E \end{aligned} \quad (\text{II.29})$$

In the convex mathematical problem²³, there is a unique range of optimal solutions $[q_{E,min}^*, q_{E,max}^*] \subset [0; T_I]$ which can be in some cases a single point $q_E^* \in [0; T_I]$. A solution splits in an optimal way the congestion management between internal and external transactions. A graphical representation is presented in figure II.14.

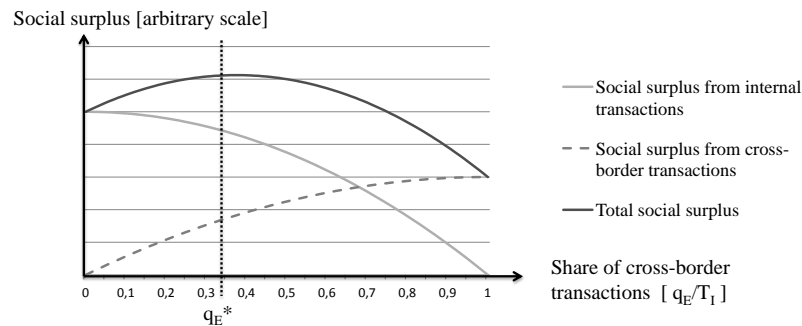


FIGURE II.14: Graphical illustration of the optimization problem described in section II.4.1 on an example set of surplus functions assuming the capacity on the bottleneck is fully used.

Based on this simple model, it is possible to offer a formal description of two sub-optimal arbitrage between internal and external congestion management corresponding to numerical examples given by Willems and Sadowska (2012). In a first case, a power system regulatory system can favor the surplus generated by internal transactions S_I at the expense of the cross-border ones if the optimal situation includes cross-border transactions,

²³The objective function is concave as the sum of two concave functions and the constraints are linear.

i.e. $q_E^* > 0$. For instance, a limitation of the export capacities can be modelled by a modification of the constraints. Indeed, the power system organization could impose a maximum external transmission capacity $T_E \in [0; q_{E,min}^*]$. The additional constraint $q_E < T_E$ excludes the optimal solution from the space of possibilities of the social surplus maximization (II.28) and the wrong arbitrage results in a suboptimal situation with $q_E < q_{E,min}^*$.

On the contrary, the power system organization can favor the surplus from external transactions S_E if $q_{E,max}^* < T_I$. It can be done for instance by preventing q_I to be included in the network constraint $q_I + q_E \leq T_I$ that can reduce the cross-border space of possibilities. In this case, the first constraint becomes $q_E \leq T_I$ in (II.28) and a second step in the decision process is necessary to correct q_I so that the power flows respect $q_I + q_E \leq T_I$, *e.g.* counter trading or redispatching. This second example of wrong arbitrage can result in a suboptimal situation with $q_E > q_{E,max}^*$ if the marginal surplus of S_E at $q_{E,max}^*$ is strictly positive, *i.e.* if there are gains to be made from additional cross-border transactions.

To sum up, the zonal organization requires an arbitrage between internal and external transactions in the congestion management as defined above. In practice, an optimum arbitrage from an aggregated social welfare point of view is probably difficult to reach for a legitimate authorities. Therefore, the lawyers working on future rules for the cross-border coordination have the difficult task to define to what extent an imperfect arbitrage resulting from a legitimate decision process would be compatible with the common competition law in module D.2 ensuring fair common markets.

II.4.2 A link between cross-border coordination level and harmonization requirement

This part links some improvements of the cross-border coordination of operation, in the sense that it fulfills better the power system objectives, to higher convergence requirements, understood as a requirement to change some rules in at least one of the coordinated area to ensure a certain level of compatibility. In this thesis, the term harmonization is also used instead of convergence, in a light sense meaning working to fit together, as it is often used in EU documents. In practice, an improvement of the coordination does not necessarily requires harmonization, but the link could be seen at

least as a strong tendency as shown with three examples. This observation is useful in the thesis argumentation because of at least two consequences. First the harmonization has a cost, either in term of negotiation costs or transition costs for those organizations that converge toward an harmonised situation. Second, once the coordinated system is harmonised, the regulation ability to adapt can be lower, which should not be neglected in a context of innovation on energy technologies and evolution of the energy resource mix.

The first example is the transition from explicit allocation to implicit allocation for auctions at DA and ID time horizons. As described previously in this chapter, the principle of this evolution is to embed the allocation process within the zonal markets of products such as DA energy products. The compatibility requirements include common gate closure ([ACER and AESAG, 2011d](#)) and a minimum of compatibility between standard products across the borders so that the implicit allocation process is able to assess the valorization of the cross-border space of possibilities. These two features have a key role in the zonal organization as briefly described in the case study about DA implicit allocation described in appendix C. For instance, the gate closure position is for instance a trade-off between better forecasts if it is closer to real time and more time for actors to adapt to the DA market results if it is further in advance. Once several zones are coupled, the ability to modify this parameter would require a large agreement and, to a certain extent, the parameter cannot differ between zones. Furthermore, concerning the implementation of a European wide ID market coupling, some PXs express their opinion that specific features of a target model in discussion could “hinder national efficiency” ([ACER and AESAG, 2011c](#)).

Another example is the coordination on Phase Shifting Transformer (PST) control or on any other controllable device helping to manage the system power flows as described for instance by [Van Hertem et al. \(2005\)](#). Optimal use of these devices can bring benefits ([Marinescu and Coulondre, 2004](#)), providing there are adequate cost sharing agreements as reminded in the functional analysis of the coordination. To this aim, an agreement shall be found on the coordinated control benefits and costs. Therefore, in a continuous improvement of the operation practice, the ability of each one of the coordinated zone to change its control rules may be to some extent constrained by the coordination if a new agreement must be found.

A more general illustration is described at the balancing time horizon by [Vandezande \(2011\)](#) or the initial impact assessment Framework Guidelines from the [ACER \(2012b\)](#). Based on the last document, [Table II.3](#) summarizes some feature of the impact assessment of four options referred as A, B, C and D. The study states first that the potential benefits that can be reached goes up with the level of harmonization. Then, it identifies a tradeoff between potential benefits of the option and the time of implementation. Finally, the harmonization level is ensured by common rules on cross-border issues for option B and on cross-border and national issues for options C and D ([ACER, 2012b](#)). This distinction shows that stronger common rules can be seen to some extent as stronger constraints on the local design flexibility.

	Option A	Option B	Option C	Option D
harmonization level	voluntary	low	high	very high
Effectiveness	-	+	++	+++
Time of implementation	++	-	--	---

TABLE II.3: Qualitative evaluation of four cross-border balancing options by the [ACER \(2012b\)](#). The effectiveness criteria shows to what extent the options can be expected to achieve European objectives described in the report as security of supply, competition, social welfare and renewable energy integration. Option A is “status-quo”. Option B is “creating a European exchange of balancing services through a legally binding regulation defining minimum harmonization requirements necessary to develop cross-border exchanges” to allow cross-border arrangement between balancing service providers and TSOs or between TSOs without common merit order. Option C is “creating a European exchange of balancing services through a legally binding regulation imposing a defined level of harmonization of the balancing mechanisms adopted by each Member State to facilitate cross-border exchanges” so that a common merit order can be applied. Option D is “creating a European exchange of balancing services through a legally binding regulation defining a single European balancing mechanism, including creating one or several regulated entities to perform the tasks of supranational balancing operators”, allowing a fully integrated balancing market.

To conclude, even if this link between cross-border options and an area internal organization is not always verified, it is still meaningful to take it into account in an impact assessment. For instance, in a public consultation on forward product, the ([ACER, 2012a](#)) asks if some harmonization are necessary, which may allow to avoid some transition costs if there is not clear benefits associated to the harmonization of some organization details. To a certain extent, it can be seen as a trade-off between local optimization and a European optimization. In specific cases, despite the expected gross-benefit from a strong coordination arrangement, the costs or drawbacks of the necessary harmonization may favor another options with lower expected gross-benefits. Similarly, between the

national and European level, the regional coordination level could be, on specific issues, the best choice depending on the objectives.

II.5 Chapter summary

By revisiting existing literature on congestion management, this chapter has developed a modular framework to analyze the various mechanisms involved in the cross-border coordination of operation as defined in the first chapter.

After a summary table of the modules, this conclusion highlights the potential applications of the modular framework and policy recommendations emerging from the analysis.

Summary table of the modules

In this summary, the codes displayed in the right column shall be used to refer to the modules in the thesis. Note that module B.2 is decomposed in four parts to highlight how the framework can be refined by considering, in this illustration, the various time horizons. Indeed, each module can be decomposed in based on the time horizon when it is performed among other features.

Function	Module	Code
Determination of the space of possibilities	Information sharing between TSOs	A.1
	Spaces of possibilities for cross-border exchanges	A.2
Allocation through a set of markets and mechanisms	Between products and time horizons	B.1
	For Long-Term (LT) time horizon	B.2.1
	For Day-Ahead (DA) time horizon	B.2.2
	For Intra-Day (ID) time horizon	B.2.3
Additional coordination between TSOs	For Balancing (BA) time horizon	B.2.4
	Coordinated security assessments	C.1
Surrounding necessary agreements	Coordination of TSO actions	C.2
	About costs and incomes	D.1
	About internal area organizations	D.2

TABLE II.4: A modular framework of the cross-border coordination of operation in an integrated power system.

Potential applications of the framework

The functional analysis performed to build the framework can complete the existing literature relative to the coordination of operation within a given region or at a single border like the interconnection between two areas. It can be performed to describe either an existing situation or a target model. The framework can first of all serve to strengthen

a common understanding among stakeholders. Indeed, the core framework which has been developed in this chapter is already used in some reports on the topic. It could be used more often in public communications to build a common knowledge, a cornerstone for further discussion. For instance, the framework could be used to identify the role of a particular coordination arrangement within the global process with a single picture or even with a single key word. Then, the framework can also guide further study on the integration process. For instance it can help to identify the relevant interactions with other modules for an impact assessment. Finally, the framework can be used to shape a monitoring board of an integration process as illustrated in section III.1.3. Similarly, it is a starting point to assess the coherence between the options of a given target model.

Conclusions from the analysis

From a methodological perspective, this analysis shows that there is much more than market coupling to couple markets of neighboring areas and, more generally, to improve the cross-border coordination of operation. Indeed, even if the regional DA market coupling represents a sensible progress in Europe, the market coupling solution improves only one of the four modules to determine and allocate the space of possibilities for cross-border exchanges and DA takes place among other relevant time horizons. For instance, the implementation of a FB solution is only a step of a continuous improvement of the determination process.

In particular, the large perspective taken in this thesis allows to emphasize a key module which is often excluded from current academic studies: the module splitting the spaces of possibilities between the time horizons and several kinds of products which may deserve more attention in the public debate. This is shown in this chapter by the regulatory questions described in four focuses about market design features: the reservation of capacity for shorter time horizons, the nature of the LT products, how the optional nature restricts the space of possibilities for this product and the regulatory choice of a base ‘market time period’.

From an empirical perspective, the observation of the implemented solution in the CWE region, several solutions are already implemented for a functioning cross-border coordination of operation. Moreover, several options of potential improvement are available from a technical perspective. Therefore, even if technical improvement of, for instance,

market coupling algorithms could always be beneficial to the system, technical challenges do not appear as the main barriers to the continuous improvement process.

In addition, the analysis has investigated two fundamental interactions with the internal organization of the areas of an integrated power system. First, because the physical power flows add up on a common transmission network, the effects of internal and cross-border congestion management also add up on the critical elements of an integrated power system. The second interaction is a tradeoff that may appear in specific cases between harmonization of the internal organizations and efficiency of a new coordination arrangement. These interactions can in some case be sensible when a modular approach is used to study solutions for the cross-border coordination of operation.

Chapter III

Measuring the impact of an improved coordination of operation

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“Impact assessment is an aid to political decision-making, not a substitute for it.”

European Commission (2009)

Chapter II has identified through a modular framework several perspectives of improvement of the cross-border coordination of operation. In this new step of the study, the first objective is to analyze how impact assessment tools can be used to guide the selection of adequate options in a decision process¹. More precisely, the aim is to review existing tools and propose adapted ones with their strengths and inherent limits assuming the bounded rationality and incomplete knowledge of actors involved in the decision process (Williamson, 2000). Indeed, within the theoretical framework of microeconomic analysis (Varian, 1992) with a focus on international trade and elements from the political economy (Krugman and Obstfeld, 2008), the quantitative methods used in an impact assessment shall be tailored to the research object, its objectives and the availability of data and reliable simulation models.

A second objective of this chapter is to provide orders of magnitude of the impact of the improvement process in the European case as in 2012. The aim is to evaluate if the perceived costs appear reasonable compared to the expected gross benefits and if the distribution effects appear sensible or not. These orders of magnitude are produced from a combination of previous impact assessments, of public data and of a few calculations performed in this chapter.

The content is structured around three fundamental impact assessment results: the gross benefits with a broad meaning, the aggregated costs and the distribution effects beyond the aggregated figures. First section III.1 focuses on expected gross benefits and indicators of progress that could help *ex ante* to decide between a set of options and *ex post* to monitor the progress once a decision is made. Then, section III.2 is about the aggregated costs. Focusing on the the second objective of this chapter, *i.e.* estimating orders of magnitudes, some costs of the process are extrapolated from public figures related to the improvement of the cross-border coordination of operation. Finally, section III.3 illustrates the distribution effects. Indeed, these effects can be strong due to an improvement of the coordination, and more generally due to further integration. In addition, a simple simulation is used to show how the vision of the system with an aggregated producer and an aggregated consumer can be refined.

¹In coherence with this thesis objectives, this chapter does not select implementation choices, the first objective is instead to analyze how an impact assessment could help the selection process.

III.1 Indicators of gross benefits or progress

This first section focuses on indicators of the gross benefits or progress that could help *ex ante* to decide between a set of options and *ex post* to monitor the progress once a decision is made. In practice, several elements from the rich literature on the simulation of benefits from cross-border infrastructure investments (Awad et al., 2009, Rebours et al., 2010a, ENTSO-E, 2012m, von der Fehr et al., 2013) can be adapted to the study of the research object. Indeed, as formalized in section I.3.3, the improvement the coordination of operation and the investments in transmission infrastructures interact to serve the same final objectives.

To assess the relevance of an indicator and its calculation method if there is one, the following framework with three large criteria is build based on the work of Gadrey and Florence (2010) and of Radaelli and Meuwese (2008). First, the indicator can be more or less directly measuring the progress toward one or more objectives of the policy according to which the decision should be taken. Thus, the indicator is as relevant as the objectives it has been proven to point at. Second, the indicator is based on measured data and it may require a calculation methods. Thus, the reliability of the measured data and the sensibility to modification of the underlying assumptions behind the calculation method can impede the relevance of the indicator. Third, the indicator can be more or less usable in a decision process. For instance, when assessing the progress *ex post*, an indicator may be relevant to compare two different periods or two different areas depending on the ability to control other variables of the system. Also, some indicators may be more accessible than others to non-expert in a public debate.

Section III.1.1 analyses first the gross social surplus in monetary unit. This section describes a simple indicator used in the literature and to answer the second objective of this chapter, a last paragraph gathers numbers from public studies to give an order of magnitudes. This first form can aggregate in monetary values the gross benefits corresponding to several objectives and it is highly appreciated in the public debate². However, its relevance can be limited by its calculation method or because it would miss some objectives that can be hardly be measured in monetary units of gross benefits. To overcome this second limit, additional partial indicators corresponding to partial

²Indeed, when it is combined with the aggregated costs, it offers a net aggregated figure in monetary value that can be easily used in the decision process between options, including the choice of doing nothing, according to the objective of maximizing the total net social surplus.

objectives of the general policy can also be used as analyzed in section III.1.2. Finally, a progress report table can be used specifically to monitor the progress after a first decision process has defined a target model as illustrated in section III.1.3. The principle is to acknowledge that once this first decision is made, a simple indicator is to monitor if the target model is reached in due time.

III.1.1 Gross social surplus in monetary unit

This first form of indicator of gross benefits or progress is a classical microeconomic object which includes for instance the economic surplus from trade as defined for instance in the glossary of a Network Code (NC)³ (ENTSO-E, 2012e):

“Economic surplus means the sum over all bidding zones, of seller surplus, being the aggregated difference between the sellers’ willingness to sell and the clearing price and of buyer surplus, being the aggregated difference between buyers’ willingness to pay and the clearing price, congestion income, and other costs and benefits, where appropriate”.

This core definition can also be enriched by additional elements added or subtracted in monetary units. If it is an estimation *ex ante* under uncertainties, it can be calculated as the expected value or a set of expected values corresponding to a small number of clearly identified scenarios. Moreover, if the costs of implementing specific coordination arrangements can be fairly assessed, then this first form of indicator can lead to a cost benefit analysis in monetary value. In practice, a form of simulation⁴ is necessary to obtain a reliable quantitative estimation. Indeed, to evaluate the impact of a change of the coordination arrangements on the market outcome, it is obviously impossible to create two identical real systems for benchmark studies for the sake of science only. Moreover, a benchmark on past experiences on different systems or on the same system at different periods is inherently limited because it is not possible to control all variables

³The NCs may become binding rules at the EU level as described in section IV.2.2.

⁴Such simulation would require a form of network and market models. For further insight, the framework built by Awad et al. (2009) to study the cross-border infrastructure investments could for instance be adapted to the improvement of the cross-border coordination.

(Green et al., 2006). However, the results from market models are inherently limited⁵. The quality of these results not only depends on the quality of the simulation but it is also inherently limited by some theoretical basis. To illustrate these limits, section (a) discusses the use of prices or market values that shall be used to evaluate the economic value of a given product⁶.

Then, section (b) describe a simple example used in the literatures. Finally, to complete the second objective of this chapter, section (c) gathers some numbers to identify an order of magnitude of the potential gross benefits of an improvement of the cross-border coordination of operation.

(a) **The prices as example of inherent limits of the economic surplus calculation**

Prices can be observed and they are often a meaningful economic signal in the sense that they result from agreements between actors, revealing their anticipations on the product exchanged. However there are, at least, three limits to keep in mind when using this value. First, in a power system as described in section I.2, several kinds of products are exchanged for a given period of delivery. Among them, the DA spot price of a bidding zone is in practice often used as a reference price, but other choices could be made. Second, the price of a given product can be subject to a high variability. For instance, the value of a long term energy product is only valid at the moment of the exchange and the most liquid financial product can see their value change in great proportion in less than one hour. This variability limits the present meaning of the pasts prices. Third, bid values on a market are not perfectly connected to the costs of the sellers and to a monetary measure of the utility of the buyers⁷. For instance concerning the costs that the price would represent in a market with marginal pricing, it is not obvious which

⁵Concerning for instance a classical equilibrium models, Neuhoff et al. (2005) show that “[t]he Cournot equilibria are highly sensitive to assumptions about market design (whether timing of generation and transmission decisions is sequential or integrated) and expectations of generators regarding how their decisions affect transmission prices and fringe generation”. Moreover Baldick (2002) argues that “several results reported in the literature are artifacts of assumptions in the parametrization of the [equilibrium] model”. Similarly, the limits of agent-based modeling are emphasized by Weidlich and Veit (2008).

⁶In this thesis, except when stated otherwise, the term product is used with broad meaning including the whole spectrum between goods and services.

⁷The utility is a fundamental economic concept defined for instance by Bentham (1781): “By the principle of utility is meant that principle which approves or disapproves of every action whatsoever, according to the tendency which it appears to have to augment or diminish the happiness of the party whose interest is in question”.

time perspective are relevant among various definitions of short term and long term marginal costs. Without entering into the details of the theoretical debate, [Mouchot \(1994\)](#) suggests that no theory of value seems to provide a comprehensive explanation of the prices. Thus, when these market signals are used, the interpretation of the resulting social surplus should be carefully analyzed as reminded by [Blumsack \(2007\)](#). Despite these limits, the prices are often the most pragmatic choice to give a value to a product thanks to its availability and its form of objectivity.

(b) A rough example used to evaluate the benefits of an improved allocation.

[Pineau and Lefebvre \(2009\)](#) and [Meeus \(2011a\)](#) have used about the same rough estimator to measure the opportunity cost due to under-allocated bilateral commercial cross-border capacities between areas with different spot prices. The first study concern transmission capacities between Quebec and neighboring areas. The second applies to a cable between Germany and East Denmark.

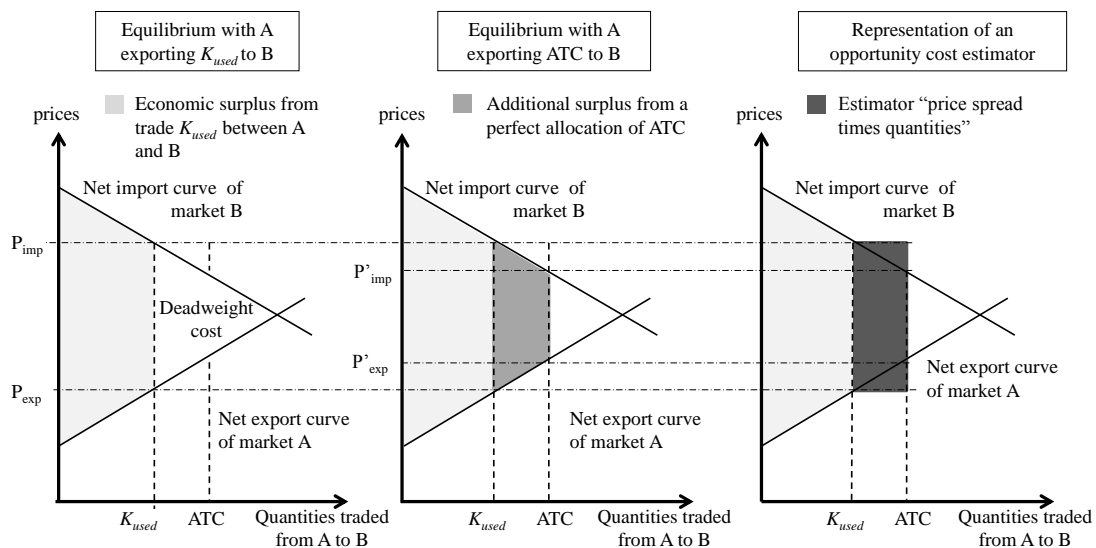


FIGURE III.1: Estimator of the opportunity cost of under-allocated bilateral cross-border commercial capacities for a given hours between two spot markets.

The principle of this estimator of potential economic benefits is a simulation on hourly datas. The network model is a simple set of hourly bilateral Available Transfer Capacity (ATC) as described in section [II.1.2](#). The market model is simply replaced by fixed hourly spot prices. The under-allocation is modeled by the ATC minus the capacity effectively used in the direction where the price spread indicates that a positive economic surplus

could have been realized through trade. The estimator E is simply the sum over the hours h of price spread ΔP_h times the unused capacities $ATC_h - K_{used,h}$. It is the area in dark grey in figure III.1.

$$E = \sum_h \Delta P_h \times (ATC_h - K_{used,h}) \quad (\text{III.1})$$

The result is an upper bound to the estimation of a potential economic surplus generated by an improvement of the allocation arrangements. The benefits of such simulation is that it is easily performed on public data and that the resulting estimator gives an order of magnitude of the potential impact.

(c) A few figures on the European power system.

The illustrative studies gathered below provide quantitative results on a real case. As described in section I.3.2 the benefits can be evaluated from at least three kinds of theoretical framework and the following description is structured around the two first of them.

Most of the social surplus assessments are performed under first theoretical framework focusing on a better system optimization assuming a fixed level of competition between actors. For instance, the two following studies are about an evolution from explicit to implicit allocations. The French regulator CRE (2009) used a simple indicator to evaluate the variation of social surplus generated by a switch from explicit allocation to market coupling with bilateral capacities at the DA time horizon. The result aggregated over the French frontiers with Spain, Italy, Switzerland, Germany and England add up to between 300 and 400 M€/year. According to (CWE, 2008b), “compared to the historical situation (the CWE region with an explicit auction mechanism between TLC and EEX), the simulation of coupling the CWE region with an implicit auction mechanism showed an increase of the social welfare by 41.8 million Euros per year”.

The improvement of cross-border coordination at balancing time horizon has also been simulated by the two following examples. According to Vandezande (2011) “yearly global cost savings of 37% - or more than 17,30 M€ - and a reduction of 22% in the amount of activated real-time energy could have occurred with cross-border balancing between Belgium and the Netherlands during the year 2008”. Similarly Jaehnert and Doorman

(2012) study the possibility of exchanging reserve capacity and balancing energy, between the Nordic and CWE regions. The study finds a social surplus “of 60-80 million Euro per year in reserve procurement and 40-50 million Euro per year in system balancing”. The authors precise that “this probably underestimates the real cost saving due to the perfect market assumptions and the market design in the model”.

The second theoretical framework is about the benefits of an increased competition on the wholesale markets. This requires additional assumptions on the evolution of market participant behavior than the first theoretical framework. For instance, Pellini (2012) assesses the impact of DA market coupling on the Italian borders with France and Switzerland. One core assumption is the level of competition in Italy and what would be the marginal cost in a perfect competition case. Based on this assumption, the study compare several cases under a reference scenario of expected load. In a ‘business as usual case’ without market coupling, the italian power producers would offer bids “at a price higher than marginal cost”. This base case is first compared to a ‘Market Coupling’ with the same bids, i.e. assuming that the improved coordination has no impact on the market participant behaviour. The positive change in social surplus is 33 M€ per year. Then, another case assumes that producers in a part of Italy bid at their assumed marginal cost because the improved allocation of cross-border capacities has increased the competitive pressure. Compared with this scenario, the change in social surplus is 396 M€ per year under a reference scenario. Given the order of magnitude of the impact measured under this second framework, the interpretation of these results should be balanced by the strong assumptions made in the model. The two figures can be interpreted as a lower and an upper boundary of the expected benefits depending on the impact of the second theoretical frameworks.

(d) Conclusions

To sum up, estimating the gross social surplus variation associated to a change of the cross-border coordination features requires simulations on more or less complex models. As a consequence, the calculation method of the indicator can end up black-box lacking transparency and the result can be highly sensible to some assumptions. Moreover, the progress toward some objectives of the energy policy may be difficult to measure in monetary units. To overcome some limits of this first indicator, additional partial

indicators of progress toward specific objectives can also be used to guide the decision making process as described in the next paragraphs.

III.1.2 Additional partial indicators

As illustrated in section B.2, an energy policy can be decomposed in intermediary objectives. More precisely, the European policy as summarized by the [European Commission \(2007a\)](#) is referred with three terms: competitiveness, security of supply and sustainability. Some indicators corresponding to these intermediary objectives can complete the estimation of a social surplus described previously. Section (a) introduces first an example of partial indicator for each one of the three sets of objectives of the EU energy policy. Then, section (b) warns about indicators that could be misinterpreted with two examples. Finally, section (c) shows how these partial indicators can be combined so that the impact assessments covers all major objectives.

(a) Illustration of partial indicators corresponding to a single objective

The capacity to build new partial indicators or recycle existing ones from other area of study is only limited by the human imagination. This diversity is illustrated with the following examples corresponding to three intermediary objectives of the EU energy policy.

Sustainability indicators. The sustainability objective in Europe includes a climate change mitigation objective which is served by the development of renewable energy sources. This can be translated in the two following sets of indicators.

The climate change mitigation requires to limit or reduce the greenhouse gases emissions. Their impact can be measured in tons of CO₂ equivalent emissions. Thus a good indicator of the impact of an evolution of the coordination on climate change is an estimation of the impact in term of CO₂ equivalent emissions that would be avoided. This indicator is sometimes translated in monetary values and included in the social surplus indicator. This conversion requires a monetary value for the tons of CO₂ which is very difficult to estimate given the strong uncertainties about the climate change amplitude and its consequences. A European scheme has been designed to reveal a market price for these

emissions, however this price has been highly unstable⁸. Given the difficulty to estimate a monetary value, it can be adequate to use an dedicated indicator of greenhouse gas emissions avoided.

The integration of renewable energy sources into the generation mix of the European power system is a policy serving the climate objective described above. Among the resources available in Europe, the ability to integrate wind and solar power to the grid in large quantities has raised many technical and economical questions because, for instance, they are intermittent generation technologies. As introduced in section (b), an improvement of the coordination of operation can greatly help the renewable generation management. This contribution can be measured for instance with the maximum integration of renewable energy sources with given costs parameters and security of supply level. This first indicator could help to estimate if an objective of renewable energy in the generation mix would be reached thanks to an improvement of the coordination of operation rather than dedicated support schemes. With the cost as an optimization variable and level of renewable energy integration as an exogenous parameter, the indicator could be the minimum costs to manage the integration of a given objective of intermittent renewable capacities with a given security of supply level. It is used by [Saguan and Meeus \(2011\)](#) considering transmission infrastructure investments rather than an improvement of the coordination of operation. This second way of modeling the improved situation is measured in monetary value and it could be included in a larger social surplus indicator.

A competition indicator. [Newbery et al. \(2004\)](#) details structural indices which can be used as competition indicators. Among them, the Herfindahl-Hirshmann Index (HHI) is an indicator built from the market share of the actors on one side of a market, for instance the sellers on a wholesale market. Behind its clear theoretical definition⁹, the calculation of the market shares requires a reference market which can be defined in many ways in term of product and in term of geographical scope. In particular, if the

⁸The prices on the official EU emission allowances for the months of 2013 and for the next phase, traded on EEX (see website: <http://www.eex.com/en/>), have dropped dramatically during the year 2012 for instance.

⁹It is defined as the sum of the square values of the market share expressed in percentage points. The values are between zero in the theoretical case with infinitely small actors to ten thousands for a monopoly.

market is restricted to one bidding zone of a market coupled over a larger area, [Perrot-Voisard and Zachmann \(2009\)](#) highlight that this indicator is not meaningful because actors compete across borders. Similarly, depending on the congestions between bidding zones, the whole coupled area may not be a relevant market either. Instead, the authors of this paper illustrate how the HHI could be calculated taking into account both the coupling and the potential congestions between zones. With such calculation methods, the HHI could be used to monitor an increase of the competition level resulting from an improvement of the integration.

A security of supply indicator. As described by [Winzer \(2012\)](#), the concept of energy security can take many forms. Among them, the following example of indicator focuses on the physical ability to ensure generation adequacy on a long term perspective. The indicator can be defined as the difference between a ‘Remaining Capacity’ and an ‘Adequacy Reference Margin’ as defined by the [ENTSO-E \(2012o\)](#)¹⁰. The relevant element for this section is that the ‘Adequacy Reference Margin’, representing a margin to ensure the long term generation adequacy, is defined as the sum of two terms including a ‘Spare Capacity’ which calculation is defined differently for one country and for a set of neighboring countries:

Spare Capacity should be sufficient to cover a 1% risk of shortfall on a power system, that is, to guarantee the operation on 99% of the situations considering random fluctuations of Load and the availability of generation units. By default, a value ranging from 5 to 10 % of net generating capacity could be used at a country-level. Since load / supply severe conditions of individual countries are not likely to occur at the same day and time, Spare Capacity for a set of countries (regional blocks or whole ENTSO-E) will be expressed in the SO & AF report as 5 % of Net Generating Capacity.

Therefore, the ENTSO-E acknowledges in this calculation method that an integrated power system is more secure for the long term generation adequacy than the sum for the same countries without taking into account the integration. In a perspective of continuous improvement of the generation adequacy forecast, the estimation method

¹⁰The definitions of these terms are reproduced in the glossary in appendix A.

may be refined to monitor more precisely the progress resulting from an improvement of the coordination of operation.

(b) Comments on indicators that could be misused

This short digression is a warning against the potential misinterpretation of two sets of partial indicators that are displayed in some reports.

Indicators of price convergence. An official study from the operators of the CWE region comparing coordination arrangements includes two convergence indicators among many others (CWE, 2008a). The report displays the annual number of hours with equal price for hourly product over a subset of countries, with a tolerance of 1€, and a graphical representation of the price divergence. In a classical theoretical vision of international trade, price convergence can be interpreted as a sign that the international trade is well functioning (Krugman and Obstfeld, 2008). However, the reader should be warned that this statement do not seem fully adequate for the wholesale electricity markets in an integrated power system for at least two reasons.

First, this indicator could point toward a wrong direction depending on the case. Indeed, as illustrated in section I.3.3 on a simple system, once the system is close to an estimated optimal situation, reducing further the price spread would require over-investments. Similarly, as suggested in a focus on the intuitiveness issue in section II.1.4, in some cases a Flow Based (FB) method without intuitiveness constraints can produce a higher social surplus and a decrease of some price convergence indicators compared to a FB method with such constraints. Thus, in these cases, using price convergence as a partial indicator would lead to select the option with a lower social surplus.

Second, the observation of a past price convergence should be carefully used because it is potentially very difficult to identify how an action on the cross-border integration has influenced price spreads. Indeed, during the congestion occurrences that are inherent to a power system without over-investments, the price difference can be influenced by many factors which have no relation with the integration progress. For instance, there is a cable between Norway and the Netherlands known as NorNed cable. It can be reasonably assumed that the prices in Norway are to a large extent correlated to the annual inflow of water in the hydroelectric dams and the price in the Netherlands are

partially correlated to the gas supply contracts of gas power plants. Thus, to use properly the price spread as an indicator of the integration level, a structured statistical method is necessary ([Zachmann, 2008](#)).

TSO congestion income in a market coupling are not a sign of a lack of integration. In the current system with bilateral capacities, the TSO congestion income is a common income shared by TSOs across each border and re-allocated to various missions for the good functioning of the system. This income can take various forms. For instance in an implicit allocation coupling two markets with reference prices, it refers to the sum over the market base periods of the product of a price spread times the capacity allocated. This price of the transmission capacity should not be confused with trade tariffs designed to block the cross-border trade. In particular, a decrease of the congestion incomes is not a sign of an improved space of possibilities for cross-border exchanges ([Frontier Economics and Consentec, 2008](#)). Indeed, considering the congestion income in an implicit allocation between two zones, additional capacity offered to the market would result in a higher allocated capacity and a lower price spread. Thus the product of both terms can go up or down independently from the evolution toward an optimal allocated capacity.

(c) **Combining several indicators**

When the gross social surplus is deemed to be completed by additional partial indicators, the various results should be combined in a way that favor its use in the decision process involving a public debate. A first possibility is to build a vector where each indicator is given a different dimension. However, the common understanding in a debate can only focus on a limited number of dimensions at the same time. Thus, to improve the form of the results, some dimensions can be combined in a composite indicators. The principle is to build a mathematical function translating several dimensions into one such as the weighted sum translated in a common unit. On this topic, additional principles and several illustrations are described by [Saisana and Tarantola \(2002\)](#). However, the limits of the exercise is that the choice of the conversion methods in a common unit and the weights influence the result ([Stiglitz et al., 2009](#)). Therefore, there is a compromise between reducing the number of dimensions for the sake of clarity and limiting the

drawbacks of a composite indicator. Such compromise is yet to emerge from the public debate.

III.1.3 Progress report table of an integration process

Once a target model has been agreed for the cross-border coordination of operation in an integration process, it is important to monitor that the decision is applied. This section shows how the modular framework proposed in chapter II can be used to build a progress report table.

Sample of target model options and observation in the CWE region. Options for a European target model emerge from the Framework Guidelines and Network Code already published as described in section IV.2.2. A sample of these options have been selected with the corresponding implemented solution in the CWE region as in 2012 according to the observations in chapter II. For the sake of simplicity, the example is limited to five key features which can be easily monitored. First, to determine the space of possibilities for cross-border exchange at the Day-Ahead (DA) time horizon, the target model is a flow-based method, as pointed out by the FG CACM (ACER, 2011e). A dedicated project is ongoing for the CWE region (CWE, 2011b). Second, concerning the allocation of cross-border products at the Long-Term (LT) time horizon, explicit auction is a possible target model according to the FG CACM (ACER, 2011e). This market design is already applied through the Capacity Allocating Service Company (CASC)¹¹. Third, concerning the allocation of cross-border products at the DA time horizon, implicit auction is a possible target model selected by the FG CACM (ACER, 2011e). This design is already applied through a common market coupling between APXendex and EPEXspot¹². Fourth, similarly, implicit allocation can also be a target model for the allocation process at the Intra-Day (ID) time horizon according to the FG CACM (ACER, 2011e). This design is for instance applied on a common market covering France and Germany and operated by EPEXspot¹². Finally, Inter-TSO Compensation (ITC) arrangements are required in Article 13 of Regulation EC 714/2009 (EU, 2009d). For instance, a mechanism is currently applied following guidelines given by a Commission Regulation (EU, 2010a).

¹¹See CASC website <http://www.casc.eu/en>, last visited February 2012.

¹²See EPEXspot website <http://www.epexspot.com/en/>, last visited February 2012.

Example of systematic evaluation and results for the sample of options. Four categories are proposed below to rate key features of an integration process with reference to the requirement of a target model.

- **Applied** means that the current situation is answering the requirement;
- **Partially applied** means that the requirement is either not fulfilled in some parts of the CWE region or that foreseeable potential of improvement remains;
- **Application scheduled** means that the requirement is not yet fulfilled but important efforts are made to improve the situation with a fixed schedule;
- **Not applied** means that the requirement is not fulfilled and there is no project under implementation.

The illustrative results within the CWE region for a sample of options are summarized in the following table.

Module	Potential target model	State
A.2	Flow-based methods	Application scheduled
B.2.1	Explicit auction	Applied
B.2.2	Implicit auction	Applied
B.2.3	Implicit allocation	Partially applied
D.1	ITC	Applied

TABLE III.1: Elements of a progress report table of the integration process in the Central West Europe region, with reference to a potential target model. The codes correspond to the summary in table II.4 from chapter II describing the modules.

Use and inherent limits of this tool. A progress report table can be adequate to evaluate the distance to a target model as illustrated in the example above. It appears on this short selection that the CWE region benefits not only from its efficient day-ahead market coupling but also from other key mechanisms already applied or under implementation. When a future target model shall be more precisely defined, the analysis could later be performed with a more complete sample of options, over several regions or borders between regions.

In practice, many aspects of the integration process are subject to a continuous improvement. Therefore, in these cases it may be difficult to define exact states of the

integration and to schedule precise objectives. Due to this limit, a progress report table may be only focusing on part of the improvement of the cross-border coordination of operation.

III.2 Aggregated costs of the current process

The first section on the aggregated gross benefits is meaningless without an evaluation of the aggregated costs or a proof that these costs could be neglected compared to the gross benefits. Thus this second section focuses on the costs. More precisely, this section intends to evaluate if in addition to the implementation costs of a new coordination arrangement in a narrow sense, the evaluation should include a broader perspective because the negotiation costs and the research costs upstream of the improvement process would be sensible. Indeed, [Coase \(1960\)](#) warns that the negotiation and transaction costs may be far from negligible and the evaluation is placed under this fundamental principle of the neo-institutional perspective.

To this aim, it gathers pieces of an incomplete puzzle of the global cost of the process to improve the coordination of operation in Europe as in 2012. Section [III.2.1](#) describes the assumptions made to build an estimation of the global costs from the partial set of public figures. Then the estimation is detailed in section [III.2.2](#). Given the inherent limits of the exercise, the outputs of this work are orders of magnitude rather than precise numbers. This level of precision is sufficient to compare the findings with other orders of magnitude of an integration process. Therefore, when estimation are proposed, the relevant information is not the exact figure but the number of its digits. To conclude this section, the results are summarized and compared with other orders of magnitude of the integration process costs and benefits in section [III.2.3](#).

III.2.1 Scope of the costs observed and general assumptions for the calculations

In order to add comparable costs, the scope for empirical observation is bounded in term of geographical space, of the time period considered and of the function considered. The geographical scope is defined as the CWE region¹³ including its external borders. This region has been selected for a combination of reasons. First of all it represents 1300 TWh of annual net generation out of the European 3300 TWh of annual load in 2011 ([ENTSO-E, 2012c](#)), which is about 40%. Then some data are already publicly available. Finally, the coordination mechanism currently used in the CWE region are

¹³This region covers Belgium, France, Germany, the Luxembourg and the Netherlands.

representative of the solutions applied or discussed in many other European regions. When a figure is only available at the scale of the European Union (EU) or at the scale of the European Network of Transmission System Operators for Electricity (ENTSO-E), then some assumptions are necessary to convert figures from this enlarged scope into costs for the CWE region when it is deemed relevant. The solution used is a pro-rata based on the annual load, i.e. a 0.4 ratio is applied. The time scope focuses on figures around 2012. Some relevant figures from an enlarged scope of realized and planned costs between 2008 and 2015 are used. Given the expected precision of the result, no actualization is performed. The functional scope includes the coordination of operation with the modules described in chapter II. The detail of the costs observed is given in the next section.

In practice, two figures are given. First a low estimation is built based on observed costs. Second, pessimistic assumptions are made in order to produce an high estimation of the order of magnitude of the costs. Without additional information, this high estimation is simply taken at twice the observed costs.

Last, the integration process is still going on as in 2012 and many costs of this process cannot be forecasted because decisions are not settled. Moreover, it may be more adequate to see the improvement of the coordination as a continuous process for at least the next decade. Therefore the improvement such as negotiation on standards, research and implementation of new software tools are evaluated as average values per year rather than total costs.

III.2.2 Empirical observations

The aim is to evaluate the annual aggregated cost for the CWE region. The costs observed are logically separated in two sets: (a) implementation costs of new arrangements for an improved cross-border coordination of operation; and (b) variation of the operational costs.

(a) Implementation costs observed or foreseeable

The analysis of the implementation costs with a broad meaning covers the costs of significant research programs favoring innovation and common learning, the negotiation

costs, the implementation costs in a narrow sense and the analysis of an early failure.

Common learning and research between TSOs. Many TSO activities require a high technical expertise and, in practice, different solutions have been developed by various TSOs. In this context, research for further software integration serves at least two purposes. It shall result in innovative coordination tools and it helps foster common learning between TSOs for further coordination.

The European Community Research and Development Information Service (CORDIS)¹⁴ offers an interesting overview of significant research projects described in section IV.2.3 on EU action supporting cross-border research projects. For instance, the PEGASE project “objectives are to define the most appropriate state estimation, optimization and simulation frameworks, their performance and dataflow requirements to achieve an integrated security analysis and control of the European transmission network”. The total cost from 2008 to 2012 was forecasted 13,6 M€. Another example would be the OPTIMATE project with a total cost of 4,2 M€ between 2009 and 2012. Thus, as an estimation, 20 M€ would be a minimum as regards to research costs over the 2008-2012 period.

It is also possible to look at planned research projects to check if the same order of magnitude appears. In particular, the ENTSO-E Research and Development plan for 2010-2020 (ENTSO-E, 2011b) provides interesting aggregated figures. However, it is difficult to distinguish the share of funds that would support further software integration from other issues, given that many projects serve multiple objectives. A relevant set of projects untitled “operational tools to make the pan-European system more secure” is associated to a total planned cost of about 75 million euros for the coming decade at the European level. This figure represents 10% of the total cost of research involving TSOs at the European level.

Based on these observations 7,5 M€/year appears as a reasonable evaluation of the research costs dedicated to the software integration module at the European level. For the CWE region the estimated cost is thus 3 M€/year applying a simple ratio based on the annual load. The high estimation of the research costs is taken as twice this amount.

¹⁴See website http://cordis.europa.eu/home_en.html.

Negotiation for further integration. To evaluate this cost, the calculation is first restricted on the ACER and ENTSO-E work for the Framework Guidelines (FGs) and Network Codes (NCs)¹⁵. It is only the emerged part of a large iceberg and a share of the immersed part is extrapolated to TSOs and NRAs with rough assumptions.

ACER annual budget for 2012 is about 7 M€/year (ACER administrative board, 2011). Since the Agency is working on electricity and gas, the starting point is only half of this amount for electricity. Then, the workforce is also working on the coordination on investment. Thus, with a simple assumption, half of the amount is again out of the scope and one fourth of the ACER budget is left, 1,75 M€/year. On the other hand, many NRA resources are involved in a way or another. This last contribution is very difficult to assess because the case of each country is different. Nevertheless, the total cost including NRAs involvement shall be evaluated somewhere between 4 and ten times this amount, between 7 and 17.5 M€/year. This is a very rough estimation is inspired by the staff and tasks of national NRAs. For ENTSO-E, the total budget was 11,2 M€/year for 2012¹⁶. According to the working program of the association for 2012 (ENTSO-E, 2011a), about less than half of this budget is related to the negotiation process on the cross-border coordination of operation, *i.e.* about 5 M€/year. Including the contribution from TSO experts, the global TSO involvement is roughly assumed to be between four to ten times this amount. The corresponding cost for the CWE region is thus estimated between 20 and 50 M€/year. Therefore, restricted to the CWE region with a ratio of 40%, the negotiation costs are estimated between 11 and 28 M€/year for the TSOs and energy regulatory authorities.

In addition, the European Commission is also actively supporting the negotiation process while the other actors including market participants are involved in public consultations and stakeholders meetings. Their contribution is even harder to identify for two reasons. First, it is not common for private actors to publicly describe their investment in a negotiation process. Second, the staff involved is often given a wider task than the cross-border coordination of operation. It is then difficult to identify the costs dedicated to this negotiation process.

¹⁵These two terms cover a common process, which aims at fostering new consensus and agreements on the functioning of the European internal electricity market as described in section IV.2.2.

¹⁶According to the ENTSO-E membership contribution. The figure can be found on some TSO websites such as www.regagen.co.me/02.04.2012.CGES12%20CLANARINE%20ENTSOE%202012.pdf, last visited January 2013. The amount was only 8,2 M€/year for 2011.

In this fog, it is not possible to have confidence in one figure rather than another. Nevertheless, a large spectrum can be defined with low and high estimations fixed at 15 and 60 M€/year for all actors. To give an idea of what it represents, with an arbitrary cost of 200 k€/year per expert involved full time, the high boundary would be equivalent to 300 peoples working full time on tasks related to the negotiation process in the CWE region.

Implementation of new mechanisms. The following observations include the costs for TSOs and the market operators (PXs) involved. In practice, an improvement of the coordination can involve a reorganization and investments in information technology (hereinafter IT in the quotes of this paragraph) when software tools are developed. The observations include the following five examples. The budget of the evaluation toward market coupling using a FB method in the CWE region is publicly available. Its cost is 33 million euros (CWE, 2008b) shared by TSOs and PXs. Concerning a common price coupling over a larger region including the CWE and Nordic region, “a preliminary budget of combined NWE PX costs of 11.1 M€ has been presented” (ACER, 2012c). For an ID implicit allocation mechanism, “IT development cost rough estimate is 1.4 - 2 M€ (excluding implementation project PX+TSO expenses [...])” (ACER and AESAG, 2012c). Another much lighter project is a module of balancing coordination aiming at netting imbalances operated by a Grid Control Center (GCC) between German TSOs. Its implementation cost is evaluated at most at 1 or 2 M€ in IT (Technische Universität Dortmund and E-Bridge, 2009). Concerning the LT time horizon, the IT costs related to the extension of the CASC for explicit auctions on Italian borders was estimated to reach 0.3 M€ (RTE et al., 2010).

Among these few public figures, the first one is the highest. It started in 2008 and the process is still going on for the FB method full implementation. Thus, an estimation of the annual cost figure is one sixth, *i.e.* 5,5 M€/year, for this project. Assuming that major project such as this one would not be more costly, 10 M€/year can be used as a low estimation of the costs to implement new coordination arrangements in the CWE region during the year 2012. The high estimation is fixed as twice the low one, 20 M€/year.

Moreover, the implementations of the single price coupling over the Nordic and CWE regions as well as the CASC extension to Italy show that once an organization is in

place and a software tool has been developed, the extension appears less costly than the original project. These observations support that the costs should not rise for cross-border coordination extension in the current European zonal organization without a change of paradigm in the integration process or area internal organization.

A complete impact assessment would also include the transition costs for market participants when it impacts their practice. However, this additional cost is only qualitatively mentioned due to a lack of available empirical observation. Besides, concerning also the impact on market players, the implementation of new arrangements should be announced as much in advance as possible to be integrated into LT product prices before they are allocated by TSOs.

Cost of an early failure of a new mechanism. A new mechanism can encounter early failures due to misconceptions that shall be corrected after the implementation. Indeed, error is part of the innovation process. Besides, in the trade-off between maximizing the quality and minimizing the implementation costs, some malfunctions with reasonable consequences can be acceptable.

So far, a significant event of this kind took place in March 2011, the 27th with an impact on the next day prices (CWE, 2011a). A day-ahead coupling arrangement had a bug when confronted with a seasonal time change. The failure of the implicit market coupling mechanism to provide consistent results lead to a full decoupling and the activation of an alternative explicit mechanism.

The most visible impact had been a high price of 2999 €/MWh¹⁷ during one hour in the DA market in Belgium observed together with a non-efficient use of the interconnection around Belgium. The event had been studied for instance by the Belgian regulatory authority CREG (2011). Their report highlights how the failure has disorganized the production in Belgium. It also points that there was enough resources to avoid the peak price. Thus, to a certain extent, this impact is as much related to a problem of internal area organization of the DA market¹⁸ than to the cross-border failure.

¹⁷This value can be explained by the price cap of the DA market which is 3000 €/MWh.

¹⁸Without entering into the details, the study suggest for instance that the use of additional sophisticated products on the DA market in Belgium could have ensured that the available generation capacity would have been optimally used and the peak price might have been avoided (CREG, 2011).

In addition, over the 24 hours of the day without a proper market coupling, some capacities have been unused. Based on public data for the spot prices and unused ATCs, it would be possible to apply the principle of the indicator described by [Meeus \(2011a\)](#). This indicator, defined as the product of the resulting spread times the unused capacity, developed to evaluate the potential social surplus gain, can also be used to offer an upper boundary of the missed gain due to the early failure. However, in this case the results are not meaningful because the peak price in Belgium described above gives an artificially large number. Without this hour, the figures may reach a few million Euros for the high estimation.

To sum up, the impact of this early failure is very difficult to evaluate but the few insight on this impact do not appear relevant compared to the previous order or magnitude of other costs related to the improvement of the system. Moreover, the alternative explicit mechanism to allocate cross-border capacities could be used more efficiently in the future since market participant are more aware of its existence after this event. Thus future malfunctions may have lower consequences. Besides, if it is estimated that the system short term security of supply was put at risk, then a probabilistic study would be required to assess the additional risk of a blackout and its cost.

(b) Evolution of the operational costs

The implementation of new coordination arrangements may result in a permanent variation of operational costs for various actors of the power system. A simple analysis consist in evaluating this variation of costs modules by modules as defined in the functional analysis of section II. Among them, the analysis identifies that further coordination may generate additional variable costs for the coordinated security assessment. Other functions may see their variable costs decrease in comparison with a 2012 reference situation.

Additional resources for coordinated security assessment. Further integration allowing additional cross-border flows may require additional work on the European system security, including congestion management methods. New common service providers

such as CORESO¹⁹ have been jointly developed by TSOs to contribute to this mission. This entity has total incomes of 3,5 M€ for its services (Coreso, 2011) over an area that may be comparable with the CWE region. Taking into account a potential development of these activities if the global coordination is reinforced, the variable costs increase is estimated between zero and 10 M€/year.

No additional variable cost for the other coordination modules. As illustrated in the following example, many coordination arrangements do not cause a sensible evolution of the variable costs of the global coordination. In case implicit allocation mechanism is used for ID as proposed in the NC CACM solution (ENTSO-E, 2012n), there are no additional direct variable costs compared to a situation without cross-border allocation. Indeed, power exchange already exists and already has to run a matching algorithms. For allocation mechanisms involving explicit auction like long term capacities and fall back modes, CASC offer an example of centralized trading platform. This entity has reduced redundancies and the creation of such common mechanism can thus be expected to reduce the operational costs.

Besides, further coordination is not expected to increase dramatically the functioning costs of the European court of justice or the European Commission role as a competition authority (EU, 2003a).

III.2.3 Summary and comparison

Summary of the costs observed at the scale of the CWE regions

As stated at the beginning of this section, given the difficulty of the exercise, the objective is to identify the number of digits rather than exact numbers. Besides, the duration of the current integration process as of 2012 is not known but the annual level of investment can be estimated based on past data and existing budget plans. Moreover, the improvement can be seen as a continuous process until the research and negotiation costs are estimated above the remaining benefits to be carried on. Therefore the initial costs are displayed with a annual average estimation at the current pace for the CWE

¹⁹This entity includes among its stakeholders RTE (the French Transmission System Operator, or TSO), Elia (the Belgian TSO) and 50 Hz (a German TSO linked to Elia) as well as Terna (the Italian TSO) and National Grid (SO over Great Britain). See Coreso website <http://www.coreso.eu>, last visited December 2011.

region including its external borders with other European regions. The results are summarized in table III.2. These results lack at least two kinds of costs. The adaptation

Type of costs	Category	Annual cost in M€	
		low	high
Initial costs	Research	3	6
	Negotiation	15	60
	Implementation	10	20
Variation of operational costs	Security assessment	0	10

TABLE III.2: Summary of the estimated annual cost of the current process toward further software integration.

costs for market participants because of the lack of data and the costs of early failures which would require a more structured risk assessment than this rough approach.

Comparison with other orders of magnitude for a large European region

Additional variable costs at less than ten million euros appear below the expected gross benefits per year which add up to several tenth of million euros per year.

The resulting positive net benefit per year is of the same order of magnitude as the high estimation of the average cost invested each year in the improvement of the coordination of operation. Thus these initial costs are acceptable compared to the promising perspectives of expected benefits of the current process of improvement.

The order of magnitude of these annual initial costs appears also to be barely one hundredth of the annual investment costs in large infrastructures based on the estimation of 100 billion euros of investment in the next ten years for the ENTSO-E perimeter as stated in (ENTSO-E, 2012p).

III.3 Distribution effects between market participants

Until this point, the chapter was focused on the aggregated social surplus and common costs. However, the literature on international trade emphasizes that distribution effects within each economic zone can strongly influence the decision process and the resulting agreements (Krugman and Obstfeld, 2008). Indeed, as analyzed in political economy studies such as (Grossman and Helpman, 1994), special interest groups naturally defend themselves by trying to influence the decision process. For instance, a form of reallocation of the surplus can be agreed to partially compensate actors that would suffer a negative net surplus variation as a consequence of further market integration.

This third section shows how an impact assessment can give insights of the distributions effects. In addition, it fulfills the second objective of this chapter with orders of magnitude of the effects for an evolution of a coordination arrangement in the CWE region.

III.3.1 Principle of the effect on buyers and producers in the literature

In the impact assessments providing results about the distribution effects of an improved coordination (CWE, 2011b, Pellini, 2012, Willems and Sadowska, 2012, Consentec and Frontier Economics, 2004), a first level of detail is the distribution of surplus of each country, control area or bidding zone of an integrated power system. Then, within each country, area or zone, the studies usually consider aggregated actors being the buyers, the sellers and the shipper over the border, *i.e.* the TSOs. In practice it is difficult to go further into the details since many commercial data are not public. This level of details allows for instance to draw conclusions on a general consumer policy taking into account political economy principle (Finon and Romano, 2009, Pineau and Lefebvre, 2009).

The following paragraphs illustrate the principle of the distribution effect for a single product with (a) a graphical representation and (b) a selection of results from a study on the CWE region by Transmission System Operators (TSOs) and Power eXchanges (PXs).

(a) **Classical representation of the effect on buyers and producers and its limits**

Concerning the cross-border exchanges of electricity products on a common transmission grid, even if the market is already open to some extent, there is room for further integration with distributive impact. Figure III.2 illustrates the impact of further exchange in an exporting zone representing not only the buyers and producers but also a TSO in charge of the bidding zone. It is an adaptation of a classical graph from international trade textbooks for one good (Krugman and Obstfeld, 2008) which has been applied to describe the impact of DA cross-border exchanges (CRE, 2009).

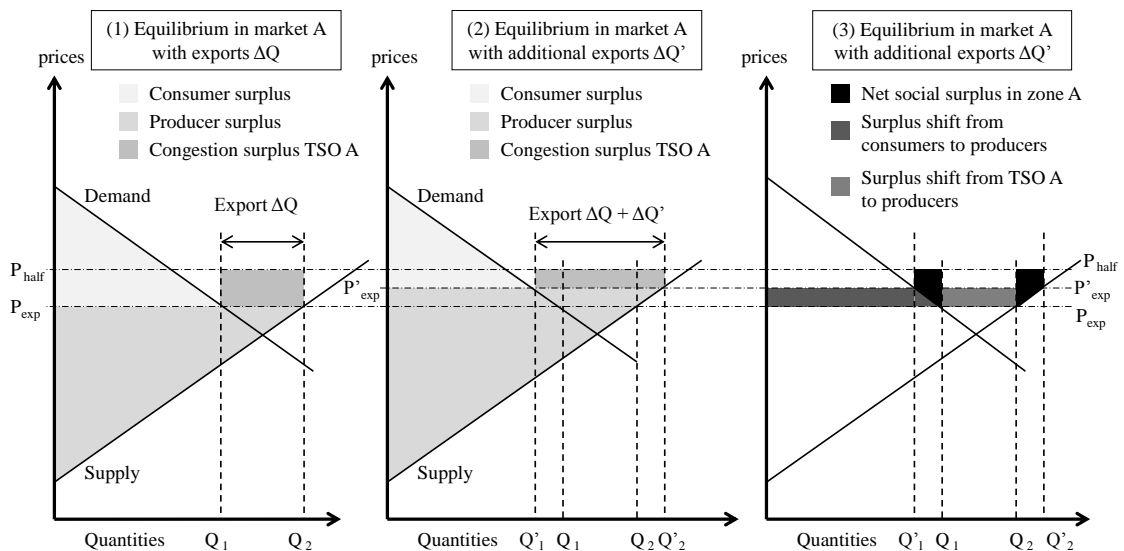


FIGURE III.2: Variation of three aggregated surpluses due to additional exchange in an exporting area. (1) and (2) display respectively the initial and modified equilibriums. To simplify the representation, the price P_{half} defining the congestion surplus of the TSO is assumed constant. (3) illustrate graphically that the net social surplus can be small compared to the surplus redistribution between actors.

This representation is based on an equilibrium model requiring many simplifications. For a start, this graph only represent the exchange of one product. Thus it neglect the complexity of a power system organization and the inherent interactions between the various products as described in section I.2 about an area internal organization. Then, the link between the demand on a wholesale market and the final power consumers depends on many features including the functioning of the retail market. For instance, if regulated tariffs protect a part of the demand, it may impact more specifically the remaining part. Thus, the change in market prices may only impact a limited share of the load. Finally, interpreting the variation of TSO congestion income is not straightforward

because it may impact the network users through the regulated tariffs or the resources available to invest on cross-border infrastructures.

Despite the limits of this model, it remains a fair illustration that there are various surplus shifts due to a modification of the quantities exchanged. Therefore the underlying model shall be used to illustrate the practice of a quantitative evaluation in section III.3.2.

(b) Sample of results from a study on the CWE region

TSOs of the CWE region have signed an official report approved by the CWE Steering Committee (CWE, 2011b). The study benefited from TSO expertise and tools to generate 2 times 2 weeks of FB constraints data allowing a comparison of ATC market coupling and FB market coupling. For the market model, the study used the CWE DA market coupling optimization solver known as COSMOS. Finally, the result are “obtained by ‘replaying’ modified historical clearings”. Therefore this study used what may be the best resources available. Besides, a parallel simulation on a longer period of ATC and FB methods shall be performed to prepare the implementation in the CWE region (ACER and AESAG, 2012b).

For the four weeks, table III.3 gathers a selection of figures about the social surplus on the DA market by countries and by buyers and producers. In these results, each country has a positive net social surplus. It appears also clearly that the redistributive effect may be higher than the net social surplus in each country.

Country	Market surplus in [k€]	Buyer surplus	Producer surplus
Belgium	46	83	-37
France	278	486	-209
Germany	195	-948	1142
The Netherlands	50	4	46

TABLE III.3: Daily average DA market surplus variation by aggregated actor in the CWE region. Aside, TSOs congestion incomes decrease by 395 k€, and the net social surplus is 174 k€ (CWE, 2011b).

III.3.2 A didactic simulation of an improved coordination between France and Germany

The following simulation is applied on a simple two-zone system for the clarity of the analysis. The aim is indeed to have an order of magnitude of the impact and one example of refined perspective. The limitation to two bidding zones allows to display a graphical representation of the model. The simulation is performed based on historical hourly values of the DA market coupling covering France and Germany between March 2011 and February 2012.

(a) Principle of the simulation.

The study on the CWE region described above required the involvement of resources which are rather reserved to TSOs and PXs. In this illustrative simulation, the aim is to use only resources publicly available for anyone.

Input and outputs. For the input, the improvement of the cross-border coordination of operation is simply modeled by an additional extra bilateral capacity allocated to the DA market coupling between France and Germany. This input is referred as $\Delta Q'$ and the results are displayed for two values: 100 and 500 MW.

The outputs are economic surplus of aggregated actors in each zone. Since the commercial data are not linked to a particular entity, the actors considered are an aggregated producer on the wholesale market, an aggregated buyer and a TSO in each zone. To some extent, if the wholesale prices are well connected to the retail market, the buyer could be assimilated to consumers and the sellers to producers. However, the wholesale market is above all an marketplace for large portfolios mixing both productions and consumptions. In addition, a 'peak producer' includes all actors selling when the price is above a certain level. The price level is referred as p_{peak} and the results are displayed for $p_{peak} = 75\text{€}/\text{MWh}$. The results for this more detail set illustrates the limits of the interpretation when there is only an aggregated result for a set of actor.

List of symbols of the model for each hour of the simulation

- ΔP the price spread between the two zones without the improvement of the cross-border coordination, in €/MWh.
- ΔQ the quantities traded between the two zones without the improvement of the cross-border coordination, in MW.
- Q_{exp} the quantities impacted in the exporting zone by the price variation in the spot market, in MW.
- Q_{imp} the quantities impacted in the importing zone by the price variation in the spot market, in MW.
- $\Delta Q'$ the additional quantities traded between the two zones with the improvement of the cross-border coordination, in MW.
- $\Delta P'_{exp}$ the absolute value of the price variation in the exporting zone in €/MWh.
- $\Delta P'_{imp}$ the absolute value of the price variation in the importing zone in €/MWh.
- p_{peak} price level defining the aggregated actor “peak producers” in €/MWh.

Model of the impact on the economic surpluses at each hour. The market model used to simulate the impact is graphically represented in figure III.3. The assumptions behind this model are driven either by a lack of data or by a simplification justified by the fact they do not have a sensible impact on the results. Three simplifications are described.

First, the supply and demand curves are assumed linear and symmetrical around a vertical axis. This assumption is acceptable for a combination of two reasons. First the linearization can be acceptable because the input is a small perturbation. Second, for a fixed total elasticity of the exporting and importing curves as described in the next paragraph, the non-symmetry would not impact sensibly the result. Indeed, it would impact only the area of the blocks referred as A and G²⁰ on figure III.3 and in the calculation of those blocks, the term Q_{exp} and Q_{imp} described below have a larger value than ΔQ and $\Delta Q'$. Second, the constraints between the 24h of a single day due to block bids are neglected. This means that each hour can be calculated independently from the others in the model. This simplification avoids the use of a complex optimization solver and it is justified because the simulation is about a small perturbation of the system. Third, the propagation of the perturbation to other markets is neglected. It is justified once more because a small perturbation is considered.

²⁰The area of the other blocks are indeed totally determined by the parameters ΔQ and ΔP , the input $\Delta Q'$ and the price variations $\Delta P'_{exp}$ and $\Delta P'_{imp}$.

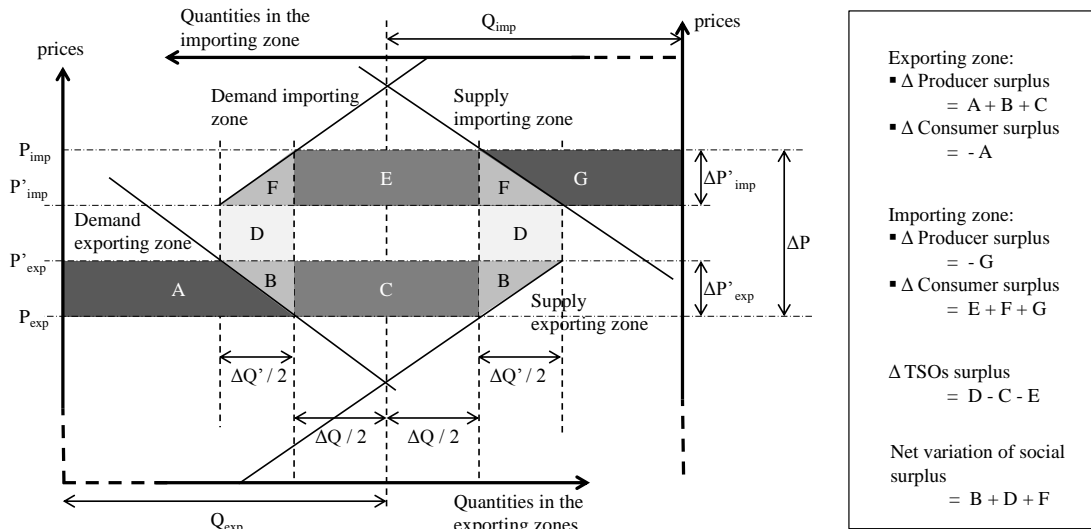


FIGURE III.3: Graphical representation of the model of the surplus variation due to additional exchange capacity between two zones. On this graph, the lower blocks referred as A, B and C are the surplus variation for the exporting zone. This lower part is a simple zoom from what is described above in figure III.2. The upper part is a similar representation for the importing zone, except that the graph has been mirrored around the vertical axis in order to be able to represent both zones with their common values such as the price spread ΔP . The description of the symbols used in the simulation are listed in this section.

Market data and related assumptions The hourly values ΔP and ΔQ are the hourly spot price spreads and bilateral commercial capacities allocated between France and Germany. These data are made public every day by EPEXspot²¹.

The quantities Q_{exp} and Q_{imp} are a rough estimation of the quantities impacted by the market. This value is at least the volume traded on the DA market which is coupled. These figures are made available by EPEXspot²¹. However, since the spot price is used as a reference price for other products, the volumes impacted may be higher. The upper boundary is the total volume delivered for the hour of delivery. These figures are made available by the TSOs. According to (ACER and CEER, 2012), the “traded volumes at power exchanges as a percentage of national demand markets” were 13% in France as in 2011 and 40% in Germany as in 2010. The percentage considered in the simulation are respectively 30 and 50% assuming that the impact is higher than the low boundary.

The price variations $\Delta P'_{imp}$ and $\Delta P'_{exp}$ are functions of the input $\Delta Q'$. It can be calculated for each hour based on the aggregated bid curves made public by EPEXspot²¹.

²¹See the webpage <https://www.epexspot.com/en/market-data>, last visited June 2012. The historical values are accessible via a subscription for the service.

(b) Results

The following tables displays the results of simulation performed based on historical hourly values of the DA market coupling covering France and Germany between March 2011 and February 2012 according to the simple model described in the previous paragraphs.

Order of magnitude of the surplus shifts Table III.4 displays the impact on aggregated actors. The result clearly show that there are winners and losers in each bidding zone. The order of magnitude of the surplus shift of each aggregated actor is of the same order of magnitude as the net benefits over both bidding zones. Moreover, the distributive effect is somewhat lessened in this couple of country because the cross-border flows during the year studied compensate each other rather well. Thus these effects are sensible.

Additional capacity [MW]	Market surplus in [M€]					
	France		Germany		TSOs	Total
	Buyer	Producer	Buyer	Producer		
100	-2.7	4.6	9.6	-8.3	1.8	5.1
500	-11.3	21.6	36.3	-28.5	5.4	23.4

TABLE III.4: Simulation of DA market surplus variation by aggregated actor in France and Germany due to an evolution of the cross-border coordination. One of the key assumption is to what extent the spot market impact other pricing processes.

Potential results from more detailed studies: example of the peak producers.

In the result, it seems the producers would end up with a positive economic surplus in France and negative one in Germany. However, as shown in table III.5, the producers selling only when the price is above 75€/MWh would see an opposite result. This can be explained with an analysis of the market data. More precisely, this can be understood by the relation between market peak prices during the year of data used in the simulation. Indeed, a study of these data shows that when the price is above 75€/MWh in Germany, the price in France is strictly lower only 10% of the time and the price in France is strictly higher 25% of the time. Reversely, when the price is above 75€/MWh in France, the price in Germany is strictly higher less than 1% of the time. Thus, an increase of the exchange capacities is likely to result in lower peak prices in France and higher peak prices in Germany and this could explain the results in table III.5.

Additional capacity [MW]	producer surplus in [M€]			
	France		Germany	
	Peak producers	All producers	Peak producers	All producers
100	-3.1	4.6	1.3	-8.3

TABLE III.5: Simulation of DA market surplus variation by aggregated actor in France and Germany due to an evolution of the cross-border coordination. The actor peak producers is defined as a subset of the producers selling only when the price is above a limit fixed at 75 €/MWh.

III.4 Chapter summary

Decision makers and stakeholders express a legitimate request for guidance to decide on an evolution of the cross-border coordination of operation. In practice, the art of impact assessment is to make the best out of limited tools and material to fulfill these potentially high expectations.

In this context, the first contribution of this chapter has been to review a panel of assessment tools that could be used to produce quantitative or systematic indicators of the impact of a new coordination arrangement or of a set of coordination arrangements. To begin with, based on the microeconomic theory applied to international trade, it is possible to simulate a gross social surplus and to evaluate some distribution effects in monetary units. To complete the analysis, the progress with reference to specific policy objectives can also be assessed with additional partial indicators. Furthermore, once a target model has been decided in an integration process, a progress report table can be build using the modular framework developed in chapter II. Besides, some costs related to the improvement process of the cross-border coordination of operation can be roughly estimated based on public data. However, these tools are globally limited by the data publicly available, the simulation methods or the ability to forecast key market drivers. Since some assumptions cannot easily be fine-tuned and challenged empirically, the quantitative results should include a full transparency about the simulation choices and sensitivity analyses. In addition, the inherent uncertainties related to a forecast of future energy trends which are strong market drivers, such as fuel prices for instance, further impede the reliability of quantitative simulations of expected impacts.

One conclusion of the analysis performed for this first objective is that quantitative indicators can be used to strengthen or challenge a position in a decision process, but it appears neither able nor meant to replace political decision-making ([European Commission, 2009](#)). In coherence with the analytical framework assuming bounded rationality, negotiation processes and platforms of discussion are a potential source of information for all stakeholders including in particular the regulators²². Indeed, these processes and platforms can potentially help to reveal how the consequences are perceived by various stakeholders.

²²The benefit of platforms of discussion has been analyzed in particular for innovative solutions by [Brousseau and Glachant \(2011\)](#).

The second contribution of this chapter has been to gather orders of magnitude of the effects of the improvement process taking place in a large European region such as the CWE region as in 2012. The results are built based on numbers identified in the existing literature or calculated in this thesis about the costs and the distribution effects. The expected annual gross social surplus generated by a switch from explicit to implicit allocation for the internal borders of a European region for the DA market has been estimated from tens to hundreds of million euros per year. Similarly, additional coordination about reserve activation could save up to several tens of million euros per year on each border between large European control areas. On the other side of the balance, it appears first that the potential increase of the variable costs of operation of the system would be lower than these figures. Second, the study of the investments related to the improvement of the cross-border coordination of operation cannot be neglected. In particular, the costs of the negotiation process to foster new agreements may add up to several tens of million euros per year at the scale of the CWE region as in 2012. Moreover, the transition costs for market participant adapting to new coordination arrangements has not been assessed in this study due to a lack of public data. Concerning the distribution effects, the analysis shows two fundamental results. First, the current improvement process is likely to generate a positive aggregated impact in each control area or bidding zone involved in the improvement of a coordination arrangement. Second, the impact on all the producers of a zone or on all the consumers of this zone may be negative. Moreover, the absolute value of the loss of social surplus for one of these two aggregated actors may be far higher than the increase of the gross social surplus.

According to the orders of magnitude identified, the improvement of the cross-border coordination of operation taking place in the CWE region as in 2012 appears promising in term of net social surplus, but it induces potentially strong distribution effects. This general picture supports that for each subtask of the modular framework of chapter II, even if technical solutions have been identified as likely to produce a positive net social surplus, some strong distribution effects may impact the decision process in the sense that some actors could oppose an evolution or ask for a compensation.

**Part 2: Two institutional
perspectives of the coordination
implementation**

The first part has analysed the solution and the methods to assess their impact. This second part enlarge the scope with two institutional perspectives on their implementation.

Chapter [IV](#) analyses the role of the EU. It is indeed the main producer of common rule and several EU initiatives aim at the improvement of the cross-border coordination of operation.

Chapter [V](#) focuses on two institutional dimensions of the coordination between TSOs. These actors are highly involved in several solutions thanks to their expertise and voluntary contribution and according to their responsibilities.

Chapter IV

The role of the European Union

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“Each man calls barbarism whatever is not his own practice.”

Michel de Montaigne¹

¹In *Essais* (1580) (translation by D. M. Frame (de Montaigne, 1958)).

Europe benefits from strong supranational institutions including in particular the European Union (EU). This chapter shall underline and analyse the key role of the EU for the cross-border coordination of operation and its improvement process.

In the modular analysis performed in chapter II, it has been introduced that surrounding common agreements are necessary to handle several kinds of cross-border externalities due to the interconnection and the cross-border exchanges between areas of an integrated power system. The first objective of this chapter is to show in section IV.1 the contribution of the EU to the good functioning of the cross-border coordination of operation in the European integrated power system. The argumentation uses some legal concepts that are either described in appendix B.3 or in legal references².

Besides, the EU also contributes to the improvement of the cross-border coordination of operation. The second objective of the chapter is to analyze how some EU initiatives with a voluntary involvement of the stakeholders have created favorable conditions for the improvement process. To this aim, section IV.2 maps and analyzes a selection of key EU initiatives as in early 2012.

²For more in-depth academic study of the legal aspects of the European energy system as in 2010, see for instance the work of Bonafé Martínez (2010) entitled *Towards a European energy policy : resources and constraints in EU law* as well as the various references given in this chapter.

IV.1 EU law contribution to the European cross-border coordination arrangements as in 2012

Section IV.1 illustrates first the need of common rules to ensure a secure, efficient and fair integrated power system. Then section IV.1.2 remind the legal ground of the EU power in a multilevel governance. The contribution of this section to the existing literature is to show how part of the EU law related to the power system regulation has a legal impact not only on the EU member states but also in several non-EU countries of Europe. Finally, section IV.1.3 emphasizes how the EU law as in 2012 supports the objective of a fair and efficient internal market for electricity.

IV.1.1 The need of common rules

The following paragraphs show with simple examples that common rules can be required over an integrated power system to ensure a secure operation, efficient price signals and fair competition.

(a) Common rules for a secure operation.

In the impact assessment of a set of Framework Guidelines, the ACER (2011c) emphasizes that:

[W]ithin a synchronous area coherent security criteria must be used; otherwise, it could lead to severe system failures or disruptions when the availability and security of a system are not matching the requirements.

Indeed, on an integrated network, a part on the system can impede the security of the others. At the extreme, a control zone of a synchronous area could act as a free rider about the frequency control and impact negatively the integrated system security level. Thus, security arrangement such as the operational handbook³ exist.

³See website <https://www.entsoe.eu/publications/system-operations-reports/operation-handbook/>, last visited in February 2013.

(b) Common rules for an efficient price signal.

The theoretical efficiency of coupling two markets over a border for a better operation over the coupled market assumed that the bid and offer prices represent comparable prices. However, many parameters can impact the bids value. For instance, a tax on the production or a tax on the consumption can impact respectively the production costs and the will to pay. As shown in the next illustrative model, any form of distortion of prices could impede the efficiency of the price signal.

The negative impact can be modeled on a simple two-node example without congestions nor losses and with a cost minimization perspective for a single period of delivery⁴. The nodes, called A and B, have cost functions C_A and C_B of the quantity produced in each node, representing comparable costs. In a simplified view, these total cost functions are convex since the market ensure that the various bids are called following a merit order between marginal costs. Let x be the production in node A and L_{tot} be the total load over the two nodes. Since there are no congestions nor losses, then the production at node B is $L_{tot} - x$ and the optimization solved by the market is simply:

$$\min_{x \in [0, L_{tot}]} C_A(x) + C_B(L_{tot} - x) \quad (\text{IV.1})$$

If the cost functions can be derived, an optimal solution x^* can be calculated from the condition:

$$\frac{dC_A}{dx}(x^*) = \frac{dC_B}{dx}(L_{tot} - x^*) \quad (\text{IV.2})$$

Let node A decide of a new regulation modifying the costs by $\Delta C_A(x)$ with $\frac{d\Delta C_A}{dx}(x) \neq 0$ for environmental reasons. Under these new conditions, the market coupling produces an outcome with $x \neq x^*$ since the condition in equation (IV.2) is modified. There is a risk that the new equilibrium does not fulfill the objective of the new regulation because the coupling arrangements compare prices that do not represent the same costs. Concerning climate policy, there is a risk of carbon leakage as defined for instance by the European Commission (EC)⁵

⁴Under perfect competition assumptions, the variable demand can be modeled as a producer and the problem is equivalent to a surplus maximization perspective. With variable demand, the total load is understood as the demand at the maximum price allowed on the market considered.

⁵See website http://ec.europa.eu/clima/policies/ets/cap/leakage/index_en.htm, last visited January 2013.

Carbon leakage is the term often used to describe the situation that may occur if, for reasons of costs related to climate policies, businesses were to transfer production to other countries which have laxer constraints on greenhouse gas emissions. This could lead to an increase in their total emissions.

Without entering into the detail of the solutions, in the absence of coordinated modification of the costs, an agreement on a form of “border adjustment” is an alternative theoretical candidate to make prices comparable ([Ismer and Neuhoff, 2007](#)).

A second example is based on the fact that the Transmission System Operator (TSO) charges on network users can be split between tariffs on load and tariffs on injection ([ENTSO-E, 2012k](#)). An increase of the share supported by producers in one node can increase both the marginal cost to produce and the marginal will to pay for energy if the variable part of the tariffs for producer is raised and the the variable part of the tariffs for consumption is reduced. Thus this modification of the costs function decided in one node can impact the outcome of the market coupling. If the impact is deemed negative by both nodes, then it can be mitigated by a coordinated evolution of both sets of TSO tariffs.

(c) Common rules for a fair competition.

One of the key example of rules for a fair competition on a coupled market is third party access to the common network and fair allocation of scarce transaction possibilities if there are congestion between bidding zones ([EU, 2009b](#)). This is supported by the regulation on TSO actions and the unbundling of TSO and production activities. More generally, there is an EU competition law actively implemented by the EC.

IV.1.2 Strength of the EU law in a multilevel governance

(a) Reminder on the EU law in a multilevel energy governance

The following paragraphs are a summary of legal principles described with more details in appendix B.3.

To sum up, the EU law has a sovereignty over member states law granted by international treaties (EU, 2010d) as well as case law and it is limited by the principles of conferral, subsidiarity and proportionality. The frontier of the EU power are partly structured by the definition of exclusive and shared competences in articles 3 and 4 the Treaty on the Functioning of the European Union (TFEU) (EU, 2010d). In particular, “the establishing of the competition rules necessary for the functioning of the internal market” is an exclusive competence of the EU. Several other areas of competences related to the liberalized power system regulation are shared competences such as energy, trans-European networks, internal market and environment.

The energy chapter of the TFEU with the article 194, which can be found in appendix B.3.1, has been added to the EU treaties by what is known as the Lisbon Treaty in 2009. In practice, the EU has influenced the energy sector and in particular power systems long before this last treaty. (Delvaux and Guimaraes-Purokoski, 2008) show how the EU has found legal ground on cross topic competences. The competition rules have in particular shaped several aspect of the European integrated power system as in 2012.

These competences can be used in particular to produce common public binding rules under the form of EU law. More precisely, the EU institutions can draft, submit for approbation to the representatives of the member states and European citizen and enforce the EU law. For instance, the Court of justice offer a well-established arbitrage court for several cross-border issues and the control of the EU powers. Besides, the European Commission (EC) is given the legislative initiative and some agenda setting powers that are used to push for the emergence of new agreements as described in section IV.2.

(b) EU law and non-EU European countries

Norway and Switzerland are not members of the EU. Nevertheless, thanks to their generation mix including large storage capacities through hydroelectricity, it is in the interest of these countries and the EU to work together on the integration of their power systems in the single European electricity market. In addition, a regional integration process involving the EU has been launched with several countries from the South East European (SEE) region.

Norway has been member of the European Economic Area (EEA) since 1993. The EEA is based on an agreement (EU, 1994) allowing some non-member countries to participate in the EU's single market. According to this agreement, Norway has to copy in its own legislation all pieces of legislation with the mention "Text with EEA relevance" as it is the case, for instance, for the texts of the third EU legislative package on energy introduced in section IV.1.3. It should concern all secondary legislation related to the single market and the environment among other topics.

The potential impact of the EU law on the coordination between Switzerland and its neighbors is less obvious due to the rejection of the EEA agreement by referendum in 1992. Nevertheless, today, the Swiss power system is *de facto* physically integrated to the formerly called UCTE synchronous area and its TSO, Swissgrid, is a member of the ENTSO-E. Moreover, the actual Energy commissioner G. Oettinger recently made a speech about the need for Switzerland to be involved in the decision process aiming at the single European electricity market⁶. Such an agreement should imply in return that Switzerland complies to some EU requirements. At least, Switzerland is member of various international treaties related to investment protection and trade as the Energy Charter Treaty for example (Energy Charter Secretariat, 1994).

Concerning the SEE region as in 2012, nine countries⁷ have contracted with the EU an international treaty establishing the Energy Community (Energy Community, 2005).

Its activities are summarized in Article 3:

⁶See the speech from (Oettinger and Commission, 2011).

⁷As summarized by Matous (2012), the first Contracting Parties of the Energy Community are: the Republic of Albania, Bosnia and Herzegovina, the Republic of Croatia, the Republic of Macedonia, the Republic of Montenegro and the Republic of Serbia, as adhering parties, and, Kosovo through the United Nations Interim Administration Mission in Kosovo (UNMIK), pursuant to the United Nations Security Council 1244. Moldova and Ukraine joined the Energy Community Treaty in 2010 and 2011.

For the purposes of Article 2, the activities of the Energy Community shall include:

(a) the implementation by the Contracting Parties of the *acquis communautaire* on energy, environment, competition and renewables, as described in Title II below⁸, adapted to both the institutional framework of the Energy Community and the specific situation of each of the Contracting Parties [...].

(b) the setting up of a specific regulatory framework permitting the efficient operation of Network Energy markets across the territories of the Contracting Parties and part of the territory of the European Community, and including the creation of a single mechanism for the cross-border transmission and/or transportation of Network Energy, and the supervision of unilateral safeguard measures [...].

(c) the creation for the Parties of a market in Network Energy without internal frontiers, including the coordination of mutual assistance in case of serious disturbance to the energy networks or external disruptions, and which may include the achievement of a common external energy trade policy [...].

Among the concrete progresses, a project groups is currently working on a coordinated auction office⁹ and the Inter-TSO Compensation (ITC) guidelines¹⁰ from the EC are to be implemented ([Permanent High Level Group of the European Community, 2012](#)). Other examples can be linked to academic studies linking additional progresses to this legal approach ([Karova, 2011](#), [Matous, 2012](#)).

Beyond the potential benefits from the regional integration, the Energy Community offers a legal framework of dispute settlement on energy issues and it is a way to prepare a future coordination with other European countries under EU law. Besides, some of these countries are candidate to the EU membership and this process is coherent with a potential future integration.

To sum up, the EU law has a legal impact not only on the EU countries but also to their close European neighbors.

⁸The *acquis communautaire* concerned by the treaty are summarized on the Energy Community webpage http://www.energy-community.org/portal/page/portal/ENC_HOME/ENERGY_COMMUNITY/Legal/EU_Legislation, last visited in February 2013.

⁹About the project, see website http://www.energy-community.org/portal/page/portal/ENC_HOME/AREAS_OF_WORK/ELECTRICITY/Regional_Market/CAO, last visited in February 2013. About the use of a coordinated auction office, see section II.1.4 about the allocation function.

¹⁰See a focus on the ITC role and the guidelines in section II.2.3.

IV.1.3 Pieces of EU law regulating the integrated power system as in early 2012

This section gathers a selection of the current EU secondary legislation supporting the good functioning of the European power system to illustrate how the existing EU law as in 2012 addresses the need of common rules shown at the beginning of this chapter. It focuses on the electricity internal market directive, the competition law, taxation issues and financial market monitoring. In addition to that, pieces of EU law on the security of electricity supply and the environmental policy are summarized in appendix B.3.3 .

(a) The electricity internal market

Directive 2009/72/EC (EU, 2009b) is the third electricity directive. It deals with various functions of the electrical system like generation, transmission, distribution, retail markets and regulation¹¹. It might not be precise enough to constitute a target model for each function, but at least it defines a first frame of common features that individual countries should not leave¹². For instance, it deals with the unbundling of TSOs as described by (Lévêque et al., 2009).

From the same EU legislative package on energy, regulation (EC) No 714/2009 introduces the ENTSO-E¹³ as well as the Network Codes (NCs)¹⁴ and addresses various issues concerning cross-border exchange like congestion management and third party access.

(b) Competition law

In a broad sense, the competition law covers both member states and undertakings. In practice, it has been used as a powerful tool to create the European internal market by opening the national markets (Scharpf, 1996). The following paragraphs describe one concept and four procedures. Concerning undertakings, the description starts with the key concept of relevant market to analyze a potential market power. Then three procedures are emphasized: the antitrust, the cartel leniency policy and the merger

¹¹Respectively in Chapter III, IV and V, VI, X and IX.

¹²See for example the (Commission, 2010) interpretative note concerning the regulatory authorities.

¹³This body is briefly described in section V.2.2.

¹⁴See section IV.2.2 on this topic.

regulation. Concerning member states, the procedure highlighted is the regulation on state aid and services of general interest.

Relevant market borders when evaluating market power. From a competition law perspective, defining the relevant market requires to find the adequate borders in at least two dimensions, the product and geographical markets. This is addressed in a Commission notice ([Commission, 1997](#)), starting from basic definitions used in EU regulations :

A relevant product market comprises all those products and/or services which are regarded as interchangeable or substitutable by the consumer, by reason of the products' characteristics, their prices and their intended use.

The relevant geographic market comprises the area in which the undertakings concerned are involved in the supply and demand of products or services, in which the conditions of competition are sufficiently homogeneous and which can be distinguished from neighboring areas because the conditions of competition are appreciably different in those area.

However, as showed in the case of Belgium by ([Dijkgraaf and Janssen, 2008](#)), the geographical borders of a wholesale electricity market are not easy to draw in a well interconnected market coupling area. This is why the conventional definition needs to be adapted. For instance the residual market indexes calculated by ([Perekhodtsev, 2008](#)) are an evolution of the classical market concentration indexes. ([Perrot-Voisard and Zachmann, 2009](#)) also “proposes an adjusted HHI taking into account wider-then-national markets as well as time varying degrees of international competitive pressure” in the case of electricity markets.

Besides, one shall keep in mind that, as often in competition law, economical measures may not be strong enough to constitute evidence in court decisions.

Antitrust: the Commission's commitment policy Council regulation 1/2003 ([EU, 2003d](#)) on rules on competition law defines a particular scheme in article 9 (1):

Where the Commission intends to adopt a decision requiring that an infringement be brought to an end and the undertakings concerned offer

commitments to meet the concerns expressed to them by the Commission in its preliminary assessment, the Commission may by decision make those commitments binding on the undertakings. Such a decision may be adopted for a specified period and shall conclude that there are no longer grounds for action by the Commission.

This allows a direct bargain between the Commission and some undertakings in order to avoid a potentially complicated and time consuming court case. Between 2003 and 2010, four commitment cases have had a sensible impact on European power systems¹⁵. Two of them are given as example of the potential impacts. Case 39-351 concerning Swedish interconnectors¹⁶, resulted in the subdivision of the Swedish transmission system into two or more bidding zones. Case 39-388 concerning the German electricity wholesale market¹⁷, resulted in E.ON divesting around 5 000 MW of its generation capacity and its extra-high voltage network. Besides, some Power eXchanges (PXs) are also under inspections that may lead to an antitrust case¹⁸.

Cartel: the leniency policy. In case the Commission suspects a cartel is infringing the EU competition law, it has in principle the right to negotiate with a member of the cartel that would help solving the case. This is explicitly written in a Commission notice ([European Commission, 2006](#)), article (8):

The Commission will grant immunity from any fine which would otherwise have been imposed to an undertaking disclosing its participation in an alleged cartel affecting the Community if that undertaking is the first to submit information and evidence which in the Commission's view will enable it to:

(a) carry out a targeted inspection in connection with the alleged cartel;

or

¹⁵Observation from a research on the Commission's website database, accessible http://ec.europa.eu/competition/elojade/isef/index.cfm?clear=1&policy_area_id=1; visited July 2011. Other cases impacted the gas sector.

¹⁶The commitments address concerns that SvK may be abusing its dominant market position in the Swedish electricity transmission market by reducing the amount of export capacity on the interconnectors between Sweden and neighboring EU and EEA member states. In addition to the legal document, see for instance the analysis proposed by [Sadowska and Willems \(2012\)](#).

¹⁷The Commission had concerns that E.ON may have withdrawn available generation capacity from the German wholesale electricity markets.

¹⁸See for instance the memo about unannounced inspections of some PXs in February 2012 available on the webpage http://europa.eu/rapid/press-release_MEMO-12-78_en.htm, last visited January 2013.

(b) find an infringement of Article 81 EC¹⁹ in connection with the alleged cartel.

Merger regulation. The Council regulation No 139/2004 (EU, 2004a) is known as the “Merger Regulation”. This piece of legislation defines first which concentrations should be monitored at the EU level using criteria like a minimum turnover within a certain geographic scope. Then it sets definitions and procedures to evaluate if concentrations that are under its scope interfere with the functioning of the internal market and if it require special measures. For instance, index like the Herfindahl-Hirschman Index described in section III.1.2 can be applied in a search for objectivity (Calkins, 1983).

Regulation of state aid and services of general interest. The general rule is that if the state aid distorts or threatens to distort competition, then it is incompatible with the internal market. However, a state aid may or shall be considered compatible under certain conditions like in the following examples. Under Article 107(2), aid having a social character granted to individual consumers and aid to make good the damage caused by natural disasters or exceptional occurrences shall be compatible with the internal market. Under Article 107(3), aid to promote the execution of an important project of common European interest or to remedy a serious disturbance in the economy of a member state and aid to facilitate the development of certain economic activities may be considered to be compatible with the internal market. Under Article 108(2), exceptional circumstances may justify that the Council, acting unanimously, decide that a specific state aid shall be considered to be compatible with the internal market. In addition to the ones mentioned in the primary law, the Council may add other categories of aid that may be compatible with the internal market on a proposal from the Commission.

According to Article 108, the Commission shall, in cooperation with member states, keep under constant review all systems of aid existing in those states. If the Commission finds that aid granted by a state or through State resources is not compatible with the internal market, or that such aid is being misused, it shall decide that the state shall abolish or alter such aid within a certain period of time. If the state concerned does not comply with this decision within the prescribed time, the Commission or any other interested State may refer the matter to the Court. For practical reasons, pieces of secondary

¹⁹This is now the article 101 of the TFEU (EU, 2010d).

legislation like the Commission Regulation referred as the General Block Exemption Regulation (EU, 2008a) addresses the compatibility of some specific aids. On a related topic, article 14 and Protocol (No 26) of the TFEU (EU, 2010d) specifically acknowledge the existence and importance of services of general interest.

(c) Tax issues.

Concerning the electricity wholesale market²⁰, there has been recently warnings against potential tax frauds in European electricity markets (ERGEG, 2010d) and this issue is on the EC agenda²¹.

(d) Financial markets monitoring, regulation and transparency.

The EU law includes several tools against market abuse²². In addition, the directive 2004/39/EC (EU, 2004b), also known as markets in financial instruments directive (MiFID), offers a frame for financial instruments regulation at the EU level. It is completed by a sector specific EU regulation on wholesale energy market integrity and transparency, also known as REMIT (EU, 2011a). From a pragmatic point of view, this distinction is to some extent related to the frontier between competencies of competition authorities and of sector specific regulatory authorities. Besides, additional transparency requirements are defined positively. For instance directive 2008/92/EC (EU, 2008b) concern a Community procedure to improve the transparency of gas and electricity prices charged to industrial end-users, involving Eurostat²³.

²⁰Several interesting issue also appears concerning the retail activities which are out of the scope of this study. For instance, irective 2003/96/EC (EU, 2003a) on the taxation of energy product introduces in article 10 “minimum levels of taxation applicable to electricity”. Moreover, the choice to classify electricity as as tangible property or not is another sensible question (EU, 2010e) from a tax point of view and the good functioning of the internal market.

²¹See the summary by the EC on the webpage http://ec.europa.eu/taxation_customs/taxation/vat/control_anti-fraud/reports/index_en.htm, last visited in December 2012.

²²See the summary by the EC on the webpage http://ec.europa.eu/internal_market/securities/abuse/index_en.htm, last visited December 2012.

²³Eurostat’s mission is to provide the EU with a high-quality statistical information service. See Eurostat webpage http://epp.eurostat.ec.europa.eu/portal/page/portal/about_eurostat/corporate/introduction, visited May 2011.

(e) Conclusion

It appears that EU competition law is rather strong in accordance with the treaty. It contrasts with several areas on which the EU law has a more limited impact such as the use of natural resources or the electricity security of supply according to additional law studies summarized in appendix [B.3.3](#).

IV.2 EU initiatives to improve the cross-border coordination of operation

This section maps the key initiatives launched by EU institutions and potentially partly supported by the EU budget for further cross-border coordination of operation. It is based on an analysis framework used in a conference paper by the author ([Janssen and Rebours, 2012b](#)) to identify initiatives for further integration. The framework is restricted to the research object and the analysis identifies initiatives: (1) to coordinate the action of sector specific energy regulators, (2) to foster new consensus on common rules, and (3) to support common research projects.

The aim is to show how the voluntary involvement of the stakeholders, encouraged by these initiatives, is a necessary step in the construction of a common understanding that is a preliminary to the emergence of new agreements. Indeed, the economic literature acknowledges more and more the role of trust and personal relations to solve common issues ([Arrow et al., 1969](#), [Janssen, 2008](#), [Ostrom, 2009, 2010](#)). Moreover, this statement appears particularly relevant in the case of the cross-border coordination of operation because it has been shown in chapter III that, according to the bounded rationality and knowledge of all actors, the decisions are made with sensible uncertainties about their impact and they can have high distributive effects, which could deter actors from investing actively in new coordination arrangements.

IV.2.1 To coordinate the action of sector specific energy regulators

The description focuses on two large initiatives launched by the EU and involving strongly the National Regulatory Authorities (NRAs): the creation of a European Agency, the Agency for the Cooperation of Energy Regulators (ACER), and the support of a regional level of coordination known as the Electricity Regional Initiatives (ERIs).

(a) The Agency for the Cooperation of Energy Regulators

The ACER has been created according to regulation 713/2009 ([EU, 2009f](#)) in order to complement and coordinate the work of NRAs. The EU institutions granted the ACER a budget of 7,3 M€ for 2012 ([ACER, 2011b](#)) along with an Administrative Board with

two members appointed by the EC, two others appointed by the European Parliament and five appointed by the Council. This Agency has been officially functioning since March 2011, taking some of the responsibilities of the European Regulators' Group for Electricity and Gas (ERGEG), for example as the Commission's formal advisory group.

The core objective of the ACER is "to assist National Energy Regulatory Authorities (NRAs) to perform their duties at European Union level and to coordinate their actions whenever necessary" (ACER, 2011b).

Without entering into the details of regulation 713/2009 (EU, 2009f), the governance of the ACER shows a control by the NRAs. More precisely, a Board of Regulators composed of representatives from the relevant NRAs ensures a strong link with the national regulatory perspectives as defined in articles 14 and 15. To complete the control of the decision process, a dedicated Board of Appeal for ACER decisions is defined in articles 18 and 19.

The following paragraphs lead to the description of the ACER work program with two preliminary steps. The first step is to show that the ACER represents a stronger involvement of the EU in the coordination between European regulators than the previous situation. The second steps introduces the legal doctrine on the European Agencies to show that such body should not be expected to be given strong binding powers.

Reminder on the ERGEG and CEER. The Council of European Energy Regulators (CEER) was founded in 2000 as a non-for-profit association of ten national regulators²⁴. It was completed by another association established officially by a Commission decision in 2003 (EU, 2003b) and known as the ERGEG. The successful but limited impact of the ERGEG has lead the Commission to propose a reinforced association with new status (Bonafé Martinez, 2010). At the end of the legislative process, this proposition became the regulation 713/2009 (EU, 2009f) defining the ACER legal ground. When the new Agency became operational, the ERGEG was dissolved by another Commission decision (EU, 2011b) with effect from 1 July 2011. In this new context, the CEER is maintained as "the voice of Europe's national regulators of electricity and gas

²⁴See EER web page http://www.energy-regulators.eu/portal/page/portal/EER_HOME/EER_ABOUT, visited July 2011.

at EU and international level” and it intends to “works closely with and supports the work of [the ACER]”²⁵.

Elements from the doctrine on European Agencies. This institutional form called European Agency has been used for instance for the EURATOM Supply Agency, the Office for Harmonization in the Internal Market (Trade Marks and Designs) and the European Environment Agency and the ACER. In the literature, the advantages of an Agency have been related to its independence, its expertise or its flexibility²⁶. However, the delegation of power to such institution is limited by its legitimacy and acceptability. First of all, as reported by (Griller and Orator, 2007), expertise is not a sufficient basis for the exercise of public authority²⁷. Then, the legal doctrine emphasizes that “[t]he Meroni principle²⁸ has stood for approaching 50 years as a constitutional limit to delegation” (Craig, 2006). Finally, (Christensen and Nielsen, 2010) found that there is little evidence of their acceptance by member countries and that there is an inverse relation between their autonomy and the power that is delegated to them. Dehousse (2008) arrived at a similar conclusion: “Given the existence of multiple principals, each with their own interests, it would have been quite surprising to witness the emergence of strong regulators”. However, the opposite view is also expressed, for example Geradin and Petit (2004) argue that independence and accountability can be combined since the control may result in greater legitimacy for the agencies.

In coherence with this doctrine, the ACER is not meant to be a powerful European regulator with binding discretionary powers. As described in the following paragraph, its promissive potential impact on the European integration process is associated to a different position in the global institutional framework.

ACER work program Its legal power is based on (EU, 2009c). According to these powers and the objectives, the ACER work program and missions for 2012 included

²⁵See EER web page http://www.energy-regulators.eu/portal/page/portal/EER_HOME, last visited in July 2011.

²⁶See for example (Smith, 1997) about independence, while expertise and flexibility are supposed to result in more efficiency than the main administration could provide

²⁷This is highlighted while studying the output legitimacy as defined by (Scharpf, 1999) about the European governance.

²⁸This principle is related to the institutional balance principle which implies that each institution has to act in accordance with the power conferred on it by the primary law as defined in article 13(2) of the TEU (EU, 2010d). Its name comes from a case ruled by the European Court of Justice in 1958, where a decision conferring true discretionary powers on an Agency, has been held unlawfully transferring responsibility (Griller and Orator, 2007).

(ACER, 2011b): the delivery of opinions and recommendations regarding actions from the European Network of Transmission System Operators for Electricity (ENTSO-E) and NRAs, some decision power related to cross-border infrastructure²⁹, the production of Framework Guidelines (FGs), an implication into the ERIs described in the next paragraphs, and a contribution to the stakeholders involvement in the public debate through public consultations for instance.

To perform this work program, the Agency can count on the NRA involvement in addition to its own EU funded resources as for instance for the production of FG.

(b) The Electricity Regional Initiatives (ERIs)

In this acronym, the term ‘regional’ refers to seven European regions displayed in figure IV.1. In practice, the term regional initiative is commonly used to refer to any new solution implemented at regional levels, but in this section, ERIs have a more precise meaning. This EU initiative is expected to create links around the NRAs at the regional level to support further integration at a regional level and *in fine* at the European level.

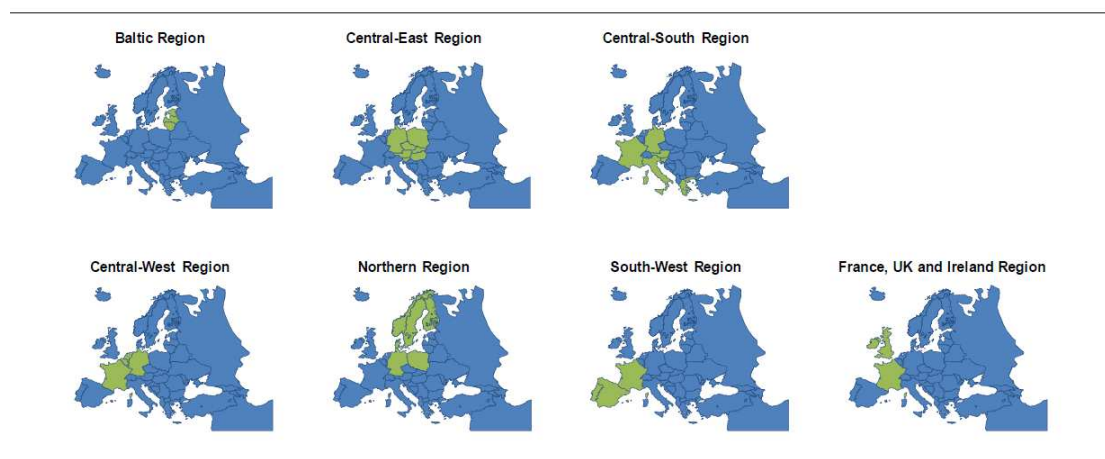


FIGURE IV.1: The seven official Electricity Regional Initiatives (ERIs) from the European Regulators' Group for Electricity and Gas (ERGEG). Source: ERGEG.

²⁹Since it is not the research object, it is not relevant to give further detail, but in practice this decision power is controlled in many ways by several actors including the EC.

Historical perspective and structure. In 2004, the EC has proposed the creation of seven informal “mini-fora”³⁰ with the same geographical area as the region of figure IV.1 to study the concrete implementation of cross-border congestion management arrangements at regional levels. This initiative was probably inspired by the success of existing regional coordination for instance in the Nordic region as described in section B.1 as well as in (Meeus et al., 2005) at about the same period. Starting from this experience, the regional level of integration has become an intermediary stepping stone in the EU strategy toward a single market (Squicciarini et al., 2010).

The official ERIs were created in 2006 in a form that heavily relies on the NRA resources with one ‘lead NRA’ per region. This object includes first of all a set of meetings and working groups producing non-binding action plans and progress reports. More precisely, three kinds of meeting are defined. The Regional Co-ordination Committees (RCC) include the NRAs and invited members such as the Commission. The Implementation Group (IG) is expected to ensure the implementation of coordination arrangement which would have been agreed. Its members are the NRAs and the actors directly involved in the implementation. The Stakeholder Group (SG) meets to exchange information with a large audience among the stakeholders.

Despite some warnings (ETSO, 2005) about a potential lack of guidance at the EU level, the ERIs were rather free to set their action plans. The first year was dedicated to the production of very ambitious work programs covering various areas from congestion management to transparency issues. The yearly progress reports produced by the ERGEG until 2010 offer an interesting perspective on the integration process. However, these reports do not show clearly if the concrete realizations observed until 2010 could be directly related to the ERI activities.

Since 2010, the functioning and efficiency of the ERIs have been questioned in public consultations launched by the ERGEG (2010c), by the European Commission (2011) and by consulting companies commissioned by the EC (Everis and Mercados EMI, 2010) and a few academics such as Squicciarini et al. (2010). At this period, the ERGEG is replaced by the ACER and the newly elected Commission intends to give a new impulsion to the integration for the completion of the internal electricity market in 2014. Following this

³⁰The term mini-forum is a reference to the European Electricity Regulatory Forum, also known as the Florence forum, described among the initiatives to foster new consensus on common rules.

period, a more humble and pragmatic direction is given to the ERIs and their work programs for the period 2011-2014 can be found on the ACER website³¹.

Elements of analysis of the ERI impact. The academic attention on the ERIs is somewhat limited by the fact that the main source of information is the ERGEG representing the NRAs. The most comprehensive and documented analysis outside of the ERGEG can be found in a report produced by [Everis and Mercados EMI \(2010\)](#)³² for the EC. Based on this report or directly on the ERGEG reports, three elements of analysis help to understand the action of the ERIs.

The official ERIs should not be confused with ‘independent’ regional initiatives that were already taking place in many parts of Europe under the impulsions of the member state governments³³. The coherence between the official ERIs and the real projects is not clear and it is thus difficult to assess the potential contribution of the ERIs beyond the production of monitoring reports.

The design of the seven regions attach both France and Germany to four different regions. This choice is not discussed in the public consultations on the creation of the ERIs. A first observation on this fact is that, given the size of France and Germany and given that they are not ‘lead regulator’, the burden to participate in four different regions appeared to have been bearable for their respective NRAs. A second observation is that, without making it explicit, France and Germany ended up as being able to ensure a connection between the regions. For instance, these regulators can ensure that the options selected in their various regions are compatible.

Several actors were not actively involved. For instance, the Stakeholder Groups have met at a very limited number of occurrences in each region³⁴. Similarly, the member states governments have not been strongly involved.

To conclude this short analysis, the ERGER ERIs supported by the EU institutions have consumed NRA resources without a clear evaluation of the benefits. Nevertheless,

³¹See webpage http://www.acer.europa.eu/Electricity/Regional_initiatives/Pages/Work-Programmes-2011-2014.aspx, last visited January 2013.

³²It is interesting to note that the first ACER Director, Mr Alberto Pototschnig, was chairman of one of the company contributing to this report.

³³As described in the last part of the historical perspective in appendix [B.1](#) many projects already existed in, for instance, the Nordic, CWE and SWE regions.

³⁴As in July 2010, five of the seventh regions had had less than 5 Stakeholder Group meetings in total.

among these benefits, it is reasonable to assume that this initiative has contributed to build a common understanding of the issues between NRAs at the regional level. Thus it prepares the regulators to answer issues that would require a coordinated regulatory action.

IV.2.2 To foster new consensus on common rules

This section shows with three examples that the EU has supported several initiatives helping to foster new consensus among stakeholders: a European Electricity Regulatory (Florence) Forum taking place regularly since 1998, a Project Coordination Group around 2009, and the Framework Guidelines FGs and Network Codes (NCs) process framed by the third legislative package voted in 2009.

In addition, the description of the FGs and NCs process is completed by an analysis of the early results as in 2012 because this ongoing process may greatly contribute to foster new consensus on common rules.

(a) European Electricity Regulatory (Florence) Forum

The first European Electricity Regulatory Forum took place in 1998 “set up and organized by [...] the European Commission in conjunction with the Robert Schuman Centre (RSC) of the European University Institute (EUI)”, located in Florence, Italy. According to its proceedings ([Florence Forum, 1998](#)), the “objective was to provide a neutral and informal EU level framework for discussion of issues and exchange of experiences concerning the implementation of the EU Electricity Directive (96/92/EC)”, i.e. the directive from the first EU legislative package on energy voted in 96. Following this first experience, 22 other forums have been held in Florence with success until 2012 and the process is likely to continue forward. They are commonly known as the Florence fora. From the start, the idea has been to let room for discussions between a large spectrum of stakeholders including the Commission, the national government representatives, the electricity industry and consumers. The documents and conclusions released after each

forum³⁵ are at the same time non-binding, valuable and rather robust pieces of information. Indeed, they display up-to-date elements of the current consensus among the participants without the inherent limits of a binding document.

The literature perspective is very positive about this kind of forum where information can be exchanged to the benefits of a common understanding and future agreements between the key stakeholder representatives. In particular, [Brousseau and Glachant \(2011\)](#) and [Eberlein \(2005\)](#) emphasize the contribution of this kind of “knowledge platform” to the regulatory process. Besides, the Florence forum conclusions are one of the important sources used by official reports studying the integration process such as ([Everis and Mercados EMI, 2010](#)).

(b) Project Coordination Group, AHAG and AESAG

As summarized in the conclusions of the 15th Florence Forum ([Florence Forum, 2008](#)):

The Forum invited ERGEG to establish a Project Coordination Group of experts, with participants from EC, Regulators, ETSO, Europex, Eurelectric and EFET, involving Member States’ representatives as appropriate, with the tasks of developing a practical and achievable model to harmonize interregional and then EU-wide coordinated congestion management, and of proposing a roadmap with concrete measures and a detailed timeframe, taking into account progress achieved in the ERGEG ERI.

This Project Coordination Group has been active and productive during the year 2009. The public documents available³⁶ on this process consists in the minutes from eight meetings and a set of slides divided in 6 blocks about capacity calculation, capacity allocation and governance issues. The form of the slides produced is very light, but the content includes most elements of target model that have been developed later in the ACER FGs. It was not binding, but it appears that the result was a consensus to a large extent approved by the regulators and the EC. In a way, the Project Coordination

³⁵These documents are made available on the EC website at the url http://ec.europa.eu/energy/gas_electricity/electricity/forum_electricity_florence_en.htm, last visited January 2013.

³⁶See the former ERGEG webpage http://www.energy-regulators.eu/portal/page/portal/EER_HOME/EER_WORKSHOP/Stakeholder%20Fora/Florence%20Fora/PCG, last visited January 2013.

Group has been a key step in a process fostering elements of a common target model for the cross-border coordination of operation in the European power system.

It is interesting to note that several European associations of stakeholders that were active members of this initiative were later part of groups that are more reactive than active in the integration process. There was the Ad Hoc Advisory Group (AHAG) which has been replaced by the ACER Electricity Stakeholder Advisory Group (AESAG). According to an ACER website³⁷, the members are the ACER, the European Commission (EC), the European Chemical Industry Council (CEFIC), the European Federation of Energy Traders (EFET), the ENTSO-E, the Union of the Electricity Industry known as EURELECTRIC, the association of European Energy Exchanges (EuroPEX) and the International Federation of Industrial Energy Consumers (IFIEC).

(c) **Framework Guidelines (FG) and Network Codes (NCs)**

The EC, ACER and ENTSO-E are lead actors in the production of binding NCs. According to the ENTSO-E³⁸, these codes “are intended as a tool to reach [the European energy] objective by complementing existing national rules to tackle cross-border issues in a systematic manner”. The main steps of a successful process, defined in article 6 of regulation 714/2009 (EU, 2009d), can be decomposed for a single topic and a single NC as represented in figure IV.2:

1. After a request has been initiated by the EC on a topic, the ACER is in charge of preparing a draft FG within 6 months.
2. Once the guidelines are deemed finished, the EC can send an official request to the ENTSO-E to draft a NC following the guidelines. Starting from this official date, the ENTSO-E has 12 months to submit a draft version.
3. After the submission of the final draft NC, the ACER shall deliver an official opinion within 3 months. Depending on the ACER’s opinion, the ENTSO-E can be invited to amend its first proposal and re-submit it to the Agency. Once the

³⁷See webpage http://acernet.acer.europa.eu/portal/page/portal/ACER_HOME/Stakeholder_involvement/AESAG, last visited in January 2013. From this page, the ACER also provides further information on the AESAG.

³⁸See webpage <https://www.entsoe.eu/major-projects/network-code-development/>, last visited March 2013.

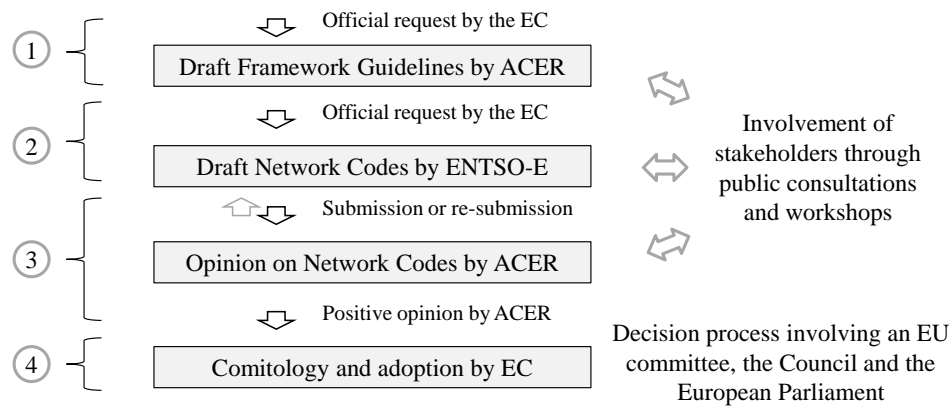


FIGURE IV.2: Representation of a successful Network Code process from the initial request to the final adoption by the EC. The steps one to four correspond to the description of the process in section (c).

ACER is satisfied that the NC is in line with the relevant framework guideline, the Agency shall submit the network code to the EC and may recommend that it be adopted within a reasonable time period.

4. The last step before a NC adoption is its submission to the comitology process by the EC as introduced in appendix B.3.2. If this last step involving an EU committee, the Council and the European Parliament is successful, then the NC can be adopted by the EC and it becomes a binding part of regulation 714/2009.

All along the process, these lead actors are to organize public consultations, workshop and to produce documents ensuring the quality of the stakeholder's involvement in the decision process before the text becomes binding. In addition to these core steps, there are alternative paths at various stages. For instance, article 6(10) of regulation 714/2009 states that:

Where the ENTSO for Electricity has failed to develop a network code within the period of time set by the Commission under paragraph 6, the Commission may request the Agency to prepare a draft network code on the basis of the relevant framework guideline. The Agency may launch a further consultation in the course of preparing a draft network code under this paragraph. The Agency shall submit a draft network code prepared under this paragraph to the Commission and may recommend that it be adopted.

Table IV.1 gives a list of the Network Codes whose drafting process has been started or is to be started before the end of 2013 and the related Framework Guidelines. In addition, table IV.2 gives more details on the progress of the drafting process for the NCs as seen by the ENTSO-E. The news concerning the progress concerning these network codes are gathered on the ENTSO-E website³⁹. More generally, for a global updates on FG, NC and additional EC comitology guidelines, see the updated version of the “3-year work plan ELECTRICITY”⁴⁰.

Framework Guidelines on	Network Code on	Acronym
CACM	Capacity Allocation and Congestion Management	CACM
	Forward Capacity Allocation	FCA
Balancing	Electricity Balancing	EB or BAL
Grid Connection	Requirements for Generators	RfG
	Demand Connection	DCC
	HVDC Connection	HVDC
System Operation	Operational Security	OS
	Operational Planning & Scheduling	OPS
	Load Frequency Control & Reserves	LFCR

TABLE IV.1: List of the Network Codes whose drafting process has been started or is to be started before the end of 2013 and the related Framework Guidelines. Source: (European Commission et al., 2012). Please note that this list is not comprehensive.

Year NC \ Q	2011				2012				2013				2014			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
CACM			I	-	-	-	F	O								
FCA								I	-	-	F	O				
EB								I	-	-	F	O				
RfG			I	-	-	F	O	*								
DCC					I	-	-	F	O							
HVDC									I	-	-	F	O			
OS					I	-	-	-	F	O						
OPS						I	-	-	F	O						
LFCR							I	-	-	F	O					

TABLE IV.2: Progress planned and confirmed as in January 2013 for the Network Code (NC) designed by their acronym summarized in table IV.1. Q stands for quarter of the year. I stands for official invitation to draft the network codes. F stands for first version of the final draft submitted to ACER evaluation. O stands for the release of ACER opinion on the first final draft. (*) marks that the NC has not been fully approved by the ACER yet. Source: (European Commission et al., 2012), confirmed by the ENTSO-E website as in January 2013⁴⁰.

³⁹See website <https://www.entsoe.eu/major-projects/network-code-development/latest-updates-milestones/>, last visited March 2013.

⁴⁰Available at the EC webpage http://ec.europa.eu/energy/gas_electricity/codes/codes_en.htm, last visited January 2013.

As in January 2013, no NC has become binding. Thus, it is not possible at this stage to observe the consequences. Nevertheless, the early analysis of the draft versions as in 2012 already offers the four following observations.

First of all, this process pushes a large panel of stakeholders to take public positions which can be found in public consultation responses. For instance, the FG proposal on Capacity Allocation and Congestion Management (CACM) (ACER, 2011e) has generated thirty public consultation responses, including only two confidential responses, gathered in (ACER, 2011a) and public positions expressed within the AESAG (ACER and AESAG, 2011a). Thus, it succeeds to pave the way toward new consensus and agreements because all stakeholders are invited to answer public consultations and more generally to take positions in the debate. For further study, at more advance stages of the process, an in-depth study of the various version of the FGs and NCs could reveal how the involvement of the stakeholder has had an impact.

Concerning the content, the first drafts appear globally in line with the current handbooks used in the UCTE region⁴¹. It is indeed not surprising that the new codes rely on years of successful past experience and that these new codes ensure a smooth transition from current practices.

Concerning the allocation of responsibilities, the NC on CACM use a functional approach. The text defines a series of functions and specifies the rights and obligations which the entity performing the function must meet but it does not link explicitly the functions to a real entity. The member states are to determine which entity is in charge of each function. This approach is justified by the observation that “in different parts of Europe different parties perform different roles” (ENTSO-E, 2012f). Other NCs do not use this approach.

Similarly, on several occasions, the draft NCs takes into account that many details of the rules can evolve by defining procedures and framework to fix the parameters rather than the parameters themselves. For instance, the NC on CACM uses the term ‘market time period’⁴² to refer to the time resolution for the delivery of energy without defining its precise value. A benefit of this approach is that, even if the binding form of the document is to some extent flexible, *i.e.* they can be changed through adequate EU

⁴¹Those documents are available at the webpage <https://www.entsoe.eu/publications/system-operations-reports/operation-handbook/>, last visited January 2013.

⁴²See the focus on this topic in section II.1.3.

procedures, the cost and duration of the amendment process could have become an unnecessary hindrance to future evolutions.

IV.2.3 To support research projects

The EU can support research favoring an improvement of the cross-border coordination under what is called the Seventh Framework Programme (FP7) according to decision No 1982/2006/EC (EU, 2006b). In particular, the design of the support scheme for so-called “Cooperation” activities support the diffusion of a common knowledge which can prepare the field for further coordination. Indeed, it is requested that actors from several countries are involved in each project. Moreover, the dissemination and transfer of knowledge are encouraged.

The description focuses on four projects involving Transmission System Operators (TSOs): PEGASE, OPTIMATE, UMBRELLA and iTESLA. Their objectives and funding are made available by the European Community Research and Development Information Service (CORDIS)⁴³.

PEGASE stands for Pan European grid advanced simulation and state estimation and its “overall objectives are to define the most appropriate state estimation, optimization and simulation frameworks, their performance and dataflow requirements to achieve an integrated security analysis and control of the European transmission network”. This project has involved 22 partners from 13 countries including 9 TSOs (in charge of control zones in Belgium, Croatia, France, Germany, Lithuania, Portugal, Romania, the Russian federation, Spain and Turkey). The EU has been financing 8,6 M€ out of a total cost of 13,6 M€ between 2008 and 2012 and the results are displayed on a dedicated website⁴⁴.

OPTIMATE is an “Open Platform to Test Integration in new MARkeT DEsigns” of massive intermittent energy sources dispersed in several regional power markets. This project is supporting the impact assessment of some market design options, including cross-border coordination options, at the DA, ID and Balancing time horizons. It involves 5 TSOs (from Belgium, France, Germany and Spain) as well as 6 Research providers specialized in market design and modeling and one company dedicated to innovation management and related dissemination activities in the power sector. The EU

⁴³See webpage http://cordis.europa.eu/home_en.html, last visited January 2012.

⁴⁴See website <http://www.fp7-pegase.com/index.php>, last visited in June 2012.

has been financing 2,6 M€ out of a total cost of 4,2 M€ between 2009 and 2012 and the results are displayed on a dedicated website⁴⁵.

UMBRELLA and iTESLA share a common “Subprogramme Area”: “Innovative tools for the future coordinated and stable operation of the pan-European electricity transmission system”. The iTESLA project is coordinated by RTE, gathering 6 TSOs (Belgium, France, Greece, Norway, Portugal and United Kingdom), CORESO and a pool of 13 R&D providers. The Umbrella project involves 9 TSOs (from Austria, Czech Republic, Germany, Netherlands, Poland, Slovenia, and Switzerland), 5 universities and 1 research institute. The EU has accepted to support financially both programs starting from 2012. For iTESLA, it is indicated that the EU support would be 13,2 M€ out of a total cost of 19,4 M€. For UMBRELLA, the figures are respectively 3,8 M€ and 5,2 M€. A form of competition may appear between the two programs. If it is the case, it is hoped that the competition does not impede the coordination between all TSOS or the diffusion of the best practices to the whole Europe. As briefly mentioned in a presentation from the iTELSA project⁴⁶, the two projects and the EC have signed a Memorandum of Understanding ensuring that the two projects would share some data for pan-European simulations of their tools.

IV.2.4 Global perspective on these initiatives’ contribution to foster new agreements

Beyond their direct objectives, these EU initiatives share a common long term benefits. Indeed, many of these initiatives use the power of the agenda and more generally soft power (Schäfer, 2006, Brousseau and Glachant, 2011) or financial support to put actors around a common table in a rather voluntary way. This concrete fact can be expected to have positive consequences because being “face to face” and knowing each other favor the success of negotiations about common pool resources, as supported for instance by Arrow et al. (1969), Ostrom (2010). The potential impact of these factors on cooperation has been identified in several experimental games (Roth and Kagel, 1995), including those when actors can withdraw from the negotiation (Janssen, 2008) which correspond to the situation where the *statu quo* is a possible output. From a theoretical point of view, the

⁴⁵See website <http://www.optimize-platform.eu/>, last visited in January 2013.

⁴⁶Available at the url www.e-umbrella.eu/download/39, last visited January 2013.

potential benefits of these voluntary initiatives are based on the assumption expressed by [Ostrom \(2009\)](#):

Sufficient research now supports an assumption that humans may endogenously adopt norms of trustworthiness and reciprocity in contexts where there is a higher probability that they share a common future, their actions are known or reported to others, and cooperative actions do lead to increased payoffs.

The mapping and analysis of key EU initiatives has shown how rather non-binding powers are used to this aim. All the initiatives stimulate the stakeholders' involvement in public debates under various forms. To begin with, public consultations and workshops are open to all actors. However, the exchanges between large numbers of individuals have obviously some drawbacks. To favor exchanges between a smaller group of representatives, some meetings such as the AESAG meetings gathers a reasonably small number of representatives from large associations. The creation of the ERIs is also an acknowledgement that a regional approach may be a stepping stone for wider agreements. Besides, the TSOs are given a central role in several initiatives such as the NC drafting process, which is coherent with their central role in the solutions for the cross-border coordination of operation described in [chapter II](#). Furthermore, the support of research project between TSOs can be expected to favor common learning and the exchange of good practices in addition to the innovation process.

It is also interesting to note that the EU does not often offer direct financial support to implement new arrangements once they have been technically developed and agreed. This result is coherent with the observation made in [section III.2](#) that these kinds of implementation costs are rather low compared to others. Thus, they should not limit the improvement of the cross-border coordination of operation.

In addition, the simple mapping of the EU initiatives performed in this section⁴⁷ offers a framework and empirical material to: (a) study the global coherence of these initiatives, (b) compare integration policies across various regions beyond Europe, and (c) analyze the evolution of European policy over the years.

⁴⁷Based on ([Janssen and Rebours, 2012b](#)).

IV.3 Chapter summary

The first objective of the chapter has been to emphasize the role of the EU law for the cross-border coordination of operation. Three kinds of examples have shown that common rules are necessary to handle cross-border externalities within an integrated power system. First common rules can ensure the secure operation of the system for instance by preventing that one control area impede the security of a shared synchronous area by acting as a free-rider. Then, common rules ensure that the economic price signals are efficient. Indeed, the comparison of prices resulting from different regulations can send wrong signals across borders from a social welfare maximization point of view. Finally, in the European liberalized markets, common rules are necessary for a fair competition between market participants on the common markets.

It has then been reminded why the EU law produced and enforced by EU institutions can be an adequate legal form for common public rules. Indeed, the EU law prevails over most of the European continent and its legitimacy is ensured by international treaties. Concerning the countries which are not in the EU, the analysis has shown that Norway is committed to enforce the EU law related to the common market. Similarly, several non-EU countries from South-East Europe have signed an international treaty concerning the implementation of the “*acquis communautaire*” on energy, i.e. a subset of the EU law on the topic. Meanwhile the relation with Switzerland, a country of the heart of the European power system, is yet under negotiation as in 2012. Concerning the area of competences of the EU institutions, the analysis highlights that the EU action is legitimate for many aspects of the cross-border coordination of operation. Besides, a focus on the EC shows that behind the EU law, there are other means of actions for the EU including the use of the so-called soft power.

As of 2012, the EU law includes several surrounding agreements supporting the good functioning of the integrated power system. The analysis shows that there is a strong EU competition law in accordance with the treaty while the EU law has a more limited impact on other aspects such as the use of natural resources or the electricity security of supply.

The second objective was to show how the EU institutions are supporting several initiatives to foster new consensus, common decisions and common knowledge among TSOs.

These initiatives provide additional occasions for actors to meet across borders, to work together and to express their differences. This should favor the negotiation process aiming at improving the cross-border coordination of operation.

To conclude, the European integrated power system clearly benefits from the EU supporting existing cross-border coordination arrangements and their improvement process. If the EU institutions are assumed to be necessary conditions to the promising process taking place in the CWE region, then by contraposition the lack of strong supranational institutions would impede the implementation of a successful cross-border coordination of operation in other integrated power system around the world.

Chapter V

Two dimensions of the institutional organization of the coordination between TSOs

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V.2 Empirical observations task by task	188
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“I have always thought the actions of men the best interpreters of their thoughts.”

John Locke¹

¹In An Essay Concerning Human Understanding (1689).

This chapter is adapted from (Janssen and Trotignon, 2012).

The empirical observation of the implemented solutions in chapter II shows that Transmission System Operators (TSOs) cooperate for an efficient use of the European power network through the cross-border coordination of operation. In practice, for each mechanism of coordination involved, an institutional mode of interaction is required to implement the technical solutions.

It is acknowledged that institutional forms can have an impact on the economic efficiency depending on the nature of the transactions that need to be performed (Williamson, 2000, Ostrom, 2010). In a few words, the institutional perspective on TSOs has focused on key TSO interactions with the network users (Rious, 2007, Pignon, 2003), with the regulatory system (Joskow, 2008b, Glachant et al., 2012) and with its owner (Rious, 2007, Moselle, 2008, Lévêque et al., 2009). In addition, the specific question of the economic modes of coordination between TSOs has been investigated by Knops (2008a, 2010). By completing the studies on this last question, the new analysis performed in this chapter should contribute to understand how TSO coordination is effective as in 2012 and if good practices can be identified.

The method is an empirical observation of the current mechanisms in place in the Central Western European (CWE) and Nordic regions² as in 2012, including foreseeable evolutions that shall be soon implemented. The trends observed in the results are then analysed from a more theoretical perspective.

These observations are made using an analysis grid built by combining two entries. The first is the modular framework from section II dividing the coordination function into subtasks that can be performed through different modes of coordination. This framework is completed with two tasks for further integration analysed in section IV.2 about the EU initiatives. The second entry is the categorization of modes of coordination between TSOs along two dimensions built in section V.1. The first dimension is about

²The CWE region includes Belgium, France, Germany, the Luxembourg and the Netherlands. The Nordic region shall refer to Denmark, Finland, Norway, Sweden and Estonia.

the institutional form of the coordination *per se* and the categorization stems in particular from (Knops, 2008a). The second dimension is simply about the expanse of the coordination arrangements.

The observations are performed task by task in section V.2 and the results are analyzed in section V.3.

V.1 Definition of modes and expanses of coordination

(a) Modes of coordination

Three generic forms of economic organization named market, hybrid, and hierarchy are often considered in the new institutional economics (Williamson, 1991). The term hybrid covers a heterogeneous set of organizations that are neither markets nor fully integrated bodies.

Market forms of economic organization are not currently used to coordinate TSOs. It is coherent with the nature of regulated monopoly over the TSO control area (Knops, 2008b) as in most network industries (Curien, 2000). Indeed, the coordination function for a better use of the infrastructure can be seen as an extension of the system operator regulated tasks over its control area.

If the coordination is not market based, one could think of a single European TSO or a hierarchy between TSOs to ensure the coordination. However, this may not be adequate in the European context where it can be assumed that several TSOs shall keep a strong national dimension. In fact, the ownership of several TSOs is at least partly controlled at a national level (Supponen, 2011) and the two particular cases of German TSOs owned by foreign TSOs analysed by Knops (2010) are excluded from the observation scope because as in 2012, there is not enough empirical evidence of the consequences for the cross-border coordination of operation. This empirical observation of limited cross-border control or European control is coherent with the fundamental principle that some deeply rooted institutions are less negotiable than others (North, 1990) applied to the historical strength of the national level in the European electrification as described in appendix B.1.

Therefore, this study focuses on hybrids modes of coordination to perform the coordinated tasks of the “software” integration. In practice, it is acknowledged that there is a wide diversity of forms (Ménard, 2004). The typology is thus built to fit for this specific case. More precisely, it is derived from the categories proposed by Knops (2008a, 2010) adapted to the case study. Apart from the trivial case of no explicit coordination, three categories are made: mode (a), coordination based on a common agreement involving only the TSOs, under a form of private ruling; mode (b), coordination through one or more common service providers being a common subsidiary of TSOs or a common

association of TSOs; and mode (c), coordination defined by common public rules and enforced by a legal authority.

For instance, a common agreement between TSOs is used to determine the space of possibilities for capacity allocation at a border between two control areas. Then, the Capacity Allocating Service Company (CASC) is an example of common service provider which is a TSO subsidiary. Finally, the European Network Codes (NCs) that are to become regulation of the European Union would be an example of international legal rules. With this last option, it is assumed the legitimate authorities and the stakeholders have been involved more directly in the decision process than with a common agreement between TSOs.

Two comments are necessary to clarify how these three categories shall be used in the observations. Modes (b) and (c) imply that there should be some kind of common agreement. Mode (a) is thus used to describe a coordinated task which is to a large extent performed without mode (b) and (c), i.e. without the strong involvement of a common service provider or without the direct involvement of a detailed public ruling. Similarly, a coordination arrangement is always indirectly supported by a set of common rules. Mode (c) is thus used to describe the situation when it is observed that the rule precisely define some aspects of the coordination rather than when the rule defines a general principle.

(b) The coordination expanse

Additionally, independently from the first categorization, the distinction is made between sub-regional, regional and inter-regional coordination. In this study, the regional level shall be either CWE or the Nordic region.

This second dimension is meaningful because the size of the coordination can have an impact. For instance, in a meshed network, a regional determination of the cross-border capacity can appear more adequate than bilateral agreements as shown with the example of the Flow Based (FB) methods described in section [II.1.2](#) and in ([CWE, 2011b](#)).

V.2 Empirical observations task by task

V.2.1 TSO interactions for the cross-border coordination of operation as in early 2012

To cover a large panel of coordination arrangements, the analysis shall consider coordination arrangements from the four functions built in chapter II: determine spaces for possibilities for cross-border exchanges, allocate these spaces of possibilities, coordinate TSO actions and security assessments and handle additional cross-border externalities with a focus on the cost sharing agreements.

(a) Determination of a space of possibilities for cross-border exchange

The space of possibilities for cross-border exchanges are determined by TSOs in accordance with the objective of a secure operation of the system they are responsible for. This space can be seen as a constraint of the global system welfare maximization³, limiting the potential benefits from these exchanges. Therefore the objective is to offer a space of possibilities respecting security requirement and allowing the system to reach the best possible welfare when combined with the other modules. Because of the physical properties of a power system, TSOs can jointly reach a more optimal result by improving their coordination as described in section II.1.2.

In the CWE and Nordic regions, the space of possibilities takes currently the form of transfer capacity for each border between two control areas (Nordic Ediel Group, 2012). This capacity is determined in practice as a Net Transfer Capacity (NTC) through a bilateral process between the two TSOs connected at this border. Therefore it is a form of common agreement at a sub-regional level.

In the CWE region, an evolution toward a regional approach with so-called flow-based mechanisms is scheduled (CWE, 2011b).

³The definition of welfare is the responsibility of each society and its regulatory system.

(b) Allocation

Before the allocation process, it may be decided to split it between various allocation time horizons (*e.g.* Long-Term (LT) or Day-Ahead (DA) markets) and kinds of product (*e.g.* financial or physical products) as described in section II.1.3.

For LT allocation, TSOs of the CWE region use a common subsidiary known as CASC⁴, responsible for organizing the centralized auctions for LT capacities. Meanwhile, TSOs from the Nordic system are not involved in LT capacity allocation. It shall be considered as an inter-regional arrangements because CASC handles a large number of frontiers around the CWE region.

At the DA time horizon, all internal borders of the CWE and Nordic regions are under implicit allocation arrangements (Janssen et al., 2012). The entities involved in these arrangements are the power exchanges APXendex, Belpex, EPEXspot and Nordpool Spot as well as the European Market Coupling Company (EMCC). TSOs are major shareholders of these entities either directly or through common subsidiaries as illustrated in Figure V.1. The only noticeable other major shareholder is EEX, which is itself owned at more than 50% by a large exchange operator⁵. Therefore, these entities can be seen as common subsidiary of TSOs which ownership is partly shared with other actors. The coordination takes place at regional and inter-regional levels.

Nowadays, for ID, Elbas is a continuous Intra-Day (ID) market for trading power across the Nordic region, Germany and Estonia⁶. It is a common subsidiary at a regional level. In addition there are in the CWE region sub-regional arrangements operated by common subsidiaries that are already involved in for the DA. There is for instance a cross-border capacity allocation arrangement between France and Germany operated by EPEXspot (EPEXspot, 2010).

Concerning cross-border exchange for balancing markets and mechanisms, the arrangement observed is the International Grid Control Coordination⁷. It is the expansion to Denmark, the Netherland or Switzerland (Tennet, 2012) of a coordination arrangement developed within the four German TSOs. A key module is the automatic netting

⁴See <http://www.casc.eu>, last visited May 2012.

⁵EEX AG is owned at 56% by Eurex which itself is a subsidiary at 100% of Deutsche Börse AG, according to <http://www.eurexchange.com/>, last visited in May 2012.

⁶See <http://www.npspot.com/TAS/Intraday-market-Elbas/>, visited May 2012.

⁷See <https://www.regelleistung.net/ip/>, visited May 2012.

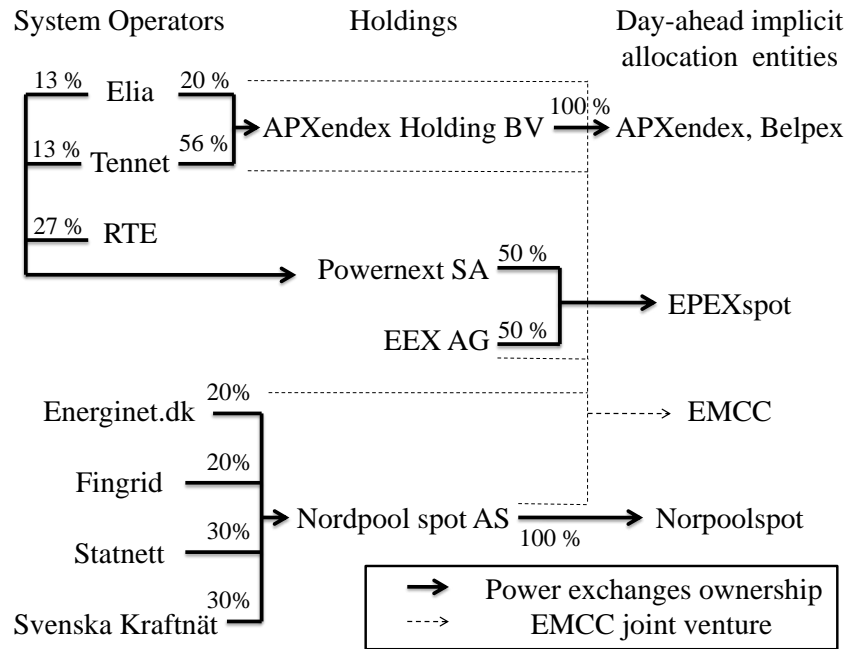


FIGURE V.1: System operators are shareholders of the DA implicit allocation operators in the CWE and Nordic regions. The figures are gathered from these operators' official web-pages, last visited in May 2012.

of power imbalances under predefined conditions. This arrangement is the result of a common agreement at a sub-regional level.

(c) Coordinated security assessment and coordinated congestion alleviation

This third function handles the stressed situations that could not be foreseen before firm allocation were made, using post-allocation congestion management methods. The first task selected identifies stressed situations requiring action. The second one provides a coordinated response to maintain a reasonable system security level. Both require a cross-border coordination because a TSO action can sensibly impact neighboring control areas.

In each control area of an integrated system, a single TSO is in charge of the security. The first sub-task aims at helping TSO by bringing a wide vision of electricity flows complementary to the national vision. To perform this sub-task in the CWE region, three TSO subsidiaries act as service providers to assess global security. Coreso includes among its stakeholders RTE (the French Transmission System Operator, or TSO), Elia (the Belgian TSO) and 50 Hz (a German TSO linked to Elia) as well as Terna (the

Italian TSO) and National Grid (TSO over Great Britain)⁸. Security Service Centre (SSC) is staffed by Tennet (Dutch TSO) and Amprion (a German TSO)⁹. TSO Security Cooperation (TSC) is owned by eleven TSOs, including Tennet, Amprion, 50 Hz and TransnetBW (another German TSO)¹⁰.

This first coordination arrangement selected is thus performed at the three possible scales of the observation framework and it involves common service providers.

Once a stressed situation is identified, a coordinated response offers a more efficient and secure action than isolated responses. Nowadays, the experts of the security assessment entities can propose coordinated responses, but each TSO keeps full control of the decision in its control area (Arrivé et al., 2012). In practice they currently work together when necessary and act within limits defined in common agreements such as the Operation Handbook¹¹.

This second coordination arrangement is thus performed thanks to common agreements between TSOs with the potential contribution of common subsidiaries at the scale of the CWE region (Arrivé et al., 2012). There are other agreements in the Nordic area and at the cables interconnecting the two regions (Philippe & Partners, 2010).

(d) Surrounding agreements: a cost sharing agreement

In addition to the rather operational agreements described above, additional surrounding agreements may be necessary to ensure the good functioning of the internal market. Concerning this fourth set of coordination arrangements, the empirical observation focuses on the example of a cost-sharing agreement conceived to compensate for the costs of hosting cross-border flows of electricity.

In the decade before 2010, an agreement was reached between TSOs (ETSO, 2008). This voluntary approach has then taken the form of a Commission Regulation from the EU on laying down guidelines relating to inter-transmission system operator compensation and a common regulatory approach to transmission charging (EU, 2010f,a). As stated in the preamble of the regulation (EU, 2010f):

⁸See Coreso website <http://www.coreso.eu>, last visited December 2011.

⁹See SSC website <http://www.securityservicecentre.eu>, last visited December 2011.

¹⁰See TSC website <http://www.tso-security-cooperation.eu>, last visited December 2011.

¹¹See <https://www.entsoe.eu/resources/publications/system-operations/operation-handbook/>, visited May 2012.

Valuable experience has been gained since the need for intertransmission system operator compensation arrangement was first recognised, in particular through voluntary arrangements by transmission system operators. However, transmission system operators have found it increasingly difficult to reach agreement on such voluntary arrangements.

Therefore, this coordinated task is currently performed following a common public constraining rule at an inter-regional level.

V.2.2 Two TSO-interactions toward further cross-border coordination of operation

For each sub-task of the modular framework described in chapter II, new coordination arrangements may improve the outcomes. To catch these opportunities, TSOs are also deeply involved in two tasks favoring the improvement of the cross-border coordination of operation.

(a) Fostering new consensus and agreements: the network codes.

The paths toward further integration may require further agreements. To this aim, TSOs and other stakeholders have been discussing at bilateral, regional and European levels. The salient arrangement selected for empirical observation is the process defined in the European Union law (EU, 2009d) which aims at fostering European binding network codes as introduced in section IV.2.2.

The redaction of the draft network codes is one of the mission of the ENTSO-E, the main European association of TSO as in 2012¹². TSO coordination is thus performed through a common association and framed by common EU rules at an inter-regional level.

¹²To sum up, European Network of Transmission System Operators for Electricity (ENTSO-E) is an association which creation and roles have been made official through the regulation 714/2009 (EU, 2009d) and which statutes shall be submitted to the Commission and the ACER. This association is not built out of nothing since it integrates 6 previous structures, including the European Transmission System Operators (ETSO) association. This contributes to explain why it has been created quickly and why it has started working on key topic rather fast for an organization at EU-level. The association is financially supported by 42 TSO members. This organization has no official legal power and the work of the TSO's association is always monitored, either by the Agency for the Cooperation of Energy Regulators (ACER) or by the Commission.

(b) Research on pan-European transmission issues.

Research and development of innovative tools shall help to meet future challenges of the European system such as the integration of large shares of intermittent generation for example.

Research cooperation between TSOs on pan-European transmission issues is common nowadays (ENTSO-E, 2011b). It allows to share costs, best practices and it eases mutual understanding of TSO processes as well. Moreover, the TSOs involved in a research project might then keener to adopt this innovation with a speeded up learning process. This joint research can be seen as a common agreement involving to a certain extent the ENTSO-E introduced above and a financial support by the EU closely framed by public rules. The expanse of the European research projects such as PEGASE, OPTIMATE, iTESLA and UMBRELLA described in section IV.2.3 is often at the scale of a European region or larger.

V.2.3 Summary

This study has analyzed a selection of salient arrangements covering all major functions of the framework. The results gathered in table V.1 are representative even if it is not an exhaustive list.

Selected coordination arrangement	Mode			Expanse		
	(a)	(b)	(c)	(1)	(2)	(3)
Bilateral capacity determination	x			x		
LT capacity auctions		x				x
DA implicit allocation		x			x	x
ID implicit allocation		x		x	x	
Netting of imbalance	x			x		
Multi-area security assessment		x		x	x	x
Coordinated response to stressed situations	x	x		x	x	
ITC cost sharing agreement			x			x
Network code fostering process		x	x			x
Research on transmission issues		x	x		x	x

TABLE V.1: Summary of the coordination arrangements observed in the CWE region. The modes are (a) common agreement, (b) common service provider(s) or association and (c) common public rules. The expanses of the coordination are the (1) sub-regional, (2) regional and (3) inter-regional levels.

V.3 Analysis and policy recommendations

V.3.1 When is a common service provider or an association adequate?

The mode (b) of coordination is currently successfully used for several tasks among those considered in table V.1. Therefore, this section aims at highlighting under which conditions and why such an option could be welcomed to handle additional coordination arrangements. In addition, the last paragraph points at foreseeable opportunities.

If a coordinated task can be clearly defined, externalized from an operational point of view and delegated from a legal point of view, then it would be possible to use a common service provider or an association to perform the task. Moreover, if the common service provider is a common subsidiary, then it should comply with the EU rules. For instance, when the EMCC was created to handle a coupling arrangement¹³, there has been a competition case regarding the governance of the TSO involved and the unbundling requirements¹⁴.

If these conditions are met, there are several reasons to favor the existence of a common service provider for the common interest. First, the operational costs could be lower if the service provider reduce redundancies as it is the example with CASC maintaining a single auction platform for several borders. Then, the employees in charge of the task may be in good conditions to share expertise as observed by Boulet et al. (2012) about the Coreso experience. More generally, the experience can foster trust between workers that may work later in different TSOs and this trust is valuable for future successful agreements (Ostrom, 2010). Finally, the service provider or association can be incentivized to promote its activities or to propose additional services to increase its business activities. In the first case, if an enlargement of the coordination appears useful for all the parties involved, it can be implemented by including new TSOs in the shareholding structure or in the association status. For instance, Terna in Italy and National Grid in Great Britain joined Coreso. In the second case, the common service provider becomes a source of innovation benefiting from the knowledge of experts coming from different TSOs.

¹³This market coupling arrangement is described in detail in appendix C.

¹⁴Details of the competition case are accessible on the Commission website http://ec.europa.eu/competition/elojade/isef/case_details.cfm?proc_code=2_M_4922, last visited January 2013.

Besides, from a governance point of view, the fact that TSOs are major shareholders or members of the entities ensures that they keep a common control on the major decisions. This institutional link may favor a situation where the employee in charge of the task would have a clear incentive to look for the common interest of the TSOs involved working for the good functioning of the integrated power system.

Since this mode of economic organization is identified as promising, three examples of potential applications are identified in the CWE and Nordic regions. First, a new common subsidiary could be in charge of hosting some cross-border coordinating arrangements for balancing. It could be an evolution of the common agreement related to the IGCC for instance. Second, it is interesting to look for new services that the security assessment center, such as Coreso, SSC and TSC, could offer in the future. Indeed, while each TSO keeps responsibility over its control area, common service providers can greatly help coordination. Third, fairness and transparency is a key to the acceptability of each TSO's work in, for instance, the determination of the space of possibilities for cross-border exchanges. The transparency platform [entsoe.net](http://www.entsoe.net)¹⁵ made available by TSOs might thus be further developed.

V.3.2 Foreseeable impact of common rules on TSO coordination

The mode (c) of coordination, common public rules, does not appear often in the results of table V.1. Indeed, even if the EU law settles several principles about the TSO coordination, this institutional form is not always used to implement an effective coordination.

In the future, EU law may become a more and more detailed legal framework. In particular, the NCs introduced in section IV.2.2 are expected to frame more closely the coordination arrangements than the EU law as in 2012. Common public rules on TSO activities differ from common agreements between TSO in the sense that other stakeholders are, in principle, more deeply involved in the decision process. With these conditions, it does not appear easier to reach a consensus. In addition, the resulting rules would probably be less flexible than a common agreement due to the EU law making procedures.

¹⁵See <http://www.entsoe.net/>, last visited May 2012.

The potential benefits of mode (c) lie elsewhere. For instance, by opening the public debate with the network code process, the regulatory system sends a signal and creates an opportunity to go forward toward the objective of further integration. Indeed, it can result in the diffusion of the current successful good practices to the whole European Union as well as associated countries. In practice most of the major stakeholders appear to participate willingly to the debate as shown by the various documents publicly available. Furthermore, the debate pushes actors to reveal their positions to others which can help identify and overcome potential acceptability issues.

Besides, in the example of the Inter-TSO Compensation (ITC), the Commission legal powers have also been used where a voluntary agreements appeared increasingly difficult to reach as quoted from (EU, 2010f) in the empirical observations in section V.2.1.

V.3.3 Three comments on the coordination expanse

A diversity of geographic expanses

The observation shows that the CWE and Nordic power systems are currently functioning with coordinating arrangements over different geographic expanses. Furthermore, a wide diversity of coordination expanses is observed and no warning has been raised about this situation. This observation support that it is possible to implement various coordination arrangements in a step by step process. Therefore, this observation strengthens the modularity of the global cross-border coordination of operation.

Coordination expanse and potential impact on short-term security of supply

A general trend appears in the selection of arrangements observed: the arrangements operated at an inter-regional level are the one which are less likely to impact the short-term security of electricity supply. This is particularly clear considering the four time horizons of allocation observed. The closer to real time, the higher is the potential impact on system security and the smaller is the geographical expanse of the coordination.

This observation can be explained as a simple coincidence, as a transitional effect because some arrangements would be easier than others or as an adequate regulatory choice regarding the power system objectives. There are currently too few observable objects

to distinguish these three kinds of explanations. Nevertheless, the observation of future evolutions could help to complete this analysis.

Toward an expansion of some coordination arrangements

The foreseeable perspectives of evolution concerning some coordinated tasks are an enlargement of the expanse covered. For instance, the determination of the space of possibilities for cross-border exchange shall evolve from a bilateral agreement to a regional agreement in the CWE region (CWE, 2011b). Similarly, the target model for ID allocation is an inter-regional arrangement that would cover a larger area than the current regional arrangements (ENTSO-E, 2012n).

As shown in section III.2 about the impact assessment of an evolution of the cross-border coordination of operation, it appears the main costs are the start up costs, including negotiation and transition costs that are difficult to measure. It also appeared that once a technical solution has been developed over some frontiers, the cost of replicating the technical solution may be comparatively lower. Furthermore, once a solution has been proven successful in a region, it may be more easily accepted in others and their may be a form of lock in effect¹⁶ which can reduce the complexity of the negotiation process. Thus, these trends support the extension of existing regional coordination arrangements as an efficient way to improve the cross-border coordination of operation. However, only a specific case study could evaluate if the expansion of an existing coordination arrangements across the European regions should be preferred to the coexistence of different coordination arrangements over neighboring borders or to an intermediary solution such as the ITVC studied in appendix C.

¹⁶For further insight on this complex economic concept, see (Martin and Sunley, 2006).

V.4 Chapter summary

This chapter investigates two dimensions of the economic organization of the coordination between TSOs for the cross-border coordination of operation through the empirical observation of the CWE and Nordic regions.

The first dimension distinguishes three modes of coordination: (a) based on a common agreement between TSOs; (b) through common service provider(s) or association; and (c) defined precisely by common public rules. The analysis of this first dimension shows how the use of a common service provider being a subsidiary, such as CASC and Coreso, or a common association appears effective whenever it is compatible with the nature of the task. Therefore, the creation of efficient common service companies with clear and transparent missions should be welcomed. The analysis also echoes back to chapter IV showing that the European Union (EU) offers a framework to produce and enforce common public rules supporting the cross-border coordination of operation. It confirms how this institutional form has been used to implement some surrounding agreements such as the Inter-TSO Compensation (ITC) agreements and to frame and support processes aiming at improving the coordination arrangements. Furthermore, this institutional form may become more and more used with the adoption of NCs as part of a EU regulation defining more precisely the coordination arrangements than the existing EU binding law.

The second dimension is the geographical area covered by the coordination. It appears first that the arrangements are often coordinated over different expanses. This strengthens the modularity of the cross-border coordination of operation analyzed in chapter II in the sense that several sub-tasks of the global coordination function can to some extent be performed independently from each other. Second, the analysis emphasizes that several existing coordination arrangements are to be expanded over a larger geographical area. This trend shows how the regional arrangements can be stepping stones toward wider coordination arrangements. Third, a negative correlation emerges between the coordination arrangement potential impact on the short term security of supply and its expanse: the higher the potential impact, the lower the expanse. This link could be a simple coincidence in the subset of coordination arrangements observed, it could be explained as a transitional effect and it could be the sign that there are fundamental reasons to keep some coordination expanse at a regional or sub-regional level. Therefore,

this observation raises a question that a more detailed investigation of the past decisions could answer in further work.

The analysis framework can be used in further study to monitor other regions as well as the system evolutions. For instance, the observation would be strengthened by additional uses of common service providers and common rules and by the geographical expansion of some coordination arrangements. Besides, new questions would appear if TSO cross-border ownership becomes more common, requiring an enlargement of this study paradigm.

General conclusions

Within the literature on the design of liberalised power systems, the research area explored by this thesis is the cross-border coordination of operation between interconnected areas sharing a common electricity transmission network.

The underlying theoretical framework of the research project stems from the new institutional economics. The central cornerstone is that institutions, understood as the ‘rules of the game’, matter (Williamson, 2000). In the case of cross-border coordination, technical solutions can be worthless without adequate institutions. The second cornerstone is that some institutions cannot be changed on a more or less short term perspective (North, 1990). In particular, it is assumed that some regulatory and technical frontiers shall remain strong between areas sharing a common electricity transmission network. The last cornerstone of this thesis is that the management of common pool resources and public goods may require complex institutions tailored to each situation (Ostrom, 2010). The potential benefits of cross-border platform where individuals representing the stakeholders physically meet, reveal their position and work together is particularly emphasized.

The **first chapter** of the thesis has defined the scope and role of the research object within its context. The concept of integrated power system is introduced to refer to a large interconnected electricity transmission network on which the organization of the electrical industry is divided by several layers of regulatory, technical and market borders. In this conceptual framework, the benefits of the implementation or improvement of the cross-border coordination appear through a combination of three frameworks. First, from an optimization point of view and with fixed assumptions about the actors behaviors, the cross-border arrangements can improve the coupling between two sub-problems allowing the integrated power system to reach a better optimum, e.g. an

increase of social welfare. Second, with an enlarged microeconomic perspective, the coupling of markets can increase the competitive pressure on each bidding zones. As a consequence, assuming common rules ensure a fair competition across the market borders, the system can benefit from the impact on the actors behaviors in term of efficiency, innovation and relevance of the price signals. Third, positive side products can emerge from the coordination between regulated actors such as the TSOs and members of the regulatory systems cooperating for the implementation of cross-border coordination arrangements, for instance through the exchange of good practices about an internal area organization. To reach for these benefits, the cross-border coordination of operation is a set of cross-border arrangements handling two core economic problems: (1) determine and allocate a scarce resource for cross-border exchanges between areas of an integrated power system considering a given set of infrastructures; and (2) handle the additional cross-border externalities that may appear due to the interconnections between areas and due to their use for cross-border exchanges. To complete the description of the research object within its context, an illustrative model formalizes the complementarity between the cross-border coordination of operation and the cross-border coordination about the investments on the common transmission network.

The two next chapters have investigated the role and the potential consequences of arrangements that altogether form the cross-border coordination of operation.

The **second chapter** has applied the modular analysis principles ([Baldwin and Clark, 2000](#)) and divides the two economic functions of the cross-border coordination of operation into two sets of four modules. The resulting modular framework has been built as a bridge between the economic literature and the public debate taking place in Europe as in 2012 about the improvement process of the cross-border coordination. It aimed at favoring common understanding among stakeholders involved in this public debate while offering a support for further study. It can also be used to shape a monitoring board of an integration process as illustrated on a sample target model. The analysis of each one of the eight module put forwards that there is much more than Day-Ahead (DA) market coupling to couple markets. In particular, the scope of the research object brings out the question of the allocation of the space of possibilities for cross-border exchange between time horizons and between several kinds of products. Another key conclusion is that several technical solutions already exists, as shown by the empirical observation of the solutions implemented in the CWE region and of the options discussed in the public

debate. Even if there are perspective of improvements, for instance concerning optimization software, technical issues do not appear as the main barriers in the European integration process. In addition, the analysis has investigated two fundamental interactions with the internal organization of the areas of an integrated power system. First, because the physical power flows add up on a common transmission network, the effects of internal and cross-border congestion management also add up on the critical elements of an integrated power system. The second interaction is a tradeoff that may appear in specific cases between harmonization of the internal organizations and efficiency of a new coordination arrangement.

The **third chapter** aimed first at analyzing how impact assessment tools can be used to guide the selection of adequate options for an improvement of the cross-border coordination of operation. Quantitative indicators can be used to strengthen or challenge a position in a decision process, but they appear neither able nor meant to replace political decision-making ([European Commission, 2009](#)). In coherence with the analytical framework assuming bounded rationality, negotiation processes and platforms of discussion are a potential source of information for all stakeholders including in particular the regulators [Brousseau and Glachant \(2011\)](#). Indeed, these processes and platforms can potentially help to reveal how the consequences are perceived by various stakeholders as well as supported and challenged by academics. The second objective of this chapter was to provide orders of magnitude of the impact of the improvement process in the European case as in 2012. Concerning the gross social surplus, the results of simulations on specific arrangements reach tens or hundreds of million euros per year. On the other side of the balance, the investment costs currently spent in the improvement process at the scale of the CWE region is investigated based on empirical observations. The estimations show first that these costs appear reasonable compared to the expected benefits, which support the improvement process in place as in 2012. The results also show that among these costs, some negotiation costs on new agreements appear far higher than the implementation costs of new technical solutions, supporting the principle that transaction costs should not always be neglected. Beyond the aggregated surpluses and costs, the analysis shows that the distribution effect between actors within each area involved in the improvement of a cross-border coordination arrangement can be potentially stronger than the gross social surpluses. In addition to the existing literature, an illustrative simulation is built in this thesis which shows on a specific case that the impact on a specific

actor is difficult to estimate. As analyzed by economists working on international trade and the political economy (Krugman and Obstfeld, 2008), these distribution effects have a strong impact on any decision process. Thus, from a theoretical perspective, agreements may not appear between stakeholders without some investments in a negotiation process and incentives to participate.

Along the first part of the thesis about the cross-border arrangements and their impact assessment, the institutional perspective appears as the key to support the improvement of the cross-border coordination of operation. Therefore, the two next chapters aim at contributing to the institutional analysis with two research angles: the role of the European Union (EU) and the coordination between TSOs.

Based on EU law studies, the **fourth chapter** has shown how the EU is contributing to the good functioning of the current cross-border coordination of operation as in 2012. Indeed, some common public rules are necessary and the EU law is an adequate legal form to implement and enforce them on the European continent thanks to existing supranational institutions such as international treaties involving EU member states as well as non EU member. The analysis highlights the key role played by the EU competence for the good functioning of the internal market which legitimates a strong EU competition law. The EU also supports several initiatives to foster new consensus, common decisions and common knowledge among TSOs. These initiatives provide additional occasions for actors to meet across borders, to work together and to express their differences. This should favor the negotiation process aiming at improving the cross-border coordination of operation.

The **fifth chapter** aimed at identifying adequate economic modes of coordination between TSOs for the cross-border coordination of operation. This research angle stems from the work of Knops (2008a, 2010). More precisely, the chapter has investigated two dimensions of the economic organization of the coordination between TSOs through the empirical observation of the CWE and Nordic regions. The first dimension distinguishes three modes of coordination: (a) based on a common agreement between TSOs; (b) through common service provider(s) or association; and (c) defined precisely by common public rules. The analysis of this first dimension shows how the use of a common service provider being a subsidiary, such as CASC and Coreso, or a common association appears effective whenever it is compatible with the nature of the task. Besides,

the use of public common rules under the form of EU law may become more and more significant with the European network code fostering process. The second dimension is the geographical area covered by the coordination and the distinction is made between sub-regional, regional and inter-regional coordination. It appears first that the cross-border arrangements often co-exist over different expanses. This observation strengthens the idea that several sub-tasks of the global coordination function can to some extent be performed independently from each other. Second, the analysis emphasizes that several existing coordination arrangements are to be expanded over a larger geographical area. This trend shows how the regional arrangements can be stepping stones toward wider coordination arrangements. In practice, it appears that several solutions implemented in the CWE and Nordic regions may become *de facto* part of a target model for the neighboring regions.

The combination of the different angles of study taken in the five chapters supports *ex post* the choice of the underlying theoretical framework. Indeed, the thesis confirms that adequate institutions matter to reach for the benefits of an improved cross-border coordination across the internal borders of a European integrated power system.

By enlarging the scope of the research object, further work could bring additional guidance to the improvement process of the cross-border coordination of operation.

First, the results of each research angle could be compared with another geographical area or another period. The case of North America is for instance a good candidate because it would allow to investigate further the specificities of a cross-border coordination between technical areas with nodal energy prices and differing regulations. Such analysis could include the experience of the Standard Market Design proposed by the North American Electric Reliability Corporation (NERC) or of the Broader Regional Market around the Great Lakes.

Second, the allocation of the space of possibilities for cross-border exchange between time horizons and between several kinds of products is a complex research problem of optimization at the border between economics and applied mathematics. Investigating the potential solutions and their economic consequences may highlight to what extent

this module of the cross-border coordination of operation could be improved and if the solutions currently discussed should be challenged.

Third, the impact of TSO cross-border ownership on the cross-border coordination remain to be evaluated. Indeed, based on the literature on TSO governance, it would be interesting to investigate further to what extent it impacts the coordination between TSOs involved in the cross-border ownership as well as with other TSOs.

Fourth, some analysis frameworks and conclusions about the cross-border coordination of operation might be adapted and bring new elements to the analysis of the cross-border coordination on investments in an integrated power system.

Appendix A

Glossary

The following glossary has been shaped by following two principles. First it is a support for the thesis reader. Second, it uses as often as possible definitions proposed by the Agency for the Cooperation of Energy Regulators (ACER), European Commission (EC) and European Network of Transmission System Operators for Electricity (ENTSO-E) according to the thesis objective of supporting the involvement of stakeholders in the decision making process on the European integration. Indeed, the choice of words and concept is highly important in the negotiation process as illustrated in the summary by the [ENTSO-E \(2012i\)](#) of the answers by stakeholders on a draft network code on operational security showing that many comments concerned definitions. In addition, some technical definitions are based on an online electrical and electronic terminology database from the International Electrotechnical Commission (IEC)¹. Besides, in a few cases, academic references are mentioned when a term appears widely used with alternative meanings.

The result is inherently limited and the reader is invited to note the following warnings:

- This glossary is built only for this thesis from documents publicly available at the end of 2012. As an example of consequence, the definitions quoted from draft versions of the ENTSO-E Network Codes may evolve or be amended before the potential final approval through a Comitology process. Besides, in many cases the

¹See website <http://www.electropedia.org/iev/iev.nsf/welcome?openform>, and more particularly the area untitled “Generation, transmission and distribution of electricity - Power systems planning and management” <http://www.electropedia.org/iev/iev.nsf/index?openform&part=603>, last visited december 2012.

definition are attached to the European power system organisation as in 2012 and may have to be adapted to future evolutions.

- In EU legal documents, capital letter are used to emphasize that terms are given a precise definition in the legal document. In this glossary, these capital letters are transposed into lower case when the legal definition is quoted.
- This glossary does not pretend to be comprehensive and several definitions are not settled in the academic litterature which may use alternative terms or definitions.

Adequacy of an electric power system refers in this thesis to the “ability of an electric power system to supply the aggregate electric power and energy required by the customers, under steady-state conditions, with system component ratings not exceeded, bus voltages and system frequency maintained within tolerances, taking into account planned and unplanned system component outages” following an IEC definition¹. This definition is understood as including not only the long term infrastructure adequacy as meant in (ENTSO-E, 2012o) but also a short term ability to react. Please note that the The North American Electric Reliability Corporation (NERC)² and academics such as Billinton et al. (1984) or Oren (2005) would use the term reliability for this broad definition while the term adequacy would be restricted to the existance of the infrastructure on a long term perspective and security would be used to refer to the ability to react. The former UCTE (2004) gives a third definition of the adequacy as “the ability of the electric system to supply the aggregate electrical demand and energy requirements of the customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements”. This last definition lies somewhere between the two previous one and it does not include “the ability of the electric system to withstand sudden disturbances such as electric short circuits or unanticipated loss of system elements”, which is called security.

Alert (disturbed) operating state “an operating state of the power system which entails that all demand is met and that the frequency, voltage and load flows are within the defined technically permitted limits/thresholds. In alert state, not all reserve margins’ requirements are fulfilled and disturbances (unplanned outages)

²See website <http://www.nerc.com/page.php?cid=1|15|122>, last visited December 2012.

could lead to further deterioration of system state. In the alert state, the power system is stable and all operational reserves (transmission capacities and remedial actions) are mobilised. It is not clear in which time frame it will be possible to return to normal operating state” (ACER, 2011d).

Alternating Current (AC) / Direct Current (DC) refers to two modes of operation of electrical devices and the distinction is fundamental from an engineering perspective. Concerning the transport of electricity, interconnected transmission lines operated with different modes can exchange power through a power converter. In practice in Europe as in 2012, meshed networks of transmission lines operated in AC mode form large synchronous areas. Some additional lines are operated in a DC mode between them or in a point to point fashion within each area. In a simplified view, one consequence is that the distribution of power flows on an AC meshed network are to a large extent subject to Kirchhoff’s laws while the power flow is controllable on a DC link thanks to the controllable power converters. Another important distinction is that frequency control is by definition associated to an AC grid. Nevertheless, these distinctions tend to become less and less relevant since AC grids are more and more controllable and the DC grid control devices could technically offer frequency control services to AC synchronous areas.

Ancillary services “services necessary for the operation of an electric power system provided by the system operator and/or by power system users” according to the IEC¹; “services necessary in support of transmission of electric power between generation and load, maintaining satisfactory level of operational security and with a satisfactory quality of supply. The main ancillary services include active and reactive power reserves for balancing power and voltage control. Active power reserves include automatically and manually activated reserves and are used to achieve instantaneous physical balance between generation and demand. Further ancillary services include black start and islanding capability. In the liberalised market, many ancillary services are procured by TSOs from the qualified and selected grid users, generators or loads” (ACER, 2011d).

Area Control Error (ACE) “means the sum of the instantaneous difference between the actual and the set-point value for the power interchange of a load frequency control area or a load frequency control block and the frequency bias given by the

product of the K-Factor of the load frequency control area or the load frequency control block and the frequency deviation” (ENTSO-E, 2012i). This technical definition refers to a parameter calculated for the frequency control and for instance for the activation of Frequency Restoration Reserve (FRR) by TSOs over control areas or control blocks. See (Kirschen and Strbac, 2004) or section I.2 for insights on this technical part of the organization.

Available Transfer Capacity (ATC) “is a measure of the transfer capability remaining in the physical transmission network for further commercial activity over and above already committed uses. ATC is the part of NTC that remains available after each phase of the allocation procedure for further commercial activity” (ACER, 2011d).

Balancing “all the actions and activities performed by a TSO in order to ensure that in a control area total electricity withdrawals (including losses) are equalled by the total injections in a continuous way, in order to maintain the system frequency within a predefined stability range” (ACER, 2011d). The balancing time horizon, as defined in this thesis, covers all the actions and activities performed by a SO close to real time in order to ensure frequency control and a balanced Control Area. The reservation of balancing products can take place during the previous time-horizons. Balancing services can be balancing reserves or balancing energy (ACER, 2012b).

Balance responsible party (BRP) “a market participant or its chosen representative responsible for its imbalances” (ACER, 2012b).

Balance service provider (BSP) “a market participant providing balancing services to one or several TSOs within one or several control area(s)” (ACER, 2012b).

Bidding zone “the largest geographical area within which Market Participants are able to exchange energy without Capacity Allocation” (ENTSO-E, 2012e); “an area which could be a part of the control area (in which case the respective balancing markets / systems must be aligned with the congestion management / redispatch systems), exactly the same as a control area or encompass several control areas, where market participants submit their bids for capacity allocation and congestion management between the bidding zone borders” (ACER, 2011d).

Black-start capability “is the ability of a generating unit to go from a shutdown condition to an operating condition and start delivering power without assistance from the electric power system it is connected to” (ACER, 2011d). It is often accounted among the ancillary services.

Blackout state “means the system state where the operation of part or all of the transmission system is terminated” (ENTSO-E, 2012i).

Common grid model “as a minimum, the common grid model shall be suitable for EUwide application and cover an area appropriate for the capacity calculation method used, at least the synchronous area. The common grid model shall include a detailed description of the transmission network, including the location of generation units and demand as well as the configuration of all switchable or adjustable elements” (ACER, 2011d).

Congestion “means any network situation, either described in a common grid model, or occurring in real time, where power flows has to be modified to respect operational security” (ENTSO-E, 2012e). More precisely, structural congestion “means congestion in the Transmission System that: can be unambiguously defined; is predictable; is geographically stable over time; and is frequently reoccurring under common circumstances” (ENTSO-E, 2012e).

Control area “is a coherent part of a synchronous area, operated by a single TSO (control area responsible), physically delimited by the power interexchange metering points, providing load-frequency control and ancillary services to physical loads and generation units connected. A control area may be a coherent part of a control block that has its own subordinate control in the hierarchy of load-frequency-control” (ACER, 2011d).

Control block “A control block comprises one or more control areas, working together in the load-frequency-control, with respect to the other control blocks of the synchronous area it belongs to” (ACER, 2011d).

Countertrading “means a Cross Zonal energy exchange initiated by System Operators between two Bidding Zones to relieve a Physical Congestion” (ENTSO-E, 2012e).

Critical network element “means a network element either within a Bidding Zone or between Bidding Zones taken into account in the Capacity Calculation Process,

limiting the amount of power that be exchanged in order to maintain the System Security” (ENTSO-E, 2012e).

Critical (emergency) operating state “the system security constraints are violated, there are no measures left and any further disturbance (e.g. unplanned outage) can lead to a system breakdown or blackout. Furthermore, the critical (emergency) operating state of the power system entails that automatic load shedding might have been applied to some degree and that further loss of generation or parts of network may occur” (ACER, 2011d).

Cross-border In this thesis, it is used with a broad meaning for all kinds of borders. In the legal documents, it can take a more precise definition such as “across a border between two or more Member States or a Member State and one or more jurisdictions in which this Network Code applies” (ENTSO-E, 2012e).

Day-Ahead (DA) market “means the market timeframe where commercial electricity transactions are executed the day prior to the day of delivery of traded products” (ENTSO-E, 2012e).

Direct Current (DC) Please refer to the Alternative Current (AC) / Direct Current (DC) entry of the glossary.

Economic Surplus “means the sum over all Bidding Zones, of seller surplus, being the aggregated difference between the sellers’ willingness to sell and the Clearing Price and of buyer surplus, being the aggregated difference between buyers’ willingness to pay and the Clearing Price, Congestion Income, and other costs and benefits, where appropriate” (ENTSO-E, 2012e).

Explicit allocation “means the allocation of cross zonal capacity only” in the context of the (ENTSO-E, 2012e). More generally, the term could also refer to an allocation arrangement of a space of possibilities for cross-border exchanges with direct access for potential users.

Flow Based (FB) methods for determination of spaces of possibilities “makes use of locational information in the grid model for the assessment of system security at the allocation stage without arbitrary assignment of capacity per border, and thus allows for better utilisation of transmission network” (ACER, 2011d).

Frequency Containment Reserve (FCR) “means the operational reserves activated to contain system frequency after the occurrence of an imbalance” (ENTSO-E, 2012l).

Firmness “means arrangements to guarantee that capacity rights remain unchanged or are compensated” (ENTSO-E, 2012e).

Frequency control “aims at maintaining balance between generation and load, what is measured by the quality of frequency (i.e. keeping frequency as close as possible to the nominal value). Load-frequency-control consists of manually activated (e.g. tertiary control in ENTSO-E Continental Europe) and automatically activated (e.g. primary and secondary control in ENTSO-E Continental Europe) control actions” (ACER, 2011d).

Flow Reliability Margin (FRM) “means the margin reserved on the permissible loading of a critical network element or a bidding zone border to cover against uncertainties between a capacity calculation timeframe and real time, taking into account the availability of remedial actions” (ENTSO-E, 2012e).

Frequency Restoration Reserve (FRR) “means the operational reserves activated to restore system frequency to the nominal frequency (50 Hz) and for synchronous area consisting of more than one load frequency control area power balance to the scheduled value” (ENTSO-E, 2012l).

Force Majeure “means, for the purpose of application in respect of capacity allocation mechanisms as foreseen in Article 16 of Regulation (EC) No 714/2009, any unforeseeable and/ or unusual event or situation beyond the reasonable control of a System Operator, and not due to a fault of such System Operator, which cannot be avoided or overcome with reasonable foresight and diligence, which cannot be solved by measures which are from a technical, financial and/or economic point of view, reasonably possible for the System Operator, which has actually happened and is objectively verifiable, and which makes it impossible for such System Operator to fulfil temporarily or definitively, its obligations in accordance with this Network Code” (ENTSO-E, 2012e).

Generation Shift Keys (GSKs) “mean a method of translating a net position change of a given bidding zone into estimated specific injection increases or decreases in

the common grid model”(ENTSO-E, 2012e). In practice, it also refers to “a set of factors describing a linear estimation of the most probable change in the generation pattern within a hub in relation to the change of the net position of this hub. If for instance we assume that 2 generation units are available in hub A (a1 and a2), a GSK A to B of (40%;60%) will mean that an increase of 100 MW of the exchange from A to B will be modelled as an increase of 40 MW and 60 MW of a1 and a2 respectively.”³. This definition can be transposed in a zonal design for instance by replacing the term “hub” by zone and “generation unit” by node, considering its net generation.

Imbalances “deviations between generation, consumption and market deals (in all timeframes . market deals include sales and purchases on organised markets or between BRPs) of a BRP within a given imbalance settlement period”(ACER, 2012b).

Imbalance settlement “a financial settlement mechanism aiming at recovering the costs of balancing applicable to imbalances of BRPs”(ACER, 2012b).

Imbalance settlement period “time units used for computing BRPs’ imbalances”(ACER, 2012b).

Implicit allocation is used to refer to an allocation arrangement for a space of possibilities for physical cross-border exchanges where the allocation is embedded in the coupling of, for instance, energy product markets or a balancing reserve activation mechanisms. Implicit auction is sometimes used to stress that an arrangement would be market based. As a result, the auctions of power and space of possibilities for cross-border exchanges are coordinated into a single process (ENTSO and EuroPEX, 2008). The terms price coupling, volume coupling, market coupling and market splitting are used to describe implicit auction implementations with specific features.

Interconnection “line (circuit) or a set of lines (circuits) between two control areas or between two different synchronous areas; an interconnection between two control

³See Belpex webpage http://www.belpex.be/uploads/Market_Coupling/20111212_CWE_FAQ.pdf, last visited November 2012.

areas can be an AC or a DC one, whereas an interconnection between two synchronous areas can only be a DC one or a back-to-back converter station” (ACER, 2011d).

Interconnected system “a number of transmission and distribution systems linked together by means of one or more interconnectors” (EU, 2009b).

Intra-Day (ID) Market “means the electricity market which operates for the period of time between Intraday Cross Zonal Gate Opening Time and Intraday Cross Zonal Gate Closure, where commercial electricity transactions are executed prior to the delivery of traded products” (ENTSO-E, 2012e).

Long-Term (LT) markets covers all markets taking place before the Day-Ahead time-horizon, trading mainly annual and monthly products.

Long term planning “the planning of the need for investment in generation and transmission and distribution capacity on a long-term basis, with a view to meeting the demand of the system for electricity and securing supplies to customers” (EU, 2009b).

Load shedding refers to “the process of deliberately disconnecting preselected loads from a power system in response to an abnormal condition in order to maintain the integrity of the remainder of the system” according to the IEC¹.

Margin against Peak Load “is the difference between Load at the reference point and the Peak Load over the season (summer or winter) the reference point is representative of. It serves to extend the results from the single reference point to the whole investigated period. Considering that Load at each reference point is normally lower than the corresponding seasonal Peak Load, the values of MaPL are expected to be non-zero” (ENTSO-E, 2012o).

Market time period “means the time resolution for the delivery of energy” (ENTSO-E, 2012e).

Market coupling is a form of implicit allocation of cross-border physical capacities. In the case of bilateral cross-border capacity for DA markets in the CWE region, it “is the process of joining market areas managed by different power exchanges with the purpose of determining volumes of exchange between the market areas, and in

the case of price coupling also prices, based on an algorithm that utilizes bid/offer information acquired from each market and cross border capacities” (ETSO and EuroPEX, 2008).

Market coupling operator “means the role of matching orders for all bidding zones, taking into account allocation constraints and cross zonal capacity and thereby implicitly allocating capacity [for a given time horizon]” (ENTSO-E, 2012e).

Market participant “means any [natural or legal] person, including transmission system operators, who enters into transactions, including the placing of orders to trade, in one or more wholesale energy markets” (EU, 2011a).

Market splitting is a form of implicit allocation of cross-border physical capacities. The term market splitting is used if only one market platform operator is involved in the allocation process (ETSO and EuroPEX, 2008, Everis and Mercados EMI, 2010). The terms market splitting can be used with a narrower definition taking into account additional features. For instance, (Booz&co et al., 2011) states that market splitting would use *de facto* a more detailed model of the coupled power system than market coupling. Besides, this term can also refer to the action of “splitting one bidding zone in two or more bidding zones” (Frontier Economics and Consentec, 2011).

Matching “means the trading mode through which sell Orders are assigned to appropriate buy Orders to ensure the maximization of Economic Surplus” (ENTSO-E, 2012e).

Net position / net export “ means the netted sum of electricity exports and imports for each market time period for a given geographical area. In the context of this Network Code (NC), geographical area is a bidding zone” (ENTSO-E, 2012e).

Network, system, grid within the context of this thesis, the terms ‘network’, and ‘grid’ refer to the transmission network unless stated otherwise. The term ‘system’ covers a larger definition including the network and all that is connected to it.

Network topology “the relative position of the ideal elements representing an electric network” according to the IEC¹.

N-Situation “means the situation where no element of the transmission system is unavailable due to a Fault;

(N-1)-Criterion refers in general to a security principle stating that the system should be able to cope with one large outage. In the network codes, it refers precisely to “the rule according to which elements remaining in operation within TSO’s responsibility area after a contingency from [a list of contingency that has been agreed] must be capable of accommodating the new operational situation without exceeding operational security limits” (ENTSO-E, 2012i). Here, contingency “means the identified and possible or already occurred fault of an element within or outside a TSO’s responsibility area, including not only the transmission, but also the distribution networks of DSOs if relevant for the transmission network security. Internal Contingency is a Contingency within the TSO’s responsibility area. External contingency is a contingency within the responsibility area of neighbouring TSO having effects in the responsibility area of the TSO” (ENTSO-E, 2012i).

Normal operating state “an operating state of the system entailing that all generation and load is in balance, requirements on ancillary services and framework conditions are met. Moreover in the normal operating state frequency, voltage and load flows are within their predefined and allowed technical limits and reserve margins are sufficient.” (ACER, 2011d)

Net Transfer Capacity (NTC) “the NTC is the maximum total exchange program between two adjacent control areas compatible with security standards applicable in all control areas of the synchronous area, and taking into account the technical uncertainties on future network conditions.” (ACER, 2011d).

Operational security “means keeping the Transmission System within agreed security limits” (ENTSO-E, 2012e).

Operating states “stand for the conditions of electric power system in real-time and are characterised by the degree of fulfilment of operational security criteria; there are three operating states (normal, alert (disturbed) and critical (emergency)) and the state of ‘restoration’ which stands for the power system in condition of restoration from any other state to the normal operating state” (ACER, 2011d).

Operational planning and scheduling “activities and tasks which are conducted prior to real-time operation. These activities include preparation of schedules for exchanges of power across control area borders and within control areas, transmission capacity calculations, preparation of re-dispatch measures where applicable,

coordination of protection settings, planned outages (maintenance) and any necessary grid topology/configuration changes” (ACER, 2011d).

Operational security “means the transmission system capability to retain a normal state or to return to a normal state as soon and as close as possible, and is characterized by thermal limits, voltage constraints, short-circuit current, frequency reference value and stability limits” (ENTSO-E, 2012i). It is also defined as “a measure of the power system operational parameters’ distance from the defined normal operating conditions and of the system capability to return to the normal operating state as soon as possible. Security limits define the acceptable operating boundaries (thermal, voltage and stability limits)” (ACER, 2011d).

Operational security limits “means the acceptable operating boundaries: thermal, voltage, short-circuit current, frequency and stability limits” (ENTSO-E, 2012i).

Order “means an intention to purchase or sell energy and/or capacity expressed by a Market Participant subject to a certain number of execution conditions” (ENTSO-E, 2012e).

Outage “the state of an item of being unable to perform its required function” according to the IEC¹. More precisely, there are planned outage “due to the programmed taking out of service of an item” and forced outage “due to the unscheduled putting out of service of an item” according to the IEC¹.

Power system “comprises all generation, consumption and network installations interconnected through the network” (UCTE, 2004).

Power Transfer Distribution Factor (PTDF) used in a FB method, it means in a zonal market design “a representation of the physical flow on a critical network element induced by the variation of the net position of a bidding zone” (ENTSO-E, 2012e). In the precise context of the European Network Code (NC) under discussion, net position means the netted sum of electricity exports and imports for each market time period for a given geographical area.

Price coupling is a form of implicit allocation of cross-border physical capacities where “all market data and all market rules of the coupled markets are included in the central market coupling calculation” (NordPoolSpot, 2012). More precisely, the same document add in the specific case of DA markets in the CWE region, “[t]he

central algorithm determines the prices in the underlying bidding areas, a list of selected block orders for each bidding area and the net positions (or flows) between the bidding areas”.

Redispatching “means a measure activated by one or several system operators by altering the generation and/or load pattern, in order to change physical flows in the transmission system and relieve a physical congestion” (ENTSO-E, 2012e).

Regulatory system is an expression used for instance by de Jong (2009) or by Bouttes and Leban (1995) to describe with a broad meaning a system producing a regulation for the economic and technical systems of a network industry. In this thesis, it refers to both the institutions and actors producing the regulation of a power system. It includes for instance the existing legal regulatory frameworks, the National Regulatory Authorities (NRAs) and the National Competition Authorities (NCAs), the national governments, the courts of justice and the EU bodies. It is used in particular when there is no need to refer to a precise rule or a precise actor.

Reliably Available Capacity “on a power system is the difference between Net Generating Capacity and Unavailable Capacity. Unavailable Capacity is the part of Net Generating Capacity that is not reliably available to power plant operators due to limitations of the output power of power plants. It is calculated by adding Non-Usable Capacity, Maintenance and Overhauls, Outages and System Services Reserves.

Reliably Available Capacity = Net Generating Capacity - Unavailable Capacity

Reliably Available Capacity is the part of Net Generating Capacity which is actually available in the power system to cover the load at a respective Reference Point in normal (average) conditions” (ENTSO-E, 2012o).

Remaining Capacity “on a power system is the difference between Reliably Available Capacity and Load at reference point.

Remaining Capacity = Reliably Available Capacity - (Load - Load Management)

Remaining Capacity is the part of Net Generating Capacity left on the power system to cover any unexpected load variation and unplanned outages at a Reference Point and in normal (average) conditions. Remaining Capacity is calculated in

the SO & AF report including Load Management, which increases the amount of Remaining Capacity” (ENTSO-E, 2012o).

Remedial action “means a measure activated by one or several system operators, manually or automatically, that relieves or contributes to relieving physical congestions. They can be applied pre-fault or post-fault and may involve costs” (ENTSO-E, 2012e).

Replacement Reserves (RR) “means the reserves used to restore/support the required level of FRR to be prepared for further system imbalances”. This category includes operating reserves with activation time “up to hours” (ENTSO-E, 2012l).

Restoration “a transition between the operating states characterised by the nominal operating conditions being restored, demand and generation adequately balanced, and frequency, voltage and/or load flows being restored to within predefined and allowed technical thresholds. During restoration after a major disturbance or supply interruption, demand is connected at a pace which the restored network and generation resources can accommodate” (ACER, 2011d).

Security analysis “a process using various standard software applications in the TSOs’ control centres to analyse and determine the overall system operational security ex ante or during the real-time operation. Security analyses include e.g. contingency analyses, where the impact of unplanned outages to operational security, relying on a specific security criteria, is computed using load-flows algorithm, voltage stability analyses (steady state or transients), etc.” (ACER, 2011d).

Security criteria “contain requirements and framework for the power system security control. Although a great deal of expert knowledge is inherent in these criteria and a large portion of that knowledge is common to most EU transmission grids, there exist at present no fully standardised approaches” (ACER, 2011d).

Security control “aims to maintain the power system in the normal state or as close as possible to the normal state, serving thus the maintenance of the operational security. If security degradation occurs, it is the security control task to ensure return as close, fast and efficient as possible to the normal state. Effective and successful security control results in an adequate and sufficient security level” (ACER, 2011d).

Social Welfare “means a quantification to assess the potential implications of alternative policy options. The assessment of social welfare shall include a consideration of the additional economic benefit or cost, defined as the sum of the additional individual benefits and costs which are expected to be accrued due to the implementation of the respective policy options compared to the status quo. These benefits and costs shall be analysed independently for tariff customers (as a whole and separated based on their ability to afford the cost of electricity), Market Participants and System Operators. In undertaking this assessment, in all cases, the undertaking party shall clearly specify: (i) assumptions about the redistributive effects of an increase of one of the above components for the surpluses of the other groups stated above; (ii) assumptions about preconditions for market functioning such as market power and liquidity; and (iii) assumptions about implications stemming from external effects used to undertake the analysis” (ENTSO-E, 2012e).

Sophisticated product “means a product with specific characteristics designed to reflect system operation practices or market needs, examples may include but shall not be limited to, Orders covering multiple Market Time periods and products reflecting start up costs” (ENTSO-E, 2012e).

Spare Capacity “reflects the additional capacity (in MW) which should be available on a power system to cope with any unforeseen extreme conditions. It comes in addition to system services reserves and Margin against Peak Load. Spare Capacity should be sufficient to cover a 1 % risk of shortfall on a power system, that is, to guarantee the operation on 99 % of the situations considering random fluctuations of Load and the availability of generation units. By default, a value ranging from 5 to 10 % of net generating capacity could be used at a country-level. Since load / supply severe conditions of individual countries are not likely to occur at the same day and time, Spare Capacity for a set of countries (regional blocks or whole ENTSO-E) will be expressed in the SO & AF report as 5 % of Net Generating Capacity” (ENTSO-E, 2012o).

System Frequency “Number of instantaneous oscillations of alternating current in a power system per time interval given in [Hz]” (ENTSO-E, 2012l). A nominal system frequency is decided in a power system operated in alternating current.

System Security “means the ability of the power system to withstand unexpected disturbances or contingencies; System Operator means a the role covering various tasks and operational responsibilities assumed by Transmission System Operators pursuant to this Network Code, including the physical transmission of electricity resulting from wholesale electricity market transactions and from all interconnectors which have an impact on the trading of electricity between Bidding Zones, without prejudice to the exemptions granted under Regulation (EC) No 1228/2003 and Regulation (EC) No 714/2009 which shall continue to apply until the scheduled expiry date as decided in the granted exemption decision” (ENTSO-E, 2012e); security can also mean “ both security of supply and provision of electricity, and technical safety” (EU, 2009b).

Synchronous area “is an interconnected electric power system, characterised by a common operating frequency and implemented as a set of synchronously interconnected transmission networks (control areas)” (ACER, 2011d).

System operator (SO) “refers here to both, the Transmission System Operator (TSO) and the Distribution System Operator (DSO), in their specific roles and responsibilities to run the electric power system and transmission network - both, AC and DC - according to the defined operational security and other requirements. This term refers also (when written in lower case) to the operating staff at the control room, e.g. control engineers and shift leaders” (ACER, 2011d).

System operation “covers the complete area of activities for operating an electric power network, including security, control and quality in terms of fixed technical standards, principles and procedures, but also the synchronous operation of interconnected power systems” (ACER, 2011d).

System protection “all measures (activated automatically and manually) to prevent or minimise damage to the environment (i.e. persons, nature, business, etc.) caused by the failures and/or unplanned outages in the power system and to protect the power system functioning and components. System protection also includes special protection schemes” (ACER, 2011d).

System state “means the operational state of the transmission system in relation to the operational security limits, namely: normal, alert, emergency, blackout and restoration” (ENTSO-E, 2012i).

Transmission “means the transport of electricity on the extra high-voltage and high-voltage interconnected system with a view to its delivery to final customers or to distributors, but does not include supply” (EU, 2009b). More precisely, transmission system “means the electric power network used to transmit electricity over long distances within and between Member States. The Transmission System is usually operated at the 220 kV and above for AC or HVDC, but may also include lower voltages” (ENTSO-E, 2012e).

Transmission System Operator (TSO) “means a natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the transmission system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the transmission of electricity” (EU, 2009b).

TSO responsibility area “means a coherent part of the interconnected system, including interconnections, operated by a single TSO with physical loads and/or generation units connected within the area, if any” (ENTSO-E, 2012i).

Transmission Reliability Margin (TRM) “is a security margin that copes with uncertainties on the computed TTC values arising from unintentional deviations of physical flows during operation due to the physical functioning of secondary control, emergency exchanges between TSOs to cope with unexpected unbalanced situations in real-time and inaccuracies, e. g. in data collection and measurements” (ACER, 2011d).

Total Transfer Capacity (TTC) “is the maximum exchange program between two adjacent control areas that is compatible with operational security standards applied in each system (e.g. Grid Codes) if future network conditions, generation and load patterns are perfectly known in advance” (ACER, 2011d).

Vertically integrated undertaking “means an electricity undertaking or a group of electricity undertakings where the same person or the same persons are entitled, directly or indirectly, to exercise control, and where the undertaking or group of undertakings perform at least one of the functions of transmission or distribution, and at least one of the functions of generation or supply of electricity” (EU, 2009b).

Voltage control “balancing of the reactive power needs of the network and the customers in order to maintain acceptable voltage profile” according to the IEC¹. Similarly, the voltage stability is defined as “the ability of a transmission system to maintain acceptable voltages at all buses in the power system under N-Situation and after being subjected to a disturbance” ([ENTSO-E, 2012i](#)).

Volume coupling is a form of implicit allocation of cross-border physical capacities. It is “a coupling system that partly or fully replicates the matching rules of each coupled market and utilizes indicative or actual anonymous bid/offer information. The algorithm determines the volume of exchanges between the underlying regions/markets. The local power exchanges utilize the generated crossborder volumes to locally determine their bidding area(s) prices and volumes. Loose volume coupling: the volume coupler uses partially indicative bid/offer information and might not fully replicate the local matching rules. Tight volume coupling: the volume coupler replicates the local matching rules and uses more precise bid/offer information than in the loose volume coupling case” ([ETSO and EuroPEX, 2008](#)).

Appendix B

Additional elements of analysis on the European history, energy policy and law

B.1 A brief historical perspective on the European electrification

The historical perspective shows that integrating power systems together is a fundamental trend of the European power systems driven not only by technical and economical reasons but also by political considerations. [Legendijk \(2008\)](#) and [Verbong et al. \(2002\)](#) offer a history of the influence of the economic pragmatism as well as the influence of the various conceptual ideas of Europe that pushed to cross the international frontiers.

Based on these sources, this section identifies five historical trends helping to understand the current European integration process:

- The fundamental economic drivers of the integration of neighboring power systems explain why integration has been a fundamental trend long before the current European process.
- The involvement of national governments explains the strength of the national level in the European power system organization.
- Cross-border interconnections and multinational coordination until 1990 gave an interconnected network to Europe.
- The involvement of European Union in the last 20 years has been a key driver of the current integration process.
- The regional initiatives for further coordination in the last 20 years offers interesting cases for empirical observations of past evolutions.

First drivers of the integration of neighboring power systems

The use of electricity as a vector of energy between a source and an application dates back to the nineteenth century. The first electrical systems were isolated with a specific application and/or a unique generator. In *Networks of Power: Electrification in Western Society, 1880-1930* [Hughes \(1983\)](#) offers details about how “the small, intercity lighting systems of the 1880s evolve[d] into the regional power systems of the 1920s”.

Then, power systems had been growing until reaching regional sizes in the early twentieth century with multiple coupled generators and a transmission system connecting the generators and consumption points. It was a rational technological and economical choice for, at least, the two following reasons:

- build a better generation mix, for example thanks to economies of scale or by using the complementarities between hydroelectricity and thermal units;
- offer mutual support in case a major generation capacity is not available.

Then the regional networks were connected to each others, both nationally and internationally until all major European networks were connected. This second phase can be explained both by the continuation of the original trend and the involvement of politics.

The involvement of national governments

After the First World War, the volatile financial climate impacted the network private investments, and “the diminishing role of foreign suppliers of capital and equipment coincided with another development: the encroaching influence of governments on electricity production and transmission” (Lagendijk, 2008). Hughes (1983) also underlines this turning point. The energy sector was sensible and electricity regulations took the following form in various European countries¹:

- interference with electricity prices, including maximum prices;
- stimulation of hydroelectricity;
- control of electricity exports;
- support of electricity development as a national public service.

Concerning the last point, “Such national electricity laws aimed at expanding production capacity, to interconnect regional electricity systems, and to encourage a wider distribution of electricity”. In fact this was an “electricity-for-all policy”.

During both the preparation for the Second World War and the reconstruction, public investments continued to develop networks and generation mix mainly at a national or

¹See details in (Lagendijk, 2008), pages 53–57

sub-national level. The means were similar to the ones exposed above, except that other generating technologies were supported in addition to hydroelectricity. For example, the European nuclear power development before 1986 was driven by national policy². One aim was to support economic expansion. As a result, most high voltage networks and many power generating units were owned by public companies before the liberalization process started.

[Cameron and Brothwood \(2002\)](#) state similarly that “it has been normal practice for governments to involve themselves in the energy business”. They list the following regulatory characteristics:

- Closure to competition;
- Vertically-integrated operations meaning that generation, transmission, distribution and retail are performed by the same company over a certain area;
- A high degree of planning with tight centralized control;
- Remuneration on the basis of historical costs.

Cross-border interconnections and multinational coordination until 1990

According to a study performed by [Verbong et al. \(2002\)](#), 1915-1950 was an “era of accidental cooperation”. This is illustrated by the connections between Switzerland and its neighboring countries in order to export Swiss hydroelectricity. Further intention of cooperation was anecdotic and for example the Third Reich had during the war a plan for a Europe-wide HVDC system. Nevertheless, according to [Lagendijk \(2008\)](#), “between 1929 and around 1937, the idea of such a [European] system gained acceptance in many circles and was regarded as a ‘natural’ extension of processes of interconnection taking place on (micro-)regional and, to some extent, national levels”. During this first half of the century, the European integration was made possible thanks to rather compatible technological choices over the continent. For instance, [Lagendijk \(2008\)](#) specifies that “[o]ver the 1920s, 50 Hz triple phase alternating current became the standard in most of Europe”³. Furthermore, the CIGRE (International Council on Large Electric Systems)

²See for example the English history of nuclear power described by [Taylor \(2007\)](#).

³This frequency standard is fundamental. As highlighted by [Neidhöfer \(2011\)](#), the Itaipu dam shared between a 60-Hz Brazilian power system and the 50-Hz system in Paraguay illustrates how the coordinated management required costly negotiation and infrastructures due to the lack of a common frequency.

gathered for the first time in Paris in 1921, and some Europeanists already proposed plans for a European transmission grid⁴.

Concerning the following 1950-1990 period, [Verbong et al. \(2002\)](#) describe the development of a “European network within national institutional boundaries”. In the post war period, there was a general context promoting European cooperation, at least in the Western part. Informal systems of cross-border electricity exchange within regional organizations were created backed by international organizations of more general purpose. One of these regional organization is the Union for Coordination of the Production and Transmission of Electricity (hereinafter UCPTE which later became the UCTE) created for continental Europe in 1951 by what became the OCDE. Another one is Nordel, created in Scandinavia in 1963 by the Nordic Council. Among the results of their cooperation, an “[a]greement was reached on 380 kV as the standard for main interconnections in Western Europe”, thus the voltage and the frequency were both harmonized on paper. Meanwhile, the Central Dispatch Organization (known as “CDO”) was created in the countries of Central and Eastern Europe under Soviet influence. All these organization were created and supported by political decisions. This historical perspective partly explain how the large infrastructures that now allow cross-border exchanges were built during this period.

In a step by step process over the second half of the twentieth century, the synchronous zones were merged on the continent into what became the UCTE⁵, whenever geography and politics allowed it. [Lagendijk \(2008\)](#) reports that after the electrical AC connection of East and West Germany in 1995, a representative of the UCPTE observed “[f]or the first time politicians were ahead of electricians”. When system are connected with AC cross border interconnections, they are synchronized and in addition to allowing power to be traded, it offers a mutual support for frequency control. For instance, the FCR, described in section [I.2.1](#), are pooled *de facto*. A clear description of the issues at stake is given by [Toljan et al. \(2009\)](#) while describing the reconnection of two European synchronous zones in 2004. Their paper gives at the same time an idea of the complexity of the operation and the main benefits which they summarize “into increased capability of operational optimization with reduced total costs and increased

⁴See examples and map illustrations in ([Lagendijk, 2008](#)).

⁵The UCTE is now itself part of the ENTSO-E, an association of European TSOs backed by the EU legislation ([EU, 2009d](#)).

total electricity trading volume”. In addition to these AC connections, DC links have been built between UCTE and the following zones: the British Islands, Nordel as well as countries from Eastern Europe, Middle-East and North-Africa. Figure B.1 is a picture of the system as in 1975.

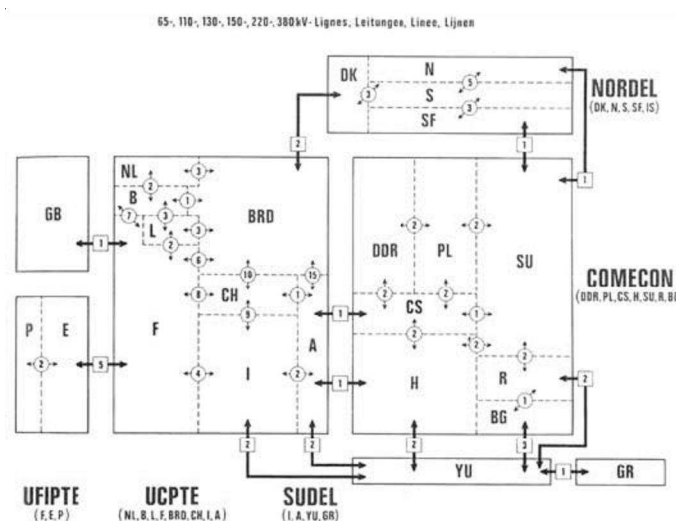


FIGURE B.1: Europe’s electrical integration and fragmentation as in 1975. Figure reprinted by van der Vleuten [van der Vleuten and Lagendijk \(2010\)](#) out of a 1976’s report from the UCPTE entitled *1951-1976 : 25 Jaar UCPTE*.

However the use of interconnection was globally not satisfactory at the end of the twentieth century. [Verbong et al. \(2002\)](#) states that in 1990 “national boundaries still provided barriers for international cooperation in production and transmission”. This is because synchronization is only the first step in the integration of European power systems. The sensible progress made concerning cross-border issues between 1990 and 2010 have been supported by the EU and implemented at regional levels as described in the following paragraphs.

Involvement of the European Union in the last 20 years

In the last 20 years, the EU framework has given a new impulsion for going beyond this first step of cooperation. [de Hauteclocque and Talus \(2011\)](#) describe the action of the EU institutions during this period. According to their work, this involvement started as follow:

As early as the beginning of the 1990s, addressing the functioning of interconnection has been a core objective of the Union and the Commission. We were however still far from addressing the market design of [the Capacity Allocation and Congestion Management (CACM)]. It was more a preliminary period with two major objectives: introducing principles of non-discrimination and transparency, and most importantly freeing interconnection from long-term priority access contracts signed before liberalization.

The result is a set of common rules ensuring in principle market-based access to some exchange capacities between neighboring networks.

The EU also supported the opening of national and regional monopolies. This action may have served the integration in at least two ways. First it paved the way for a European common market. The second way is a less direct link. Though generally being efficient at their level, national monopolies had low incentives to think at the scale of Europe. One way to create European actors is to allow part of each national system to be operated by actors already working in other European countries⁶. This is one of the fundamental aspects of European governance as highlighted by [Scharpf \(1996\)](#), referring to it as “negative integration” and links it to the “constitutionalization” of competition law⁷. Following this point of view, further integration is favored by dismantling the control of national governments over their own economic boundaries.

Finally, there are several initiatives more recently implemented by the EU in order to support the integration of the European power system which are described in chapter [IV](#).

Regional initiatives for further coordination in the last 20 years

To complete the historical perspective, the following list is a non-exhaustive overview of regional initiatives progress in the last 20 years. The focus is placed on the price coupling of wholesale DA markets⁸ because it is often emphasized by the stakeholders, but as shown later in the thesis this particular mechanism is only an emerged part of

⁶On this topic, see for instance a survey of 96 mergers and acquisitions in the EU from January 1998 to August 2002 by [Codogno et al. \(2002\)](#) showing a sensible number of cross-border cases. See also the recent case of cross-border TSO financial participation described by [Knops \(2010\)](#).

⁷The legal strength of EU competition law is assessed in section [B.3](#)

⁸Those arrangements are defined in section [II.1.4](#).

a large iceberg of coordination arrangements. Figure B.2 shows that many European countries are involved in these regional arrangements as in 2012.

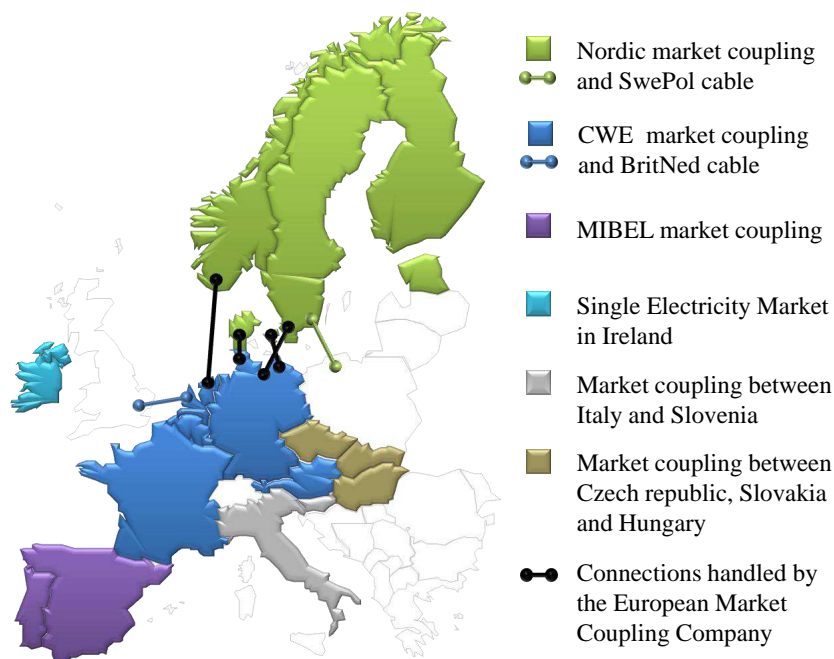


FIGURE B.2: Regional Day-Ahead price coupling and volume coupling in Europe as in 2012. Map built from the information below. This kind of map can also be found for instance in (ACER and CEER, 2012).

Nordic region and Baltic states. The [Electricity Market Group of the Nordic Council of Ministers \(2008\)](#) offers a summary of the Nordic integration between the introduction of a common spot market between Norway and Sweden in 1993 to 2008. This history shows a strong political support for both the liberalisation of the national organizations and the creation of open common markets in the region. As early as in 1996, an operator that shall become Nord Pool Spot appears as the first international Power eXchange (PX). As a result of an active process, in 2000 Denmark, Finland, Norway and Sweden share a common Day-Ahead market, Intra-Day market and market for long term cross-border financial products. In parallel, additional mechanisms have been developed between TSOs. Moreover, the integration process is still going on in 2012 as shown by the integration of the Baltic states to the common DA market ([Nordpool spot, 2012](#)) and the coordination through various nordic institutions. Besides, the SwePol cable between

Sweden and Poland has been included in the Nordic DA implicit allocation process in 2010 ([POLPX, 2010](#)).

Central Western Europe (CWE) region. A Trilateral Market Coupling (TLC) was created in 2006 between Belgium, France and the Netherland ([APX et al., 2006](#)). The enlargement of the arrangements to the whole CWE region was acted when its energy ministers signed in 2007 a Memorandum of Understanding for a DA market coupling ([Pentalateral Energy Forum, 2007](#)) resulting in a new mechanism including Germany and the Luxembourg implemented in 2010 ([APXendex et al., 2010](#)). In addition, a particular mechanism link DA capacity allocation on the BritNed cable between the Netherland and Great Britain to the CWE market coupling ([APXendex, 2011](#)).

Ireland. Following agreements signed in 2004 and 2005, the Republic of Ireland and Northern Ireland share a Single Electricity Market (SEM) since 2007 and a Single Electricity Market Operator, as a joint venture between EirGrid plc and SONI Limited ([Single Electricity Market Committee, 2012](#)).

Iberian peninsula. The ([MIBEL Regulatory Council, 2009](#)) describes the functioning of the Iberian Electricity Market over Portugal and Spain, also known as MIBEL. Several agreements have been signed since 2001 and the Spanish DA market was extended to Portugal in 2007.

Italy and Slovenia. There is a coupling of DA markets between Italy and Slovenia since 2011 ([Borzen et al., 2011](#)).

Czech Republic, Slovakia and Hungary. A coupling mechanism of Czech, Slovak and Hungarian DA electricity markets also started in 2012 ([ERU et al., 2012](#)).

These regional initiatives offer interesting cases for empirical observations of past evolutions. All along this thesis the CWE region is used as a guiding example because it is a large area⁹ at the centre of the European power system . The Nordic region is also mentioned at several occasions because it has a strong history of successful coordination and because of it is involved in an interregional coordination with the CWE region.

⁹The CWE region gathers about 40 % of the load in the areas covered by the European association of TSOs ([ENTSO-E, 2012c](#)).

B.2 General objectives of energy policies and the European energy policy

(a) A diversity of possible objectives

This section gives first an overview of the classical energy policy objectives composing an energy policy. Since a power system is one of the main vector of energy, the European energy system is meaningful level to choose the objectives that shall drive a power system policy. At this level, the diversity of energy objectives applicable to power systems¹⁰ can be gathered in four sets detailed below:

Physical ability to deliver energy in an adequate form, when and where it can generate wealth. This first set covers for instance reliability issues because a physical shortage of energy can impact negatively the welfare of a society. It is the case during a large blackout of the power system ([International Energy Agency, 2005](#)). Besides, a minimum level of power quality is expected to be maintained for power system products.

Acceptable costs of delivery. This second set covers affordability. Overall, the system cost for the society should be kept at a reasonable level. Moreover, it can be decided that every citizen should have access to the energy system. In developed countries, social scheme for energy access are designed for poor people.

Coherence with other economic policies directly linked to energy. Beyond the cost issues mentioned above, the impact of a general economic policy of a political authority on its energy policy can take additional forms. For instance, an industrial policy can lead to promote a specific technology of electricity generation. On the demand side, the promotion of electrically driven modes of transportation such as electric cars and electric public transports shall be coordinated with the development of the power system to supply these new modes of consumption. Similarly, the policy on heating technologies for buildings and isolation can have

¹⁰See for instance ([European Council, 2011](#)) promoting a “safe, secure, sustainable and affordable energy”. See also the academic perspective of [Knops \(2008b\)](#) or the “three A’s” definition by the world energy council website http://www.worldenergy.org/publications/energy_policy_scenarios_to_2050/the_3_as/892.asp, last visited November 2012.

a strong impact on the demand profile. The power system objectives could include the adaptation with sufficient anticipation to the induced new constraints and opportunities.

Adequate management of the environmental impact. This fourth set of objective corresponds to the coherence with environmental policies. The objective is to internalize environmental impact through common agreements because acceptability is a key issue in our modern democracies. Indeed, elected governments are not supposed to build new infrastructures or operate existing plants against the will of the population. This is why the Not In My Back Yard (NIMBY) reaction at a local level is a complex issue to handle for authorities at all geographical level. This acceptability issues can more specifically include local pollution or global sustainability issues when it impacts climate change.

Out of this four sets of classical objectives, it is necessary to select priorities and compromises to build a coherent energy policy. Once a coherent direction has been selected, the energy policy should be, at least partly, translated into a set of intermediary goals, indicators or policy tools. Section III discusses the economic tools available to produce indicators. For instance, increasing the use of a renewable energy generation technology to a higher level is an intermediary goal that can serve industrial and environmental objectives if they are weighted more than the potential additional costs.

In any case the policy shall be served by efficient operation of the energy system as well as an efficient use of energy and efficient investments with regard to the objectives selected.

(b) Example of the European Commission's energy policy

The objectives selected for the EU by the [European Commission \(2007a\)](#) can be found in a communication to the European Council and the European Parliament, entitled “[a]n energy policy for Europe”. This comprehensive non binding document uses a framework with three entries:

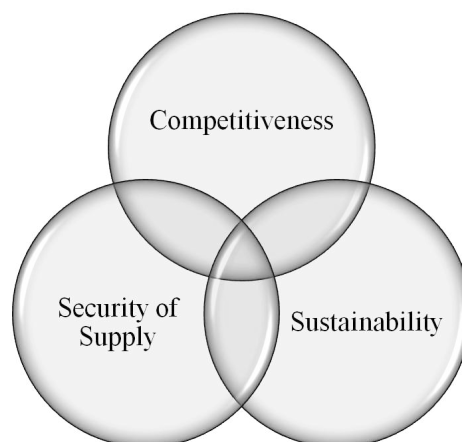


FIGURE B.3: Example of objectives mapping using overlapping circles.

Sustainability refers to environmental sustainability and, more precisely, the aim is to actively tackle climate change by promoting renewable energy sources and energy efficiency¹¹.

Security of supply covers two main challenges¹². The first is to decrease the dependence on imported fossil fuels. The second is to ensure solidarity between member states in the event of an energy crisis.

Competitiveness takes a broad definition with various social and economic aspects including the level of economic activity localized in Europe. For instance, a functioning internal market should help the EU economy to receive full benefits of energy liberalization. Indeed, competitive energy prices should emerge and energy-intensive industries should not suffer from international competition. The Commission foresees also more investments and innovation resulting from a properly functioning market.

One can see these three topics as three overlapping circles as in Figure B.3. Indeed, some political decisions can serve two or three of these objectives at the same time. To reach these objective, making the internal energy market work, *i.e.* the continuation of the liberalisation process and the European integration process are the key policy tools according to the [European Commission \(2012\)](#).

¹¹As summarized on the website of the Commission http://europa.eu/legislation_summaries/energy/european_energy_po visited in August 2010.

¹²Please note that as highlighted by [Winzer \(2012\)](#) the term security of supply can have many other meanings.

B.3 Reminder on the EU law in a multilevel energy governance

This section summarizes three legal aspects of EU law impacting the research object:

- Section [B.3.1](#) describes the vertical division of power between the EU and the member states because it both supports and draws limits to the legitimacy of the EU law on energy issues .
- Section [B.3.2](#) focuses on the EC role and the Comitology process
- Section [\(b\)](#) describes the connection between non-EU countries and the EU law or other international agreements with the EU.

B.3.1 Principles behind the EU competences on the energy sector

The following paragraphs describes that the EU power are limited by legal principles and in term of area of competences.

General legal principles of the EU law

The EU law has a sovereignty over member states law garanted by international treaties as well as case law and it is limited by the principles of conferral, subsidiarity and proportionality.

The sovereignty of EU law over member states law. This sovereignty is described as a combination of principles. First the supremacy of EU law is ensured by the primacy of EU law and the pre-emption doctrine. The primacy refers to the fact that the laws of European Union member states that conflict with laws of the European Union must be ignored by national courts. This doctrine emerged from Court cases as remembered in the Declaration concerning Primacy in annex of the Treaty on the Functioning of the European Union (TFEU) ([EU, 2010d](#)):

In accordance with well settled case law of the Court of Justice of the European Union, the Treaties and the law adopted by the Union on the

basis of the Treaties have primacy over the law of member states, under the conditions laid down by the said case law.

As primacy, the pre-emption doctrine's content can be deduced from the Court's case law¹³. Under this doctrine, member states are prohibited from legislating if it could conflict with EU law to the extent of its competence¹⁴. Hence it is in a way complementing the primacy. One of the foundations of both these principles is the principle of sincere cooperation between the EU and the member states as reminded in Article 4(3) of the TEU:

The member states shall take any appropriate measure, general or particular, to ensure fulfillment of the obligations arising out of the Treaties or resulting from the acts of the institutions of the Union.

The member states shall facilitate the achievement of the Union's tasks and refrain from any measure which could jeopardize the attainment of the Union's objectives.

Then, the principle of direct effect refers to the fact that, for example, regulations and decisions emitted by EU institutions can be considered as act of parliament by national court as they need no further implementation by member states, thus the term direct effect. Under this doctrine, directives can have direct effect provided they are sufficiently clear, unconditional and precise. Whether or not any particular measure satisfies the criteria is a matter of EU law to be determined by the EU Courts. This means by contrast that most of a directive's impact can to a certain extent be modulated by member states in the transposition process into national law.

The principles of conferral, subsidiarity and proportionality. These three principles concerning the EU competences are defined in a clear way in Article 5 of the Treaty on European Union (TEU) (EU, 2010d):

The limits of Union competences are governed by the principle of conferral. The use of Union competences is governed by the principles of subsidiarity and proportionality.

¹³According for example to (Delvaux and Guimaraes-Purokoski, 2008)

¹⁴See for example the definition by (Chalmers, 2006) p.188 of *European Law*

Under the principle of conferral, the Union shall act only within the limits of the competences conferred upon it by the member states in the Treaties to attain the objectives set out therein. Competences not conferred upon the Union in the Treaties remain with the member states.

Under the principle of subsidiarity, in areas which do not fall within its exclusive competence, the Union shall act only if and in so far as the objectives of the proposed action cannot be sufficiently achieved by the member states, either at central level or at regional and local level, but can rather, by reason of the scale or effects of the proposed action, be better achieved at Union level.

Under the principle of proportionality, the content and form of Union action shall not exceed what is necessary to achieve the objectives of the Treaties.

The applicability of the principle of conferral rely on the ability of the TFEU to define the level and area of competences. The application of the two others is guided by the protocol (No 2) of the TFEU on the application of the principles of subsidiarity and proportionality.

Relevant area of competences as defined in the Treaties.

The international agreement supporting the EU power has been shaped by various treaties signed between 1951 and now, including the protocols and annexes of these treaties. The last updates have been agreed in the Lisbon Treaty¹⁵ and the whole EU primary law is in 2011 made of four consolidated documents:

Treaty on European Union (TEU) (EU, 2010d). This treaty defines the role of the EU, its legal personality, its institutions and some aspects of its practice. For instance, article 3 states that the Union shall establish an internal market and this support the EU action to build an internal market of electricity.

Treaty on the Functioning of the European Union (TFEU) (EU, 2010d). As stated in its article 1: “[t]his Treaty organizes the functioning of the Union and

¹⁵It entered into force in 2009.

determines the areas of, delimitation of, and arrangements for exercising its competences”. Its content is further detailed below.

Charter of Fundamental Right of the European Union (EU, 2010b). This charter is primary law since the entry into force of the Lisbon Treaty in 2009¹⁶. It settles legal basis at the EU level concerning human rights. It states for example that the Union shall ensure environmental protection and consumer protection.

Treaty Establishing the European Atomic Energy Community (also known as EURATOM) (EU, 2010c). It acts in several areas connected with the atomic energy, including research, safety standards, investment issues, fuel issues and the peaceful uses of nuclear energy (see article 2). Some European directives are based specifically on this treaty¹⁷. In practice, the rule of every country having a veto power is maintained in this area. This particular treatment out of the three first documents can be explained by the high sensitivity of the topic for member states.

Table B.1 gives a selection of articles of the TFEU (EU, 2010d) rather directly related to the european power systems. Most of the binding secondary law¹⁸ quoted in this chapter refer to one or more of these articles of the treaty among their legal ground.

Article(s)	Topic
Art. 3 and 4	Categories and areas of the EU competences
Art. 26 to 27	Internal market
Art. 101 to 106	Rules on competition: rules applying to undertakings
Art. 107 to 109	Rules on competition: aids granted by States
Art. 114 to 118	Rules on competition: approximation of laws
Art. 122	Solidarity between member states
Art. 169	Consumer protection
Art. 170 to 172	Trans-European networks
Art. 191 to 193	Environment
Art. 194	Energy

TABLE B.1: Articles of the TFEU related to power systems.

Exclusive versus shared competences. Article 3 states that “the establishing of the competition rules necessary for the functioning of the internal market” is an *exclusive competence* of the EU. It means that where Art 101 to 118 apply, the EU is

¹⁶See article 6 of the Treaty of Lisbon, OJEU C 306, 17.11.2007, p. 1.

¹⁷See for example Council Directive establishing a Community framework for the nuclear safety of nuclear installations (EU, 2009a).

¹⁸i.e. the directives, regulations and decisions.

not subject to the principle of subsidiarity, as quoted in section B.3.1. Meanwhile, the EU has *shared competence* with the member states over several areas including internal market, environment, trans-European networks and energy. This distinction strengthens considerably the EU competition law compared to other binding rules based for example on the other articles selected from the TFEU in table B.1.

Detail of the energy chapter in the TFEU. Article 194 of the TFEU deserves a full quotation since energy is its main topic:

1. In the context of the establishment and functioning of the internal market and with regard for the need to preserve and improve the environment, Union policy on energy shall aim, in a spirit of solidarity between member states, to:

- (a) ensure the functioning of the energy market;
- (b) ensure security of energy supply in the Union;
- (c) promote energy efficiency and energy saving and the development of new and renewable forms of energy; and
- (d) promote the interconnection of energy networks.

2. Without prejudice to the application of other provisions of the Treaties, the European Parliament and the Council, acting in accordance with the ordinary legislative procedure, shall establish the measures necessary to achieve the objectives in paragraph 1. Such measures shall be adopted after consultation of the Economic and Social Committee and the Committee of the Regions. Such measures shall not affect a member state's right to determine the conditions for exploiting its energy resources, its choice between different energy sources and the general structure of its energy supply, without prejudice to Article 192(2)(c).

3. By way of derogation from paragraph 2, the Council, acting in accordance with a special legislative procedure, shall unanimously and after consulting the European Parliament, establish the measures referred to therein when they are primarily of a fiscal nature.

Besides, among the annexes of the TFEU, the “Declaration on Article 194 of the Treaty on the Functioning of the European Union” states that article 194 does not affect the

right of the member states to take the necessary measures to ensure their energy supply under the conditions provided for in Article 347. Since the conditions of this article deals with disturbances affecting the maintenance of law and order, it acknowledge that energy supply is more important than the internal market in extreme conditions.

However, before the Lisbon Treaty, energy was not explicitly an area of competence of the EU. This fact did not prevent the EU from producing binding documents in this grey area based on cross topic competences as described in the next paragraph.

How the EU used cross topic competences before the energy chapter. Article 352(1) of the TFEU (EU, 2010d) states that the Council, to attain one of the objectives set out in the Treaties if these documents have not provided the necessary powers, may still adopt appropriate measures, if the action prove necessary and acting unanimously on proposal from the Commission and after obtaining consent of the European Parliament. The limits of this opening is to be given by the Court¹⁹ but as a practical limitation, the unanimity must be found in the Council.

In addition to this article and in order to illustrate how the EU has made use of some of its competences in areas where it had none, this section looks at the legal foundation of energy legislation used before the third package and the Lisbon Treaty. In fact, there was no equivalent of Article 194 of the TFEU on energy before 2009²⁰. However, as described by (Delvaux and Guimaraes-Purokoski, 2008), “the Community legislature’s competence in the energy area has not evolved in a vacuum”. In practice it has been based on, at least, the internal market objective and the environmental competences. One might also have added the EU primary law concerning economic policy, consumer protection and of course trans-European networks.

Among the primary law giving powers to the EU for installing a functioning internal market, Article 114 of the TFEU on the approximation of laws is used when harmonisation is among the objectives. For example the main electricity directive (EU, 2009b) is taken under this article. Similarly, the directive on a common framework for the taxation of energy product and electricity (EU, 2003a) is taken under the Article 113 of the TFEU.

¹⁹See for example the cases and opinion of the Court given by (Delvaux and Guimaraes-Purokoski, 2008).

²⁰See for example the consolidated Treaty of the European Community of 2006. OJEU C 321, 29.12.2006, p. 1.

Concerning environmental competence, the legitimacy to act in the energy area comes from what are now Article 191 and 192 of the TFEU²¹. Indeed since the energy system is a natural area of action to meet the objectives of Article 191(1), the EU has competence. However, in the case of a legislation impacting the choice of energy supply for example, respecting the procedure and provisions of Article 192(2) require the unanimous act of the Council. As a consequence any action require absolute consensus between member states.

These examples show how in the past the EU energy policy has found legal ground and how cross topic competences have been used within the framework of the vertical division of power between the EU and the member states.

The European Court of Justice. Article 19 of the TEU (EU, 2010d) defines the existence and role of the European Court of Justice. Among its task, it is competent to judge that the EU power is used in accordance with the EU treaties and that the EU law is applied by all member states as well as institutions, natural and legal persons under the EU law.

This EU institution has thus a sensible impact on both the practice and the doctrine concerning the EU competences on the energy sector and the effective impact of the existing EU law.

B.3.2 Focus on the EC and the Comitology

The EC (also referred as the Commission) is an institutional body at the heart of the EU. This brief focus describes the EC powers and the control of its actions by committees through what is known as Comitology.

The EC power

Article 17 of the TEU (EU, 2010d) states that:

The Commission shall promote the general interest of the Union and take appropriate initiatives to that end. It shall ensure the application of

²¹See section B.3.1. This exclude Article 11 of the TFEU which only states that where the EU has competence, environment protection shall be taken into account

the Treaties, and of measures adopted by the institutions pursuant to them. It shall oversee the application of Union law under the control of the Court of Justice of the European Union. It shall execute the budget and manage programs. It shall exercise coordinating, executive and management functions, as laid down in the Treaties. [...] It shall initiate the Union's annual and multi annual programming with a view to achieving inter institutional agreements.

In the same article, the legislative initiative is given to the Commission in the general case:

Union legislative acts may only be adopted on the basis of a Commission proposal, except where the Treaties provide otherwise.

To understand the importance of this body, it might be seen as a form of 'European Government'. The president of the EC is proposed by the European Council and elected by the parliament and the Commission has in total 27 members representing each member states. It is divided in portfolios, including Energy, Environment, Climate Action, Competition, Trade, Internal Market and Services. The current Commission has been approved in February 2010 and is due to serve until 2014²².

About the legislative initiative and the agenda setting power. As quoted above, the EC has a hand on the legislative agenda. For instance, in the last 15 years, three electricity directives repealing each the previous one have been produced²³ among numerous other binding texts including those described in section IV.1.3. However, this movement is slowed down by the member states. Indeed, the last electricity directive 2009/72/EC voted in 2009 ought to be implemented by march 2011 by the member states (except for Art 11 of the directive), but most of the member states are failing this deadline. Between September 2011 and November 2012 the EC "has launched 19 infringement cases for nontransposition of the Directive 2009/72/EC" (European Commission, 2012). In practice, this kind of procedure can often be seen as a warning and an invitation to seek for solutions to complete the transposition and implementation

²²See the Commission website for more information http://ec.europa.eu/index_en.htm.

²³Directive 96/92/EC, directive 2003/54/EC and directive 2009/72/EC.

process. More generally, [Tsebelis and Garrett \(1996\)](#) argue that the agenda setting power, including “the ability to make proposals that are difficult to amend”, is an important part of the decision making process. For additional points of view, [Peters \(2001\)](#), [Schmidt \(2000\)](#) also discuss the place of this power within the EC means of action.

About the power of soft law. Among alternative means to classical binding legal acts, there are voluntary agreements and non-binding legal acts (like recommendations) which can be referred to as soft law²⁴. A paper from ([Schäfer, 2006](#)) suggests that “non-binding coordination is first and foremost a means to foster compromises in the absence of substantial agreements”. More generally, it is a way to put common objectives on paper.

About the competition, environment and climate portfolios The competition portfolio of the Commission is both very active and very effective in the liberalisation process, thanks to the EU power in this area of competence as highlighted previously. Three fields of action are described in section (b): antitrust, merger and State aid. Meanwhile, some visible actions in the environmental area of competence are given in section (b). The observation is that despite limited power, the Commission succeeds to build step by step a binding framework supporting environmental objectives.

Committees: a control of the Commission’s actions.

The legislative branch of the EU, composed of the European Parliament and the Council, can delegate implementation power to the executive branch, being the Commission. Within this context, the Treaty provides for the Commission to be assisted by committees which represent the control by the member states. These committees are made of one expert per member state and the voting procedures are related to the Council voting procedures for legislative acts. Since the work of these committees has an impact on the implementation of EU law, they should be controlled as emphasized by [Dehousse \(2003\)](#) in “Comitology: Who watches the watchmen?”. Indeed, there has long been a

²⁴See for example ([Senden, 2004](#)), *Soft law in European Community law*.

lack of transparency, but the situation has been improved incrementally since 1999. For instance in 2006, a committee register with public access²⁵ has been created.

About the old and new comitology procedures. For most pieces of EU law concerning power systems such as regulation 714/2009 (EU, 2009d) about the network code procedure, the control of the Commission implementing powers was organised following the Council Decision 1999/468, amended in 2006 (EU, 2006a). The procedure has been known as comitology²⁶ and the term is commonly used even if it is not an official legal term in the text. In practice four types of procedures were defined: the advisory, the management, the regulatory and the regulatory with scrutiny procedures²⁷.

Since 2011, a new regulation is in charge “control by member states of the Commission’s exercise of implementing powers” (EU, 2011c). This new regulation of the committees control is based on article 291 of the TFEU (EU, 2010d) about implementing acts and it simplifies the situation with two modes of control: advisory procedure and examination procedure²⁸. It repeals the previous Council Decision 1999/468 with adequate transitional provision and one exception: “The effects of Article 5a of Decision 1999/468/EC shall be maintained for the purposes of existing basic acts making reference thereto”. This article is about the regulatory procedure with scrutiny and it is exactly the one referred for the network code adoption as an appendix of regulation 714/2009, *i.e.* as a legal binding document (EU, 2009d). Thus the comitology procedure in the adoption of the network codes should not be strongly impacted by this new regulation.

Example of the network codes potential adoption. The relevant committee is the “Committee on the implementation of legislation on conditions of access to the network for border exchanges in electricity”²⁹. Its final implication in the adoption procedure of a NC is described here in a simplified version based on the relevant Council

²⁵See web page of the 2008 updated version <http://ec.europa.eu/transparency/regcomitology/index.cfm>, last visited in August 2010.

²⁶See definition of Comitology in Europa; Glossary on the web page http://europa.eu/legislation_summaries/glossary/comitology_en.htm, last visited in January 2013.

²⁷See Comitology Decision (EU, 2006a) for details on these former procedures, the safeguard procedure could have been added to this list.

²⁸For an overview of the current procedures, see the EC webpage <http://ec.europa.eu/transparency/regcomitology/index.cfm?do=implementing.home>, last visited March 2013.

²⁹Its activity can be found on the comitology register with the committee code: C08200. See webpage url <http://ec.europa.eu/transparency/regcomitology/index.cfm?do=HowTo.howto>, last visited January 2013.

Decision (EU, 2006a). When the document is deemed ready by the Commission to be adopted as EU law, the committee's opinion shall be delivered with a voting procedure requiring a qualified majority³⁰. If "the measures envisaged by the Commission are in accordance with the opinion of the committee", then the document shall be adopted unless the European Parliament or the Council opposes the document within three months based on a particular set of justifications including for instance the fact that it would not comply with the subsidiarity or proportionality principle. If the opinion is negative, then a different sequence involves first the Council which is expected to act within two months and which can oppose the proposed measures without constraints on the justifications. Then, if the Council has not opposed the proposition, the Parliament is expected to vote within four months. If the proposition is opposed, the Commission can nevertheless submit an amended proposal or present a legislative proposal on the basis of the treaties.

B.3.3 Additional EU law related to power system regulation

(a) The security of electricity supply

The directive on electricity security of supply (EU, 2006c) defines its object in Article 2(b) as "the ability of an electricity system to supply final customers with electricity". Largely inspired from a study by (Bjørnebye, 2008) this section gathers commentaries on the relevance and potential impact of this directive as an example of directive's analysis.

According to article 1 of this directive, the ambition is put on adequate generation capacity and an appropriate level of interconnection. Concerning the generation, balance between supply and demand means "the satisfaction of foreseeable demands of consumers to use electricity without the need to enforce measures to reduce consumption". Hence the responsibility is placed on generation capacity rather than consumption. Meanwhile, the economical efficiency criteria is not explicitly used. In fact it may barely be assumed that it is included in the term "adequate" used in Article 1. As such it means that the cost of peak capacities would be preferred to the cost of interruption of distribution of electricity to final consumer even if the first one is higher. However two statements offer limits to this requirement. The first can be found in the general provisions, in

³⁰As laid down in Article 238(2) of the TFEU (EU, 2010d)

Article 3(4) : “member states shall ensure that any measures adopted in accordance with this Directive [...] do not place an unreasonable burden on the market actors”. The second can be found in the preamble, interpreting another directive and stating that policies “should not result in generation capacity that goes beyond what is necessary to prevent undue interruption of distribution of electricity to final consumer”. According to (Bjørnebye, 2008), the relevance of this last statement is not obvious and it is hard to assess it in practice.

In order to apply these requirements, the roles and responsibilities need to be precisely defined. On the particular issue of ensuring sufficient reserve capacity, Article 5 precises that “member states shall [...] require transmission system operators to ensure that an appropriate level of generation reserve capacity is available for balancing purposes”. However, this obligation is already given to TSO in Article 12(d) of the 2009 electricity directive (EU, 2009b). Hence this directive does not clarify further the situation. Likewise, other minor provisions concerning member states can already be found in other directives.

A benefit of this directive could be the fact that it fixes in the legislation an obligation to facilitate a “stable investment climate”. Indeed since the choice has been made to let private investors in charge of the new generation and (a share of) the new transmission infrastructures, the more the regulation is stable, the more efficient and coherent these long term investments can be expected to be. This obligation is explicitly made in Article 3(1), with some detail like the fact that transparency is part of the solution. However, as noticed by Bjørnebye, the directive does not provide much guidance on what is meant by a “stable investment climate”. Once again there lies an objective that is hard to assess.

Bjørnebye concludes that the directive “focuses almost exclusively on [...] how to ensure the making of sufficient investments” and the fact that “new investment should be market-based”. However, he suggests that this security of electricity supply directive should have been adopted as amendments of the electricity directive, because of the reduced added-value and the overlapping with other directives. One of the reason is that overlapping between directives can make the situation unnecessarily complex. In addition to that his main concern is “the fact that unclear provisions, such as the obligation

to facilitate a stable investment climate, are liable to create regulatory uncertainty for member states”.

(b) **Environmental policy**

Three issues at the crossing of EU energy policy and EU environmental policy are introduced in order to show that:

- The economic impact of any environmental policy is taken into account.
- The national energy sources are out of the EU scope.
- Some constraints are harmonised at the EU level and for instance there is a common carbon price resulting from a climate policy.

About the economic impact of an environmental policy. Since the use of energy is associated to many negative externalities concerning the local and global environment, the related law has a sensible impact on the energy policy. For example, some coal-fired power plants may not fulfil certain requirements³¹.

As stated in Article 191 of the TFEU (EU, 2010d), “the economic and social development of the Union as a whole and the balanced development of its regions” shall be taken into account when preparing the EU policy. It shows that the economic interest shall be officially put in the balance when considering environment protection at the EU level.

National energy sources. As mentioned in Article 191 of the TFEU, the Union policy shall contribute to a “prudent and rational utilisation of natural resources”. This could include the resources that are used to generate power, be it gas or water for example. However, according to (Delvaux and Guimaraes-Purokoski, 2008) referring to (Cameron and Brothwood, 2002), an “Intergovernmental Conference noted that the Community’s activities in environmental matters may not interfere with national policies on the exploitation of energy sources”.

³¹See for example the news released by Reuters, “EU states give 14 more years to dirty coal plants”, Fri Jun 18, 2010 3:40pm GMT, available at <http://af.reuters.com/article/worldNews/idAFTRE65H3L520100618>, visited in August 2010. It can be linked to the impact of directive 2008/1/EC of the European Parliament and of the Council of 15 January 2008 concerning integrated pollution prevention and control, OJ L 24, 29.1.2008, p. 8.

EU climate policy. As expressed in a communication from the ([European Commission, 2007a](#)), to combat climate change is an objective of the European energy policy. Indeed, energy related activities are the main threat for climate change, since according to ([Eurostat, 2009](#)), the sector of energy accounted in 2007 for 80 % of the total EU greenhouse gases emissions (60 % excluding transport) and according to the Intergovernmental Panel on Climate Change³² these gases can impact the climate.

The European Community (which is now the EU) has signed the Kyoto protocol, founding its competence to enter into international agreement on Article 192. However, it is not an exclusive competence of the EU and this signature is in addition to the member states' ones. Article 191 also reminds on this topic that “within their respective spheres of competence, the Union and the member states shall cooperate with third countries and with the competent international organisations” which allows the EU to be globally responsible for its greenhouse gases emissions for example.

In this case, according to Article 24(2) of the Kyoto protocol³³, the EU (addressed as a regional economic integration organization) and its member states “shall decide on their respective responsibilities for the performance of their obligations under this Protocol” and they “shall not be entitled to exercise rights under this Protocol concurrently”.

On this issue, a Declaration by the European Community³⁴ reminds that the distribution of competences is already define in the primary law. Indeed it is the only legitimate distribution of power between the two levels. As a consequence, finding the equilibrium is neither more simple, nor more complex than on related issues.

In the EU legislation, the Kyoto protocol has been adopted by council decision ([EU, 2002](#)) and the implementation of the EU Emission Trading Scheme (hereinafter EU ETS) has been prepared in 2005 by the directive 2003/87/EC ([EU, 2003c](#)) establishing a scheme for greenhouse gas emission allowance trading within the Community. The resulting scheme is a European multi-sector greenhouse gas emission trading system involving the power sector until 2012. This directive has been amended by the directive 2009/29/EC ([EU, 2009e](#)) reshaping the scheme for the 2013 - 2020 period.

³²It is the leading body for the assessment of climate change, established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO). As stated in what is now Article 191(3) of the TFEU ([EU, 2010d](#)), the Union shall take into account the available scientific and technical data when preparing its policy on the environment, which includes this panel's work.

³³This document can be found in annex of the council decision about the BSA ([EU, 2002](#)).

³⁴This document is also put in annex of the council decision about the BSA ([EU, 2002](#)).

Appendix C

Study of an Interim Tight Volume Coupling solution

This section is adapted from ([Janssen et al., 2012](#)). The case studied is the Interim Tight Volume Coupling (ITVC) operated by the European Market Coupling Company (EMCC) that implicitly allocates the interconnection capacities between CWE and Nordic (Nordpool) day-ahead electricity spot markets. As indicated in its own name, this interim solution is to be replaced in the near future, by a single price coupling option. This case has been selected for three reasons. First, it is an interesting example of implementation solution involving technical limits and interactions with internal organization features. Second, it is a case where a theoretical mathematical model has been developed and applied by the author to answer a pragmatic question about the causality of an unwanted effect and to complete the existing economic literature on this solution. Third, though it is to be replaced by a single price coupling in the near future, the volume coupling principle might still inspire pragmatic solutions for future challenges in other situations.

In order to learn from the current experience, this section offers elements of understanding on the interim volume coupling run by the EMCC that are not highlighted in the documents already available. In particular, a new analytical model of the tight volume coupling is developed to show that the ITVC principle would not generate any inefficiency under three assumptions. This result offers a new perspective on the causality of adverse flow events. Furthermore, this model could be used to study other tight volume

coupling mechanisms because it can be applied with minor modifications to any number of areas, other kinds of traded products or areas using a flow-based method.

Section C.1 and C.2 describe respectively the ITVC role and an analytical model of the optimizations performed during the volume coupling as well as the price coupling taking place in each region. Then section C.3 introduces what is known as adverse flow events and apply the model to help understand the causality of these events. Last, learning from the ITVC experience, this paper describe in section C.4 one example of improvement of the tight volume coupling method based on a stronger coordination between the numerical solvers. This improved mechanism could serve as an interim solution if a price coupling numerical solver does not provide satisfactory results because of the optimization problem size or complexity. In this case, the proposed solution is expected to be a satisfactory implicit allocation method from both a technical and a governance points of view.

C.1 Description of the EMCC volume coupling

The EMCC volume coupling as the result of key choices

As described in section I.2, the European electricity day-ahead markets are currently based on zonal pricing, meaning that the markets are organized in rather broad zones with a homogeneous price for each electricity product in each zone. At each border between two zones that are physically connected, there is a possibility for cross-border trade as long as the power transmission capacity are not congested. Therefore, an efficient method of capacity allocation shall be in place to allow cross-border trade while preventing congestions on the network.

First of all, it is agreed within the European Union that a market-based allocation method shall be used (EU, 2009d). Then, implicit allocation is currently preferred to explicit allocation by a wide consensus of European stakeholders (ACER, 2011e) for the reasons expressed in a focus of section II.1.4 describing the allocation function. Finally, the preference for a price coupling solution is strong in Europe (ACER, 2011e). This option is implemented at a regional level over the CWE and Nordic regions as described in the next section. However, this option has not been implemented yet to allocate

cross-border capacities on cables linking the Nordic region and the CWE region. This might be explained by a lack of harmonization or governance issues between the two areas (Meeus, 2011a). Until a single price coupling becomes reality over both regions, the implicit volume coupling solution has empirically proved to be able to handle these hindrances with limited drawbacks, including those discussed in section C.3. Volume coupling is thus the current functioning option, taking explicitly the name of “interim” solution.

In practice, a volume coupling can be applied with more or less accuracy as a consequence of, among other factors, a lack of compatibility between the products on the coupled markets. The term tight is used when the volume coupling “uses full information on the bids and offers submitted in each constituent market and fully replicates the individual matching rules” (ETSO and EuroPEX, 2008). On the contrary, a loose volume coupling misses at least one of these conditions. In the case studied, the EMCC runs a tight volume coupling. Pragmatically, it means that the optimization problem handled by the EMCC volume coupling replicates constraints and objective functions of the price couplings performed in the areas it is coupling. Unless specified explicitly, the term tight volume coupling shall be referred in this paper simply as volume coupling.

Description of the EMCC action in the day-ahead markets.

The objective of the volume coupling is to allocate the interconnection capacities between market areas using independent price coupling algorithms. In the case of the EMCC, two day-ahead market couplings using zonal pricing are connected, namely (see figure C.1):

- The CWE region, covering Belgium (BE), France (FR), Germany (DE), the Luxembourg (LU) and the Netherlands (NL);
- The Nordic market covering Denmark¹ (DK), Estonia (EE), Finland (FI), Norway (NO) and Sweden (SE).

Both market platforms offer the possibility to submit block bids, i.e., bids linking several hours together. This kind of bids shall introduce dynamic constraints in the optimization

¹The Western Denmark zone is synchronous with the CWE area but it is included in the Nord-PoolSpot market.

process described in section C.2 and they are a key element in the explanation of adverse flow events given by EMCC, as summarized in section C.3.

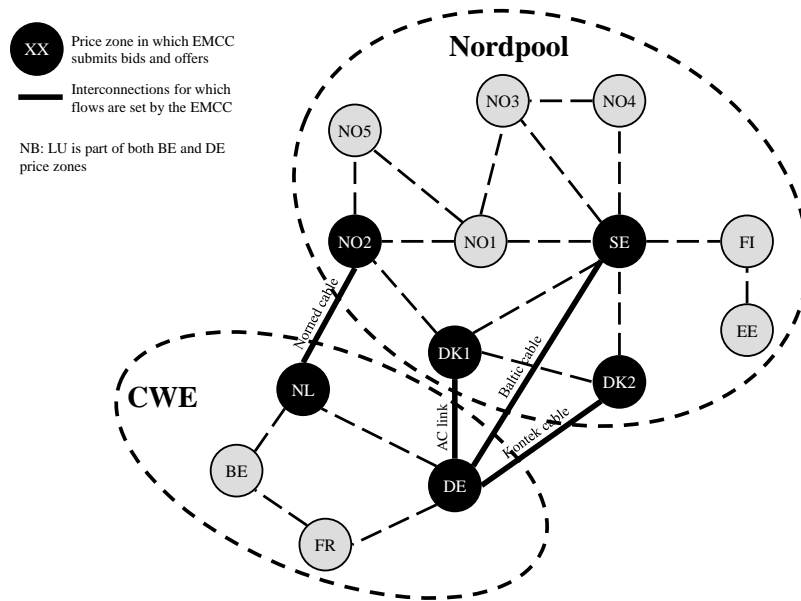


FIGURE C.1: Overview of the geographical situation of EMCC's ITVC as in September 2011

In practice, the process can be described with three chronological steps (see figure C.2, using notations that are introduced in sections C.2 and C.3):

1. The power exchanges (PXs) operating day-ahead market platforms collect selling and purchasing bids in each of the two areas, while the TSOs calculate the available commercial capacities. The PXs receive the TSOs data while all data are sent to EMCC.
2. EMCC fixes the interconnection flows between both areas, which are represented in plain lines in figure C.1.
3. Two independent price couplings are performed in the Nordic market and the CWE region taking into account the interconnection flows through specific bids and offers.

Step (2) and (3) are performed within a limited period of time which must also include the time to send the information in step (1). This period starts with what is known as the gate closure for submitting offers and bids in the day-ahead market and it ends

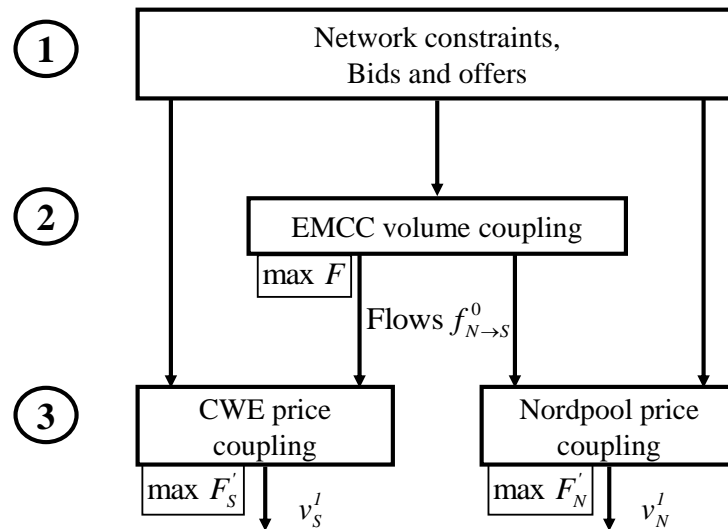


FIGURE C.2: Overview of the ITVC process as in September 2011

with the market clearings, i.e., the decision of accepting or rejecting offers and bids that are sent to the market players. It is agreed that the duration of this calculation period shall be kept as low as possible. Indeed, the sooner the market players are informed of the market results, the better they can handle other tasks requiring this information, such as the optimization of the generation portfolios. Therefore, there is in principle a maximum duration for each optimization numerical solver.

Finally, additional features of the optimization problem solver are interesting for the perspectives given in section C.4:

- The optimization problem, described in section C.2, can be expressed by Mixed Integer Linear Programming (MILP). Indeed, the problem can be modeled with continuous and binary optimization variables and a linear objective function.
- The numerical solver run by EMCC uses a branch and cut method (EMCC and REM, 2010).

The most interesting characteristic of this problem is the complexity added by binary variables which are here to model the bids with dynamic constraints. Moreover, when the number of these binary variables is multiplied by two, the calculation time to solve the problem can be much more than twice longer. This explains that despite the great current potential of the numerical solvers, the duration constraints introduced in

the previous paragraph may prevent from finding every times the optimum solution of the problem.

C.2 Analytical model of the market coupling optimizations

This section introduces a general formulation of the EMCC optimization problem, built from the information given in (EMCC, 2009b). A list of symbol is added at the end of this section.

Objective function and optimization variables

Let the optimization variables of the EMCC's objective function F be gathered in three vectors²:

- \mathbf{v}_N as the vector of all variables strictly in the northern area, including the zonal prices, the internal flows and the accepted bids for each hour;
- \mathbf{v}_S as the similar vector in the southern area; and
- $\mathbf{f}_{N \rightarrow S}$ as the vector of the flows on the interconnectors between the northern and the southern area; the positive flows are set by convention going from North to South and these are the only optimization variables involved in both areas.

The objective function to maximize is “the generated social welfare summed over all areas and hours, and bid types” (EMCC, 2009b). In practice, this generated welfare is the sum of two kinds of surplus (APXendex et al., 2010).

- the transaction surplus for every accepted selling or purchasing bids calculated with reference to the market price in each price zone;
- the congestion surplus between two zones with differing prices.

²This statement is based on a more complete model as detailed in appendix of the technical report (APXendex et al., 2010).

In fact, the congestion surplus can be expressed as financial flows for the respectively importing or exporting zones as described in the EMCC optimizer (EMCC, 2009b). The volume coupling's objective function can thus be expressed as a sum over the zones and over the hours of the aggregated sells and imports minus the aggregated purchases and exports in monetary value. Let $F_N(\mathbf{v}_N, \mathbf{f}_{N \rightarrow S})$ be the sum of these surpluses over the zones of the northern area. This function as expressed above does not depend on any variables included in \mathbf{v}_S . Similarly, $F_S(\mathbf{v}_S, \mathbf{f}_{N \rightarrow S})$ is defined as the sum of surpluses over the zones of the southern area. Then the EMCC objective function F can be expressed as:

$$F(\mathbf{v}_N, \mathbf{v}_S, \mathbf{f}_{N \rightarrow S}) = F_N(\mathbf{v}_N, \mathbf{f}_{N \rightarrow S}) + F_S(\mathbf{v}_S, \mathbf{f}_{N \rightarrow S}) \quad (\text{C.1})$$

Constraints

The optimization problem includes various constraints such as bid usage³, demand-supply balance in each zone, transmission capacities or the transmission flow ramp rates⁴. The constraints involving variables concerning both the northern area (Nordpool) and the southern area (CWE) are only the transmission constraints involving exclusively the transmission flows on the cables between these two areas.

The set of constraints $\{C\}$ is introduced as the set of all constraints of the volume coupling optimization problem. This set includes the three following subsets⁵:

- $\{C_I\}$ the subset of constraints involving only optimization variables included in the vector $\mathbf{f}_{N \rightarrow S}$;
- $\{C_N\}$ the subset of constraints involving at least an optimization variable included in the vector \mathbf{v}_N ;
- $\{C_S\}$ the subset of constraints involving at least an optimization variable included in the vector \mathbf{v}_S .

³For instance, paradoxically rejected blocks are allowed and paradoxically accepted blocks are forbidden as described in (Meeus et al., 2009).

⁴These flow ramp rates limit the variation of the flows between successive time periods (EMCC, 2009b).

⁵These three subsets happens to form a partition of $\{C\}$, i.e., the union of the subsets is equal to $\{C\}$ and the subsets do not intersect each other. In particular, there is no constraints in the EMCC description involving at the same time an optimization variable included in the vector \mathbf{v}_N and one in \mathbf{v}_S . This property is not used in the following analysis, but it might be useful to others.

Relation between price and volume coupling objective functions.

The objective functions of the price couplings sum the same kind of surpluses as the objective function of the volume coupling F described in section C.2. Nevertheless, there are two differences:

- the congestion surplus on the interconnectors handled by the volume coupling is no more part of the objective function of the price couplings;
- the way the flows are fixed by EMCC can add new offers and bids in the price coupling objective functions.

Based on this observation, the section aims at expressing the objective function of the price coupling in the northern area F'_N as a function of F_N which is the objective function of the volume coupling restricted to the northern area as introduced in section C.2.

First, let $\{I_{N \rightarrow S}\}$ be the set of interconnection flows which are corresponding to the elements of $\mathbf{f}_{N \rightarrow S}$ so that each $i \in I_{N \rightarrow S}$ refers to a given interconnector and a given time period where $f_{N \rightarrow S, i}$ is the amount of power flowing.

Each interconnection flow is physically attached to a northern bidding zone and a southern bidding zone, and it is related to a single time period. Then, let $\mathbf{x}_N(\mathbf{v}_N)$ be the vector of zone prices such as $\forall i \in \{I_{N \rightarrow S}\}$, the element $x_{N, i}(\mathbf{v}_N)$ is the zone price in the northern area related to the element $f_{N \rightarrow S, i}$. The function x_N thus allows to exhibit the prices related to congestion surpluses.

The EMCC objective function F includes the congestion surplus between the northern and southern areas, which is equal to $(\mathbf{x}_S(\mathbf{v}_S) - \mathbf{x}_N(\mathbf{v}_N)) \cdot \mathbf{f}_{N \rightarrow S}$. Therefore, let $F_{f, N}(\mathbf{v}_N, \mathbf{f}_{N \rightarrow S})$ be the surplus that shall be subtracted from F_N because it has become external to the optimization problem related to F'_N :

$$F_{f, N}(\mathbf{v}_N, \mathbf{f}_{N \rightarrow S}) = -\mathbf{x}_N(\mathbf{v}_N) \cdot \mathbf{f}_{N \rightarrow S} = - \sum_{i \in \{I_{N \rightarrow S}\}} (x_{N, i}(\mathbf{v}_N) \cdot f_{N \rightarrow S, i}) \quad (\text{C.2})$$

Second, the bids and offers created in order to fix the flows between the two areas are now included in the objective functions of the price couplings. As described for example in (Weber et al., 2010), the inter-area transmission flows that are the solution

of the volume coupling optimization are fixed in practice by unlimited bids included in the price coupling of each area. The surplus $F_{b,N}$ to be added for the northern price coupling is given in the following paragraphs.

Let $P_{min,N}$ and $P_{max,N}$ be the price caps in this area, i.e., respectively the minimum and maximum bid prices authorized by the regulation, the PXs and used by the algorithm in case of curtailment in a bidding zone. In order to exchanges the quantities $f_{N \rightarrow S}^0$ calculated through the volume coupling, purchasing bids at the price $P_{max,N}$ are included in the exporting zone (these extra purchases are exported), while selling bids at the price $P_{min,N}$ are defined in the importing zone (these extra sells are imported). This way, the bids and offers are to be activated in the northern price coupling.

Let $F_{b,N}(\mathbf{v}_N, \mathbf{f}_{N \rightarrow S}^0)$ be the additional producer or consumer surplus associated to the unlimited bids and offers, which quantities are determined by $\mathbf{f}_{N \rightarrow S}^0$. The case of the exporting and importing interconnectors shall be differentiated in $\{I_{N,exp}\}$ and $\{I_{N,imp}\}$ forming a partition of $\{I_{N \rightarrow S}\}$.

$$\{I_{N,exp}\} = \{i \in \{I_{N \rightarrow S}\}, f_{N \rightarrow S,i}^0 \geq 0\} \quad (C.3)$$

$$\{I_{N,imp}\} = \{i \in \{I_{N \rightarrow S}\}, f_{N \rightarrow S,i}^0 < 0\} \quad (C.4)$$

The surplus $F_{b,N}$ is thus an addition of purchasing and selling surpluses from the exporting (purchases at any price) and importing (sells at any price) zones, respectively. Note that the ‘minus’ sign in the second term is added to translate the negative flows from North to South into a positive surplus.

$$\begin{aligned} F_{b,N}(\mathbf{v}_N, \mathbf{f}_{N \rightarrow S}^0) &= \sum_{i \in \{I_{N,exp}\}} (P_{max,N} - x_{N,i}(\mathbf{v}_N)) \cdot f_{N \rightarrow S,i}^0 \\ &+ \sum_{i \in \{I_{N,imp}\}} (x_{N,i}(\mathbf{v}_N) - P_{min,N}) \cdot (-f_{N \rightarrow S,i}^0) \\ &= -\mathbf{x}_N(\mathbf{v}_N) \cdot \mathbf{f}_{N \rightarrow S}^0 + \sum_{i \in I_{N,exp}} P_{max,N} * f_{N \rightarrow S,i}^0 \\ &+ \sum_{i \in I_{N,imp}} P_{min,N} \cdot f_{N \rightarrow S,i}^0 \end{aligned} \quad (C.5)$$

From equations (C.2) and (C.5), the objective function F'_N for the price coupling of the northern area can be rewritten in (C.6) as a function of the volume coupling objective

function F_N .

$$\begin{aligned}
F'_N(\mathbf{v}_N, \mathbf{f}_{N \rightarrow S}^0) &= F_N(\mathbf{v}_N, \mathbf{f}_{N \rightarrow S}^0) - F_{f,N}(\mathbf{v}_N, \mathbf{f}_{N \rightarrow S}^0) + F_{b,N}(\mathbf{v}_N, \mathbf{f}_{N \rightarrow S}^0) \quad (\text{C.6}) \\
&= F_N(\mathbf{v}_N, \mathbf{f}_{N \rightarrow S}^0) \\
&\quad + \sum_{i \in \{I_{N,exp}\}} P_{max,N} \cdot f_{N \rightarrow S,i}^0 + \sum_{i \in \{I_{N,imp}\}} P_{min,N} \cdot f_{N \rightarrow S,i}^0
\end{aligned}$$

Therefore, the new objective function F'_N is equal to F_N plus $\Delta F_N(\mathbf{f}_{N \rightarrow S}^0)$ which is a constant expressed in (C.7).

$$\Delta F_N(\mathbf{f}_{N \rightarrow S}^0) = \sum_{i \in \{I_{N,exp}\}} P_{max,N} \cdot f_{N \rightarrow S,i}^0 + \sum_{i \in \{I_{N,imp}\}} P_{min,N} \cdot f_{N \rightarrow S,i}^0 \quad (\text{C.7})$$

Obviously, the situation is similar in the southern region, with $P_{min,S}$ and $P_{max,S}$ as the price caps. The new objective function F'_S is equal to F_S plus a constant $\Delta F_S(\mathbf{f}_{N \rightarrow S}^0)$:

$$\Delta F_S(\mathbf{f}_{N \rightarrow S}^0) = - \sum_{i \in \{I_{N,imp}\}} P_{max,S} \cdot f_{N \rightarrow S,i}^0 - \sum_{i \in \{I_{N,exp}\}} P_{min,S} \cdot f_{N \rightarrow S,i}^0 \quad (\text{C.8})$$

Potential application of this analytical model in more general cases

This section points at three other cases that can be studied with the model developed in section C.2 for the EMCC case. The aim is to illustrate that the conclusion of section C.3 can also be valid for another interim tight volume coupling solution with differing conditions, including at least the conditions listed in this section.

Generalization to more than two areas. The model could be easily generalized to numerous regions. The results of this section would thus apply to a volume coupling handling interconnectors between more than two regions.

Generalization to other products. A market platform in one or more areas covered by a tight volume coupling might be willing to offer standard products differing from the

one considered in the EMCC's case. The conclusions of this section would remain valid if these products fit in the model described in section C.2 without any modification.

Compliant with flow-based. The current market coupling frameworks in Europe use so-called ATC-based⁶ transmission capacity values in the algorithm. A flow-based solution is expected to calculate more optimally the physical transmission capacities and the TSOs of the CWE region intend to implement it (ETSO and EuroPEX, 2008).

For example, in the model described in section C.2, the flow-based implementation in the northern area would lead to the change of $\{C_N\}$ to $\{C_N^{flow-based}\}$, a new subset of constraints. The new transmission constraints have a more complex expression, but they can be kept linear. Therefore, if flow-based capacity calculation is applied independently in one or both areas, the model used in this paper is still valid assuming that the EMCC updates its algorithm to manage it similarly, meaning it would work with the new set of constraints $\{C^{flow-based}\} = \{C_N^{flow-based}\} \cup \{C_S\} \cup \{C_I\}$.

As a result, the flow-based capacity calculation in one area would not prevent inherently the implementation of a volume coupling with another area. This result can also be found in a technical report about flow-based implementation in the CWE area (CWE, 2011b).

List of symbols

- $\{C\}$ the set of constraints of the volume coupling optimization problem
- $\{C_I\}$ the subset of constraints involving only optimization variables included in the vector $\mathbf{f}_{N \rightarrow S}$
- $\{C_N\}$ the subset of constraints involving at least an optimization variable included in the vector \mathbf{v}_N
- $\{C_S\}$ the subset of constraints involving at least an optimization variable included in the vector \mathbf{v}_S
- ΔF_N the difference between F_N and F'_N
- ΔF_S the difference between F_S and F'_S

⁶Where ATC stands for Available Transmission Capacity.

- $\mathbf{f}_{N \rightarrow S}$ the vector of the flows on the interconnectors between the northern and the southern area
- F the objective function of the volume coupling
- F_N the restriction to the northern area of the objective function of the volume coupling
- F_S the restriction to the southern area of the objective function of the volume coupling
- F'_N the objective function of the northern price coupling
- F'_S the objective function of the southern price coupling
- $\{I_{N \rightarrow S}\}$ the set of interconnection flows which are corresponding to the elements of $\mathbf{f}_{N \rightarrow S}$
- $\{I_{N,exp}\}$ the subset of $\{I_{N \rightarrow S}\}$ of all interconnection flows exporting from the northern area
- $\{I_{N,imp}\}$ the subset of $\{I_{N \rightarrow S}\}$ of all interconnection flows importing to the northern area
- $P_{min,N}$ the minimum price in the northern area
- $P_{max,N}$ the maximum price in the northern area
- \mathbf{v}_N the vector of all variables strictly in the northern area, including the zonal prices, the internal flows, the accepted bids, etc.
- \mathbf{v}_S the vector of all variables strictly in the southern area, including the zonal prices, the internal flows, the accepted bids, etc.
- \mathbf{x}_N the vector of zone prices in the northern area corresponding to the elements of $\mathbf{f}_{N \rightarrow S}$
- t_0 the time when the improved volume coupling is launched
- t_1 the time when the improved volume coupling shifts to independent price couplings
- $t_{1,max}$ the maximum value for t_1
- t_{max} the maximum duration of the improved solution for market coupling

In addition, the numbers 0 and 1, placed in superscript next to a vector of variables or an objective function, refer to a result from the volume coupling and price coupling, respectively.

C.3 Adverse flow event causality and application of the model

Aim and content

This section introduces an analytical model that helps understanding some EMCC's volume coupling principles. Based on the model developed in section C.2, a mathematical argumentation shows that if the numerical solvers were always converging to an optimum, then the volume coupling could in theory handle block bids and differing price caps in one area without adverse flow events. This supports that the volume coupling is not so inherently limited.

Pragmatic reasons explaining adverse flow events.

In practice, the outcome of the independent price couplings, i.e., step three of the process described in section C.1, may differ from the ITVC's outcome. From the EMCC's efficiency point of view, this is a problem especially when independent price couplings result in adverse flows on the cables between the two areas, i.e., when energy flows in the opposite direction of the price spread (exchange from an expensive bidding zone to a cheaper one). A report (FGH and IAEW, 2009) gathers the result of tests about the occurrence of these adverse flows and a presentation (EMCC, 2009a) lists four explanations of this effect:

- rounding procedures;
- currency conversion;
- differing price caps in each area;
- block bid selection.

The two first reasons have both a “low impact” (EMCC, 2009a) and there are perspectives of improvement. Indeed, as stated in (EMCC, 2009a) “EMCC has already implemented an ‘intelligent’ rounding which respects the flow direction and which reduces adverse flows significantly”. In addition, the three optimization algorithms could agree on values and mechanisms they use to handle the currency conversion issue.

The price cap is a meaningful parameter from a regulatory point of view, but this does not prevent the regulators and PXs from negotiating a common value. Anyhow, the present study shows that the use of different price caps should not be an issue as soon as these constraints are correctly implemented within the EMCC optimization problem.

Concerning the fourth reason, it is not difficult to imagine that the block bid selection can have an impact if the algorithms used in step two and three differ. However, it is stated in presentation (EMCC, 2009a) that “differences in block bid selection, which may result in adverse flows, are considered as inherent to volume coupling”. Furthermore, report (FGH and IAEW, 2009) also states more generally that “[adverse flows] are inherent to a volume market coupling”. The present paper shows that in theory adverse flows are not inherent to block bid selection, but they are likely to appear in practice for reasons described above and in section C.3.

Assumptions

First, it is assumed that price couplings in the northern area (respectively the southern area) use the set of constraints $\{C_N\}$ (respectively $\{C_S\}$), i.e., the three optimizations EMCC, CWE and Nordpool market couplings work with similar constraints. This assumption is reasonably acceptable if the volume coupling and the price couplings share a common network model.

Second, it is assumed the solution of the volume coupling is unique. In fact, it is conceivable that two differing solutions may provide the same surplus. In this case, it is also conceivable that an additional step in the three algorithms use a common discriminatory process to select one of the optimal outcomes. With this additional step the solution can be made unique.

Third, it is assumed that the three numerical solvers converge to the optimal solution within the period allocated to them. This is the main assumption, given the complexity of the non-convex Mixed-Integer Linear Programming (MILP) problem induced by the introduction of block bids (Meeus, 2006).

Mathematical intuition

The idea is that when the interconnection capacities are fixed by the volume coupling, the space of possibilities of the optimization problem is reduced. This could lead to adverse flows if the optimal point was not included in the new optimization problems.

However, since the variables are fixed with the results of the optimization, the reduced space of possibilities still include the first optimal solution. Therefore, there should not be any adverse flows as shown in the following paragraph.

Mathematical proof

Let $(\mathbf{v}_N^0, \mathbf{v}_S^0, \mathbf{f}_{N \rightarrow S}^0)$ be the result of the volume coupling, i.e., the optimal solution of the optimization problem (C.9).

$$\max_{\mathbf{v}_N, \mathbf{v}_S, \mathbf{f}_{N \rightarrow S}} F(\mathbf{v}_N, \mathbf{v}_S, \mathbf{f}_{N \rightarrow S}), \text{ subject to } \{C\} \quad (\text{C.9})$$

Following this first optimization, $\mathbf{f}_{N \rightarrow S}^0$ is fixed and the two price couplings are performed separately. For example, the optimization problem for the northern area is given in (C.10). The additional term $\Delta F_N(\mathbf{f}_{N \rightarrow S}^0)$, introduced in equation (C.7), does not impact the optimum point of the price coupling optimization because it is a constant. Therefore, it can be removed from the optimization problem.

$$\begin{aligned} & \max_{\mathbf{v}_N} F'_N(\mathbf{v}_N, \mathbf{f}_{N \rightarrow S}^0), \text{ s.t. } \{C_N\} & (\text{C.10}) \\ \Leftrightarrow & \max_{\mathbf{v}_N} F_N(\mathbf{v}_N, \mathbf{f}_{N \rightarrow S}^0) + \Delta F_N(\mathbf{f}_{N \rightarrow S}^0) \text{ s.t. } \{C_N\} \\ \Leftrightarrow & \max_{\mathbf{v}_N} F_N(\mathbf{v}_N, \mathbf{f}_{N \rightarrow S}^0) \text{ s.t. } \{C_N\} \end{aligned}$$

Similarly, the optimization problem for the southern region is equivalent to:

$$\max_{\mathbf{v}_S} F_S(\mathbf{v}_S, \mathbf{f}_{N \rightarrow S}^0) \text{ s.t. } \{C_S\} \quad (\text{C.11})$$

Let v_N^1 and v_S^1 be the optimal solutions to problems (C.10) and (C.11), respectively, and:

$$F_N^0 = F_N(v_N^0, f_{N \rightarrow S}^0) \quad (\text{C.12})$$

$$F_N^1 = F_N(v_N^1, f_{N \rightarrow S}^0) \quad (\text{C.13})$$

$$F_S^0 = F_S(v_S^0, f_{N \rightarrow S}^0) \quad (\text{C.14})$$

$$F_S^1 = F_S(v_S^1, f_{N \rightarrow S}^0) \quad (\text{C.15})$$

On both sides of the border, the new optimization can at least achieve the same value for F_N and F_S . Indeed, the EMCC solution is included in the space of possibilities, i.e., v_N^0 and v_S^0 are still possible outcomes. Therefore:

$$F_N^1 \geq F_N^0 \quad (\text{C.16})$$

$$F_S^1 \geq F_S^0 \quad (\text{C.17})$$

Summing term by term leads to the new relation (C.18).

$$\begin{aligned} F_N^1 + F_S^1 &\geq F_N^0 + F_S^0 & (\text{C.18}) \\ \Leftrightarrow F_N^1 + F_S^1 &\geq F^0 \end{aligned}$$

From relation (C.18), it is obvious that the outcomes of price couplings cannot be different from the volume coupling.

Proof. Since the point $(v_N^1, v_S^1, f_{N \rightarrow S}^0)$ is fulfilling the constraints $\{C\}$ of the EMCC optimizer, and since it results in a solution at least as optimal as the EMCC optimization as shown in (C.18), then $(v_N^1, v_S^1, f_{N \rightarrow S}^0)$ shall be equal to $(v_N^0, v_S^0, f_{N \rightarrow S}^0)$. \square

Thus there shall not be any adverse flow, and the volume coupling solution is as optimal as the result of a single price coupling, except that the duration of the process between the gate closure and the clearing time may be longer with the volume coupling solution.

Conclusion on the explanation of adverse flow events

The mathematical argumentation given in section C.3 proves that adverse flows should only appear if at least one of the three assumptions made in section C.3 is not fulfilled.

The first assumption about the use of equivalent models for the constraints is not fully met as highlighted in the EMCC's communication summarized in section C.3. Nevertheless, these issues can be solved with a reasonable level of coordination. Similarly, the second assumption about the uniqueness of the theoretical optimum can be fulfilled with a coordinated selection process to discriminate two solutions offering the same outcome.

Last, adverse flows can also appear if the third assumption is not met, i.e., if the numerical solvers provide an acceptable solution which is not necessary the optimum. In practice, this issue appears with block bids and other sophisticated products, which introduce binary variables in the optimization problem (Meeus et al., 2009) potentially increasing the calculation duration required by the numerical solvers.

This demonstration brings a new theoretical insight completing the pragmatic explanation of adverse flow events given in reference (EMCC, 2009a).

C.4 Perspectives for an improved interim tight volume coupling

If a single price coupling solution proves to be fairly efficient, it is agreed that it should be preferred to a tight volume coupling solution. As stated in the introduction, the EMCC runs an interim solution that shall be replaced sooner or later. Moreover, the difficulties encountered with the first experiments on the Kontek cable between Germany and Denmark may have limited the enthusiasm for the volume coupling solution (Meeus, 2011a), while a European price coupling solution is progressing (Glachant, 2010), supported by potential improvements of the algorithms (Tersteegen et al., 2009).

Nevertheless, this section intends to show that the door should be kept open for improved interim tight volume coupling solutions in specific cases as in the example described in section C.4.

Criteria for a good coupling of day-ahead electricity markets

The three following criteria shall be used to assess the quality of a coupling between two or more day-ahead markets:

- the distance to the optimum solution, which can be evaluated afterwards;
- the duration of the process between the day-ahead market gate closures and the market clearings;
- the capacity to handle complex electricity products.

The acceptability of a new solution depends not only on these criteria but also on the initial situation and on the expected visible improvements. In particular, the acceptability of a volume coupling depends on a low occurrence of adverse flows, i.e., low visible inefficiencies.

An improved tight volume coupling if a single price coupling solution fails to obtain acceptable results.

If the implementation study of a single price coupling solution does not bring satisfactory results⁷, the following interim solution might be more acceptable, while offering better outcomes than explicit allocation. Compared to the classical volume coupling, the proposed solution should improve cross-border allocation between areas, while preserving the market efficiency in the coupled areas.

The improvements are based on additional coordination between the volume and price coupling numerical solvers:

- The first improvement can be assimilated to a hot start, a method used in various optimization processes (Wu and Debs, 2001). The principle is that some additional output data from the first numerical solver may be useful to accelerate the calculation of the price coupling solutions. It should result in a more efficient utilization of the duration allocated to the market coupling process.

⁷Such a situation may appear while applying market coupling to other time horizons or geographical areas, resulting in a too large or too complex optimization problem.

- The second improvement is to allow a progressive evolution toward a single price coupling within a stable market coupling organization for the market players.

The resulting mechanism is shown in figure C.3 based on the notation used in section C.2. Let t_0 be the gate closure of the day-ahead market couplings and let $(t_{max} - t_0)$ be the maximum duration given to the whole coupling process.

1. The volume coupling is operated with the algorithm built as if it were to be used as a single price coupling. This optimization is performed between t_0 and a time t_1 with $t_1 < t_{max}$.
2. At t_1 , the cross-border flows are fixed (as $f_{N \rightarrow S}^0$) and the numerical solver is copied *in its current state* in each of the two areas. In the northern area, the variable v_S is fixed at v_S^0 while in the southern area v_N is fixed at v_N^0 . Though this operation can be performed reasonably quickly in theory, operational procedures should be designed carefully to reduce this duration as much as possible.
3. Between t_1 and t_{max} , the two new problems with their reduced number of optimization variables are run in parallel. They start exactly where the volume coupling stopped with all that has been “learned” by the algorithm between t_0 and t_1 .

At the end, even if $f_{N \rightarrow S}^0$ is fixed at a not-so-optimal state, the hope is that the overall solution $(v_N^1, v_S^1, f_{N \rightarrow S}^0)$ might be better than the one the single price coupling would have found. The potential benefits lies in the fact that the problem is transformed into two smaller sub-problems run in parallel between t_1 and t_{max} in the improved volume coupling solution. These two sub-problems are solved with a reduced number of variables and constraints, while benefiting from the learning made between t_0 and t_1 .

The choice of t_1 between t_0 and t_{max} could for example be determined empirically. It can be fixed before the optimization has started or it can be linked to an indicator of convergence towards a stable solution. In the second case, an upper boundary $t_{1,max}$ can be fixed. Besides, this choice can evolve with the exogenous constraints, such as an improvement of the numerical solvers. For instance, when the numerical solvers are improved so that the benefits of a better calculation after t_1 do not compensate anymore the fact that $f_{N \rightarrow S}^0$ is less optimal than it could be, it will be decided that t_1 is pushed

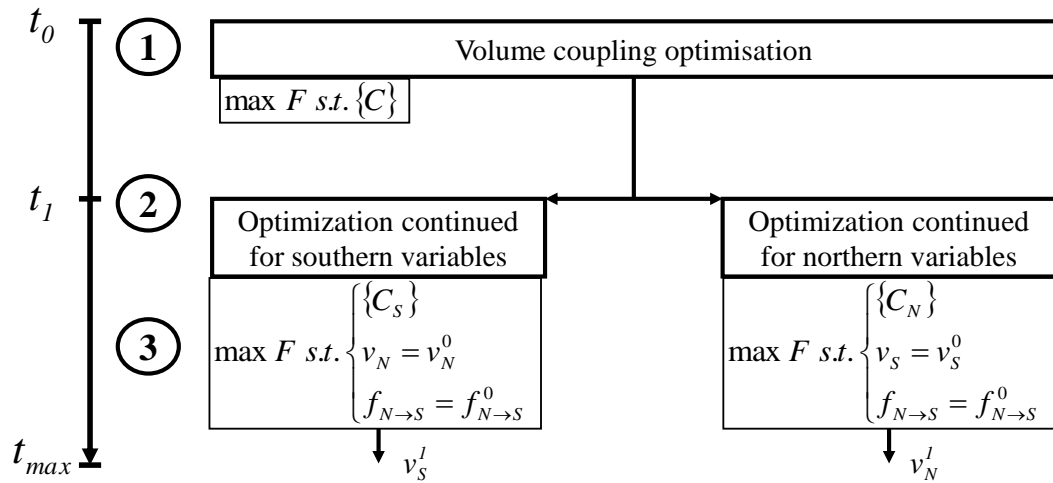


FIGURE C.3: Scheme of the proposed improved volume coupling with price couplings taking over the same optimization process.

further from t_0 . When t_1 reached t_{max} , it means that the single price coupling solution has become the best option.

Similarly, the choice of the internal interconnectors fixed in $f_{N \rightarrow S}^0$ can also evolve as a function of the network topology, the solver capacities, or political issues.

Test of the proposed solution

The stakeholders having access to the appropriate data and algorithms are well placed to test this solution if there is any interest for it.

Conclusion on the perspective of improvement for future applications

The interim tight volume coupling run by the European Market Coupling Company is to be replaced sooner or later by another solution. Nevertheless, the volume coupling principle can still inspire pragmatic solutions for future challenges.

Learning from the ITVC experience, this last section proposes an example of improvement of the tight volume coupling method based on a stronger coordination between the numerical solvers. This improved mechanism could serve as an interim solution if a price coupling numerical solver does not provide satisfactory results because the optimization problem is too large or too complex. In this case, the proposed solution is expected to

be a satisfactory implicit allocation method from both technical and governance points of view.

Appendix D

Résumé en français

Introduction

L'Europe bénéficie d'un système électrique interconnecté dont l'organisation est découpée en des mosaïques de zones politiques, techniques et marchandes, créant des discontinuités dans l'organisation du système. La coordination de l'exploitation sur les frontières entre zones est introduite comme une composante de la dimension européenne des systèmes électriques pour utiliser au mieux les ressources disponibles du système en exploitant un ensemble d'infrastructures donné.

Ce résumé synthétise les travaux de thèse sur l'analyse économique de cette coordination.

- La section 1 définit le rôle de la coordination de l'exploitation.
- La section 2 détaille un cadre d'analyse fonctionnel des mécanismes participant à la coordination de l'exploitation.
- La section 3 résume et compare des ordres de grandeurs des variations de surplus économique associées à l'évolution de la coordination en 2012.
- La section 4 décrit le rôle joué par l'Union Européenne.
- La section 5 analyse deux dimensions de la coordination entre GRTs.

A partir de ces éléments d'analyse, la conclusion offre une perspective globale sur l'évolution future de la coordination transfrontalière de l'exploitation en Europe.

1. Définition de la coordination transfrontalière de l'exploitation dans le système électrique européen

Cette section est adaptée de ([Janssen and Rebours, 2012a](#)).

Le concept de système électrique intégré

Un réseau de transport d'électricité interconnecté peut être vu comme un système découpé en zones en fonction de contraintes techniques et administratives héritées de l'histoire. L'organisation du système électrique interconnecté est donc avant tout zonale, puis des mécanismes d'échanges et de coordination entre zones complètent le dispositif. De fait, le réseau de transport d'électricité européen est interconnecté puisque presque tous les pays du continent au sens large sont reliés les uns aux autres. Il serait même peu évident de deviner les frontières politiques à partir d'une carte des lignes de transport en Europe comme le montre la Figure D.1.

Cette interpénétration des réseaux nationaux est l'héritage d'un siècle de développement facilité par une compatibilité précoce des choix technologiques. L'utilisation du courant alternatif triphasé opéré à une fréquence de 50 Hz est devenu par exemple un standard en Europe dès les années 1920 ([Lagendijk, 2008](#)). Le principal problème technique levé, la première moitié du XXe siècle voit ainsi apparaître les premiers réseaux à haute tension traversant les frontières pour, par exemple, permettre à la Suisse d'exporter son hydro-électricité vers les bassins de consommation des pays voisins ([Verbong et al., 2002](#)). La généralisation des interconnexions depuis la deuxième guerre mondiale s'est ensuite faite de manière plutôt continue afin de bénéficier des avantages apportés par les interconnexions décrits par exemple dans ([Janssen and Rebours, 2012b](#)). Jusque dans les années 1990, la coopération était centrée sur les blocs politiques tels que la région nordique. Puis, avec l'éclatement de l'URSS, les blocs de l'est et de l'ouest de l'Europe se sont réunis électriquement pour former un unique réseau synchrone ([Lagendijk, 2008](#)). Enfin, plus récemment, des câbles à courant continu renforcent les liens vers les pays scandinaves, les îles britanniques ou encore la péninsule ibérique¹.

¹La mise en service de la ligne à courant continu entre Baixas (Pyrénées-Orientales) et Santa Llogaia (Espagne) est prévue pour début 2014, selon le site du projet <http://www.liaison-france-espagne.org/>.

Le réseau de transport européen est donc aujourd'hui interconnecté, mais avec des capacités d'échanges limitées. Par exemple, la Grande Bretagne, dont la pointe de consommation est aux alentours de 62 GW, est limitée dans ses échanges avec le continent à 2 GW vers la France et à 1 GW vers les Pays-Bas.

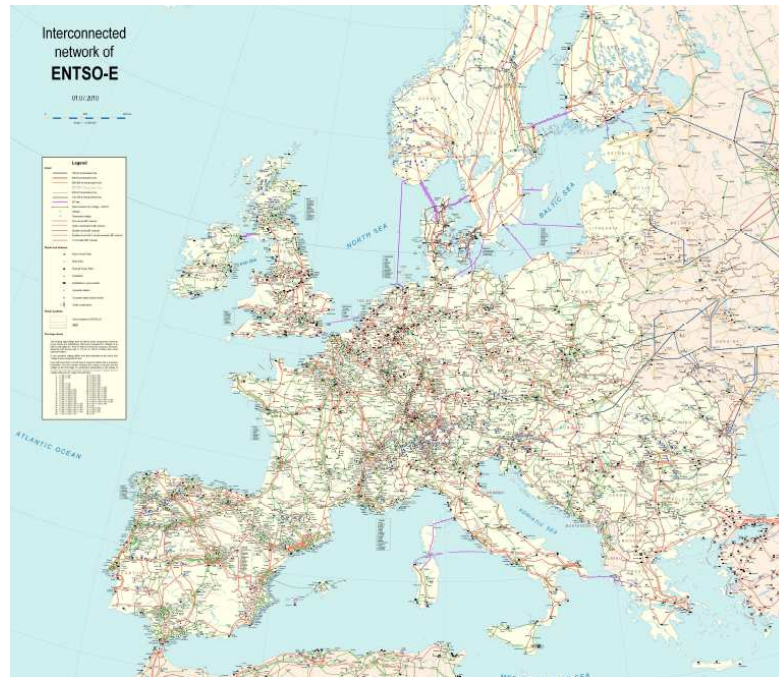


FIGURE D.1: Carte des réseaux de transport d'électricité en Europe en 2010. Seules les lignes opérées à une tension de 220 kV ou plus sont représentées. Les lignes de 110 à 150 kV qui traversent des frontières politiques apparaissent également. Reproduit avec l'aimable autorisation de l'ENTSO-E.

Un système électrique est soumis à de fortes contraintes. En particulier, l'équilibre entre production et consommation doit être maintenu en temps réel. De plus, les flux électriques circulant dans les lignes, qui dépendent largement de la topologie des injections et des soutirages, doivent être maintenus sous un seuil maximum admissible². Le bon fonctionnement du système est assuré zone par zone, par la combinaison de règles de fonctionnement et l'action d'opérateurs dédiés. Ces zones, très bien organisées en interne, sont plus ou moins coordonnées entre elles.

Typiquement, trois familles de frontières subdivisent en zones le système interconnecté : politiques, techniques et marchandes. Les frontières politiques démarquent les zones dont la régulation présente une certaine homogénéité, comme les frontières nationales

²Pour citer une limite physique, le courant circulant dans une ligne aérienne conduit à un échauffement par effet Joule et donc à une dilatation. Un courant supérieur à sa valeur admissible peut conduire à une dilatation excessive de la ligne aérienne, et donc à une diminution potentiellement dangereuse de la distance entre les conducteurs et le sol.

ou celles entre états fédéraux. Les régulateurs et les législateurs interviennent à ce niveau. Les zones techniques ont attiré à la gestion du système électrique. Par exemple, les Gestionnaires de Réseaux de Transport (GRTs) tel que RTE en France, ont pour mission d'assurer la coordination technique sur leur zone géographique. Le découpage technique des aires de contrôle des GRTs se superpose le plus souvent aux frontières nationales, à l'exception notable de l'Allemagne qui comprend quatre GRTs différents. Enfin, les frontières marchandes délimitent les entités homogènes permettant d'échanger entre acteurs les produits liés au marché de l'électricité. Les bourses d'électricité agissent typiquement à cette maille. Les zones de prix du marché journalier d'électricité peuvent par exemple être considérées comme des zones marchandes. En pratique, les pays scandinaves ont opté pour plusieurs zones de prix dans une zone de contrôle afin de révéler certaines contraintes réseaux (cf. Figure D.2). La région scandinave illustre la diversité des options puisque les zones de prix en Norvège sont, dans une certaine mesure, modifiables à court terme par les opérateurs tandis que le découpage zonal est figé sur plusieurs années dans les autres pays scandinaves ([Nordpool spot, 2012](#)). Cette organisation des marchés libéralisés en Europe est dite "zonale".

De fait, les trois découpages conduisent souvent à des frontières similaires, comme par exemple dans le cas de la France métropolitaine qui correspond à une zone de régulation homogène, une aire de contrôle et une seule zone de prix pour le marché journalier. Malgré des mécanismes de coordination entre zones de marché, GRTs et autorités locales, les frontières nationales sont difficiles à dépasser. En effet, proposer une fusion des zones qui franchirait les frontières politiques requerrait en pratique une forte cohérence entre les régulations de chaque côté de la frontière et une forte solidarité dans la répartition des coûts. Par conséquent, la coordination des zones européennes semble actuellement plus adaptée que la fusion.

Rôle de la coordination de l'exploitation

Dans ce contexte, la coordination de l'exploitation vise à utiliser au mieux les ressources existantes pour un niveau d'infrastructure donné. Pour cela, les mécanismes de coordination doivent assurer deux grandes fonctions économiques :

⁴Disponible sur la page <https://www.entsoe.eu/about-entso-e/working-committees/system-operations/regional-groups/>, novembre 2012.

⁴Disponible sur la page <http://www.nordpoolspot.com/Market-data1/Maps/Power-System-Overview/Power-System-Map/>, novembre 2012.

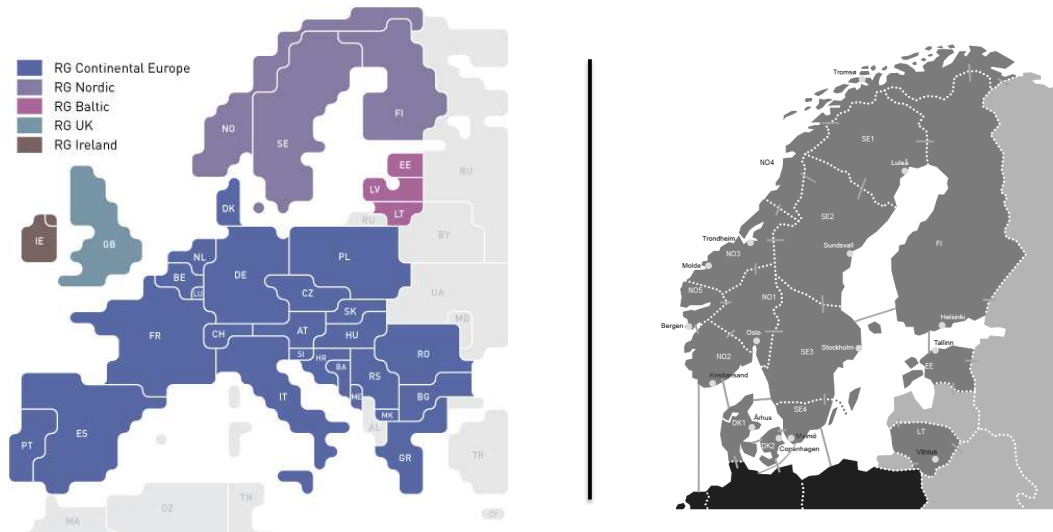


FIGURE D.2: A gauche: les GRTs membres de l'ENTSO-E font parties de 5 aires synchrones différentes. Source: ENTSO-E³. A droite: les zones de prix du marché journalier en 2011. Source : site internet de Nord Pool Spot⁴.

- Etant donné les limites physiques du réseau de transport d'électricité européen, il faut déterminer et allouer une ressource rare, à savoir un espace de possibilité pour les échanges transfrontaliers de produits tels que de l'énergie via le marché journalier ou des réserves.
- Par ailleurs, il faut gérer de manière acceptable les externalités transfrontalières associées à l'interconnexion et aux échanges autorisés.

Les mécanismes en place pour répondre à ces grands problèmes économiques sont décrits plus précisément dans la section suivante. Cette coordination de l'exploitation est complémentaire du niveau d'infrastructure physique permettant les échanges transfrontaliers. La complémentarité entre ces deux ensembles est décrite sur un cas simplifié dans (Janssen and Rebours, 2012b).

2. Analyse fonctionnelle des solutions pour la coordination de l'exploitation

Cadre d'analyse fonctionnel illustré par la région CWE

Différents mécanismes d'échanges et de coordination existent entre les zones de prix, les aires de contrôle et les autorités locales. Les flux d'énergie entre pays résultants de cette

coordination sont de l'ordre de 400 TWh par an en Europe (Rebours et al., 2010b).

Pour cartographier ces mécanismes, nous avons utilisé un cadre d'analyse fonctionnel (Janssen and Rebours, 2012c) respectant l'esprit des travaux des régulateurs et GRTs (Lavoine et al., 2006). Le principe, tout à fait classique, est de réduire la complexité de l'objet d'étude en décomposant sa fonction principale en tâches, ou modules, puis en décrivant les interactions entre ces modules (philosophie de l'analyse fonctionnelle descendante, SADT en anglais). Cette partie offre une synthèse de la définition des modules identifiés lors de notre analyse. Par soucis de clarté, nous avons considéré que les frontières des zones techniques (aires de contrôle) et politiques (autorités locales) se superposaient.

La fonction globale "coordonner les zones pour utiliser au mieux les infrastructures existantes" est dans un premier temps décomposée en quatre sous-fonctions notées de A à D tel que décrit dans la liste ci-dessous. Dans un deuxième temps, chacune de ces quatre sous-fonctions est à son tour décomposée en plusieurs modules. Dans un souci de concision et de cohérence, l'analyse est illustrée par les mécanismes actuellement en place dans la région dite Europe Centre-Ouest dont l'acronyme anglais CWE⁵ est plus couramment utilisé.

- A. Déterminer des espaces de possibilités pour échanger entre zones, en tenant compte des différentes contraintes du système coordonné.
 - 1. Maintenir un ensemble de bases de données et d'informations communes nécessaires aux autres modules.
 - 2. Déterminer les espaces de possibilités pour les échanges entre zones (possibilité d'un sous-module par horizon temporel).
- B. Allouer ces espaces de possibilités en arbitrant entre les différents usages possibles.
 - 1. Arbitrer entre les types de produits et les horizons temporels de marchés pour l'allocation des espaces de possibilités des échanges.
 - 2. Allouer les différents produits aux différents horizons temporels (un sous-module par produit et par horizon temporel).

⁵Cette région inclut l'Allemagne, la Belgique, les Pays-Bas, le Luxembourg et la France.

- C. Coordonner les moyens de gestion des congestions complémentaires au processus d'allocation.
1. Analyser la sécurité sur plusieurs zones. Identifier les situations nécessitant une action préventive des GRTs pour maintenir le bon fonctionnement du système.
 2. Agir de manière coordonnée pour gérer les congestions en complément des mécanismes d'allocation.
- D. Répondre au besoin d'accords et de règles communes.
1. Répartir les coûts et les revenus communs entre les opérateurs.
 2. Assurer la compatibilité entre les mécanismes et les différentes régulations des zones.

La première fonction A détermine les espaces de possibilités pour échanger entre zones, en tenant compte des différentes contraintes du système coordonné. Dans la région CWE, les espaces de possibilités à l'horizon temporel du marché journalier sont définis en allouant une capacité d'échange appelée en anglais Net Transfer Capacity (NTC) à chaque frontière entre zones, qui exprime la quantité de puissance pouvant transiter entre les deux zones durant une heure, indépendamment de tous les échanges commerciaux possibles sur les autres frontières. Ce choix d'une forme simple pour exprimer l'espace des possibilités cache la grande difficulté de son évaluation en pratique. Cette fonction peut être décomposée en au moins deux modules. Un premier sous-module élabore un ensemble de bases de données communes (ENTSO-E, 2009, Panciatici et al., 2012), incluant au moins une modélisation du réseau et un "cas de référence" pour les calculs réalisés en différentiel⁶. Le deuxième sous-module utilise ces données d'entrée pour déterminer les NTCs en tenant compte de diverses règles de sécurité. Deux types d'incertitudes sont en particulier gérés. D'une part, les incertitudes liées au risque d'incident sur un élément du système, ce qui se traduit par des règles de type "N-1" permettant au système de continuer à fonctionner malgré la perte d'un élément important du système (ex. ligne, transformateur, groupe de production, etc.). D'autre part, les approximations et incertitudes sur tout le processus de cette fonction conduisent à prendre des marges additionnelles. Le calibrage de ces marges est essentiel pour libérer le maximum de capacités d'échange tout en garantissant la sécurité du système électrique.

⁶Les GRTs voisins se concertent afin de planifier au mieux les travaux sur le réseau électrique situé à proximité des frontières. La base de données commune fournie par le sous-module A1 retranscrit cette vision partagée des travaux.

La deuxième fonction, désignée par B, alloue ces espaces de possibilités en arbitrant entre les différents usages possibles à chaque séquence du marché électrique (ex., long-terme, journalier, mécanisme d’ajustement, réglage de fréquence). Un premier sous-module définit donc sous quelle forme de produit et à quel horizon temporel l’espace doit être alloué. Par exemple, aux horizons de marché mensuels et annuels, des droits d’accès aux NTCs de la zone CWE sont alloués avec le produit PTR UIoSI, brièvement décrit Figure 3, qui combine des droits financiers et physiques. Ce produit offre aux acteurs un marché primaire de produits de couverture aux différences de prix entre zones. Ce marché primaire peut être complété par un marché secondaire⁷ dont la responsabilité n’est pas portée par les GRTs (CRE, 2009). De plus, il convient de définir la part réservée à chacun des horizons de temps, afin d’équilibrer entre les avantages de révéler le maximum d’information à long terme et les inconvénients de tenir des engagements infaisables à court terme. Ainsi, au moment des allocations mensuelles et annuelles, une partie de la capacité est réservée au marché journalier (cf. Figure D.3). A noter que, dès l’allocation long-terme, la détermination de l’espace des possibilités pour les marchés de l’énergie tient compte des flux imputables au réglage de la fréquence, comme par exemple l’activation des réserves entre des zones d’un réseau synchrone (ACER, 2011d). Pour chaque horizon de temps, le deuxième sous-module alloue le produit défini par le premier sous-module. Une distinction importante pour les produits physiques est faite entre les méthodes dites explicites et implicites. Dans le premier cas, les acteurs sont appelés à expliciter directement la valeur qu’ils accordent au produit (ex. en €/MWh). Dans le deuxième cas, l’allocation implicite révèle la valeur du produit d’échange à partir d’autres produits marchands, typiquement l’énergie injectée ou soutirée dans une zone de prix. Dans la zone CWE, l’allocation des PTRs UIoSI aux horizons mensuel et annuel est faite par enchères explicites via la plate-forme CASC-CWE. A l’horizon journalier, les capacités sont en revanche allouées implicitement à travers le couplage des marchés spots (technique dite du “market coupling”).

La troisième fonction, désignée par C, coordonne les moyens de gestion des congestions complémentaires au processus d’allocation. Les actions à la main des GRTs sont par exemple la modification de la topologie du réseau ou, dans un deuxième temps, le redispatching de groupes de production sous contrainte réseau (Panciatici et al., 2012). Un

⁷Le marché secondaire permet d’échanger entre acteurs des actifs déjà existants. Dans notre exemple, le marché secondaire modifie uniquement la répartition des produits entre acteurs. La quantité de droits physiques mise en circulation est modifiée par le marché primaire.

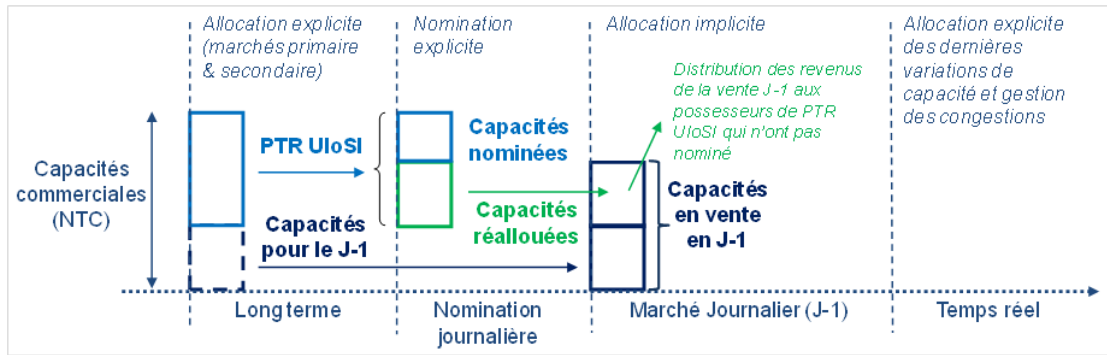


FIGURE D.3: Dans la zone CWE, le produit PTR UIoSI est mis aux enchères par les GRTs pour des périodes annuelles ou mensuelles. Son nom est un acronyme de l'anglais Physical Transmission Rights with Use It or Sell It conditions. Le volume maximum offert par les GRTs est toujours inférieur aux capacités commerciales disponibles en J-1 (par soucis de simplicité, nous considérons ici que la capacité J-1 est parfaitement connue à long terme). Chaque jour, l'utilisation du produit préalablement acquis est déterminée par le possesseur du PTR lors d'une étape de nomination avant le marché journalier (J-1). Lors de cette étape, le possesseur du PTR choisit s'il le nomme. En cas de nomination, le produit devient un droit physique sur la capacité (Use It) : l'utilisateur doit physiquement réaliser la transaction. Sinon, le produit devient automatiquement un droit financier sur l'utilisation future de la capacité (Sell It). Dans ce deuxième cas, le possesseur du PTR récupère les bénéfices de la vente des capacités non nominées dans le mécanisme d'enchère implicite du marché journalier.

premier sous-module anticipe les situations critiques pouvant apparaître (“what if ?”). Ce travail est réalisé par chaque GRT au minimum sur sa zone dans le cadre de ses responsabilités, et souvent en modélisant sommairement les zones voisines. En outre, des entités émanant des GRTs, comme par exemple Coreso, SSC ou TSC⁸, apportent une vision multizone complémentaire (Arrivé et al., 2012). Un deuxième sous-module coordonne les solutions apportées par les GRTs, en particulier si les congestions se situent dans une zone très maillée dont les flux sont très dépendants.

Compte-tenu de leur forte inter-dépendance, des arbitrages sont nécessaires pour répartir entre les différentes fonctions A, B et C la contribution à la sécurité du système, comme les marges choisies en A, les quantités mises en vente en B, ou les leviers activables en C.

Enfin, la quatrième et dernière fonction de ce cadre d'analyse, désignée par D, répond au besoin d'accords et de règles communes. En effet, l'acceptabilité des mécanismes requiert au moins deux types d'accord. Le premier sous-module répartit les coûts et les

⁸Coreso est centré sur l'axe Royaume-Uni-France-Belgique-Italie, Security Service Centre (SSC) aide à coordonner les actions des GRTs allemands et néerlandais et la TSO Security Cooperation (TSC) regroupe 11 GRTs européens.

revenus entre opérateurs. Historiquement, l'accord entre GRTs européens appelé Inter-
TSO Compensation (ITC) permet de répartir certains coûts induits par les échanges
transfrontaliers entre les aires de contrôle. En effet, une zone de prix peut par exemple
être simplement de "transit" : des flux électriques entrent et sortent, mais pour une
balance commerciale nulle. Cette zone porte donc une partie du coût de l'échange sans
en tirer de bénéfices, et cela peut être corrigé par un fond de compensation. Dans le même
esprit, les revenus issus des enchères aux interconnexions sont aujourd'hui partagés à
parts égales entre les zones concernées. Concernant la coordination des actions liées à la
sécurité du système, une piste serait de faire porter le coût de chaque action au GRT qui
la demande (Lavoine et al., 2006). Dans chacun des exemples donnés, une évolution des
mécanismes de répartition des coûts est dépendante de la capacité à trouver un accord
entre les acteurs. De manière plus complexe, cette question se pose également pour
les opérateurs de marchés couplés dont l'activité n'est pas régulée. Le deuxième sous-
module de D vise un traitement équitable entre acteurs des différentes zones. Cela inclut
un minimum de cohérence entre les régulations des zones couplées. Pour répondre à ce
besoin, plusieurs éléments du droit de l'Union Européenne assurent un socle de règles
communes, comme par exemple le marché commun de certificats d'émissions de gaz
à effet de serre. En effet, le coût des émissions impacte directement le coût variable
d'opération des centrales thermiques et donc la place des moyens de production dans
l'ordre d'appel. A ce sujet, la Grande-Bretagne, en introduisant la taxe carbone dès
2013, enchérira le coût de production de ses centrales combinées gaz (CCG).

Cette analyse montre donc que les échanges entre zones sont une réalité importante, mais
complexe, des systèmes électriques. Les mécanismes cités pour la zone CWE se retrou-
vent également en partie dans d'autres régions européennes comme les pays scandinaves
ou la péninsule ibérique.

Interactions avec l'organisation interne de chaque zone

Le choix des solutions pour la coordination de l'exploitation est en pratique dépendant
de l'organisation du système électrique dans chaque zone coordonnée. Pour montrer ce
lien, deux types d'interaction fondamentale ont été identifiés.

Premièrement, sur un réseau maillé, les flux de puissances liés à des transactions trans-
frontalières s'additionnent aux flux liés à des transactions internes à chaque zone. La

détermination des espaces de possibilités d'échanges transfrontaliers est donc un arbitrage entre transactions internes et transactions externes.

Le deuxième type d'interactions concerne la conditionnalité entre certains mécanismes de coordination et un niveau minimum de compatibilité entre les organisations internes de chaque zone. Par exemple, il apparaît clairement dans une analyse par l'ACER (2012b) que, à l'horizon de temps proche du temps réel, plus les options de coordination sont efficaces, plus elles requièrent une harmonisation des pratiques de chaque zone. Lorsque cette situation apparaît, un arbitrage est donc nécessaire entre les bénéfices attendus d'une meilleure coordination et les coûts de l'harmonisation.

Option	A	B	C	D
Niveau d'harmonisation	volontaire	faible	élevé	très élevé
Efficacité	-	+	++	+++
Durée de la mise en place	++	-	--	---

TABLE D.1: Analyse comparative entre quatre options pour la coordination transfrontalière à l'horizon de temps proche du temps réel. Le critère d'efficacité estime la contribution d'une option aux objectifs européens en termes de sécurité d'approvisionnement, de compétition, de surplus économique et d'intégration des énergies renouvelables. Les quatre options sont détaillées par l'ACER dans le document (ACER, 2012b).

3. Analyse de l'impact d'une modification de cette coordination

Cette section concentre des résultats du chapitre IV du manuscrit de thèse portant sur l'étude d'impact du choix d'une évolution de la coordination. Plus précisément, elle décrit des ordres de grandeurs de certains bénéfices et coûts associés au processus d'amélioration de la coordination de manière agrégée. Dans un deuxième temps, l'analyse montre que les effets distributifs entre acteurs dans chaque zone de prix sont potentiellement importants comparés aux bénéfices pour la zone.

Ordres de grandeurs des bénéfices et coûts agrégés.

Les bénéfices les plus faciles à estimer portent sur l'amélioration de la détermination et de l'allocation des possibilités d'échanges transfrontaliers. Dans ce cas, l'évaluation quantitative des bénéfices repose sur une combinaison de modèles du système physique

et de modèles sur le comportement des acteurs de marchés⁹. Des études effectuées par les régulateurs, les GRTs ou les opérateurs de bourses avec les données et outils adaptés donnent des ordres de grandeurs des bénéfices bruts liées à certains mécanismes de couplages sur une frontière ou une région européenne. Ces bénéfices sont de l'ordre de quelques dizaines à quelques centaines de million d'euros par an.

Concernant les coûts, une estimation a été produite à partir d'observation des évolutions en 2012 sur la région CWE. L'objectif est d'identifier des ordres de grandeurs des coûts du point de vue système à l'échelle d'une grande région européenne. Cet exercice est limité par la disponibilité de données et la transparence sur les coûts passés, présents ou futurs.

Les coûts variables associés aux mécanismes de coordination semblent peu évoluer dans le processus d'amélioration en cours en 2012. Parmi les données disponibles, il est possible de considérer les coûts de fonctionnements des filiales de GRTs chargées d'analyser la sécurité du système à l'échelle de plusieurs zones¹⁰ comme de nouveaux coûts variables associés à une meilleure coordination. En 2012, pour la zone CWE, l'ordre de grandeur des coûts variables de ces filiales est de quelques millions d'euros par an. En revanche, certains coûts de coordination sont potentiellement réduits car ils sont mutualisés par la mise en place de nouveaux mécanismes communs comme dans le cas des mécanismes d'allocation implicite remplaçant des allocations explicites. On observe donc que l'évolution des coûts variables semble d'un ordre de grandeur bien inférieur aux bénéfices potentiels.

Etant donné que l'amélioration de la coordination suit un processus plutôt continu, l'estimation des coûts initiaux est faite sous la forme d'un coût moyen annuel d'investissement observé sur une période de quelques années autour de 2012. De plus, l'absence de données publiques concernant les coûts supportés par les acteurs de marchés pour s'adapter aux évolutions limite l'estimation aux coûts supportés par les entités publiques et régulées. Plus précisément, l'observation porte sur trois types d'investissements : les coûts du processus de négociation pour les GRTs et régulateurs, les coûts de projets de recherches

⁹Ces études se concentrent pour la plupart sur l'augmentation du surplus social générée par les échanges ou la réduction de certains coûts du système, à niveau de sécurité de fourniture constant. D'autres bénéfices plus difficilement quantifiables sont parfois considérés comme par exemple les bénéfices attendus d'une augmentation de la pression concurrentielle résultant d'une forme d'élargissement des marchés vu par chaque acteur. Etant donné la difficulté de l'exercice, les travaux de thèses montrent comment des indicateurs correspondant à des objectifs partiels peuvent compléter ou se substituer à l'évaluation quantitative pour aider à la décision ou mesurer l'impact d'une évolution.

¹⁰Par exemple Coreso, SSC et TSC.

européens contribuant à une meilleure coordination de l'exploitation et enfin les coûts de mise en place des nouveaux mécanismes de coordination.

A partir des budgets des projets de recherche européens liés à une meilleure coordination et du plan de recherche et développement produit par l'association européenne des GRTs, il est possible d'estimer le coût moyen annuel pour l'ensemble des financeurs à quelques millions d'euros par ans.

Ensuite, des données publiques sur les coûts de mise en place de nouveaux mécanismes conduisent à proposer une fourchette de 10 à 20 millions d'euros par ans pour la région CWE. Par ailleurs, il apparaît que les coûts d'extension des mécanismes existants à de nouvelles frontières est relativement faible comparé au coût de conception du nouveau mécanisme.

En amont et en parallèle de ces deux premiers types de coûts initiaux, les processus de concertation et de rédaction de nouveaux accords semblent avoir des coûts moyens annuels plus importants. Par exemple, une estimation des coûts supportés par les GRTs, les régulateurs et l'ACER dans ces processus donne une fourchette de 15 à 60 millions d'euros par ans ramené à l'échelle de la région CWE.

On en conclut que les coûts d'amélioration de la coordination aux frontières apparaissent supportables comparés aux bénéfices potentiels. Parmi les coûts estimés, les coûts initiaux semblent avant tout porter sur la production d'accords, ce qui contraste avec les investissements dans les réseaux où une bonne partie des coûts est liée aux infrastructures. Par ailleurs, il reste beaucoup d'inconnues dont les coûts d'adaptation des acteurs à l'évolution de la coordination.

Un effet re-distributif potentiellement important.

Une modification de la coordination aux frontières peut influencer les marchés et mécanismes de chaque zone. Par exemple, à l'horizon de temps journalier, une évolution des méthodes de détermination des possibilités d'échanges commerciaux influence le prix spot qui sert de prix de référence pour la valorisation de nombreuses transactions. L'évolution de la coordination modifie donc les flux financiers entre de nombreux acteurs. L'ordre de grandeur des variations de surplus pour les acteurs est potentiellement supérieur au surplus économique global comme illustré par deux simulations. Dans chacun des deux

exemples, les variations de surplus sont observés pour un “ensemble des consommateurs” et un “ensemble des producteurs”. Les GRTs et opérateurs de bourses ont comparé par simulation une option d’évolution des méthodes de calcul des possibilités d’échanges transfrontaliers avec la méthode actuelle (CWE, 2011b). Les résultats reproduits dans le Tableau D.2 montrent clairement que, dans chaque zone, les variations de surplus entre “producteurs” et “consommateurs” peuvent représenter plusieurs fois le surplus économique de la zone (hors GRT).

Surplus économique [k€/jour]	Total (hors GRTs)	Consommateurs	Producteurs
Allemagne	195	-948	1142
Belgique	46	83	-37
France	278	486	-209
Pays-Bas	50	4	46

TABLE D.2: Variation de surplus économiques générés par la mise en place d’une méthode Flow-Based sur la région CWE (CWE, 2011b). Les revenus de congestions diminuent de 395 k€ et le surplus net total est de 174 k€.

En complément de cette étude, un cas plus simple a été simulé dans le cadre de la thèse pour d’une part observer les effets d’un deuxième type d’évolution et pour d’autre part montrer que le raffinement de la première étude pourrait apporter des observations complémentaires. Cette simulation a été effectuée à partir des carnets d’ordre déposés par les acteurs de marché sur la bourse EPEXspot pour les zones France et Allemagne. Avec quelques hypothèses sur le lien entre les prix spots et le reste du marché, la simulation évalue les conséquences d’une augmentation des capacités d’échange fixe de 100 MW entre les deux zones. Cette deuxième illustration confirme l’effet distributif. Par ailleurs, les conséquences sont aussi simulées pour les acteurs qui ne vendraient que lorsque le prix spot est supérieur à un certain prix, ici 75€. Pour ces acteurs, l’impact apparaît, dans chaque zone, opposé à celui simulé pour l’ensemble des producteurs. Cet exemple illustre donc comment les conséquences peuvent être spécifiques pour chaque portefeuille de production et de consommation.

Capacité additionnelle [MW]	France			Allemagne			TSOs
	Cons.	Producer		Cons.	Producer		
		Tous	$p > 75\text{€}$		Tous	$p > 75\text{€}$	
100	-2.7	4.6	9.6	-8.3	1.8	5.1	1,8

TABLE D.3: Variation de surplus économique observé pour des acteurs suite à une amélioration de la coordination aux frontières permettant d’allouer 100 MW supplémentaire de capacité d’échange bilatéraux entre France et Allemagne sur le marché journalier.

4. Le rôle de l'Union Européenne

L'UE joue un rôle important dans la gouvernance partagée du système électrique intégré européen. En particuliers, le droit européen contribue fortement au bon fonctionnement de la coordination et plusieurs initiatives soutenues par l'UE forment un terreau propice à l'émergence de nouveaux accords pour une amélioration de la coordination de l'exploitation.

Le rôle du droit Européen

Des règles communes sont nécessaires au bon fonctionnement du système. Il faut par exemple des critères de sécurité cohérent et des règles pour prévenir les comportements de type "passager clandestin" (ACER, 2011c). Il faut aussi encadrer certaines taxes, normes ou subventions pour s'assurer que les signaux prix intégrant ces aspects sont cohérents entre les zones marchandes. Plus généralement, un droit de la compétition commun assure une égalité de traitement entre les différents acteurs de marchés.

Le droit européen est une forme adaptée pour ces règles communes. En effet, ce droit est souverain sur les droits nationaux¹¹ et les institutions existantes permettent de produire et de faire respecter ces règles dans les pays membre de l'UE.

Etant donné que des pays importants pour le système électrique ne sont pas membre de l'UE, plusieurs accords peuvent prolonger la validité du droit européen sur le marché commun de l'énergie à ces pays. C'est le cas de la Norvège qui est membre de l'Espace Economique Européen (EEE) et qui, à ce titre, se doit de transposer l'acquis communautaire lié au bon fonctionnement du marché commun. De même, plusieurs pays du sud-est de l'Europe sont membre de la Communauté de l'énergie et se sont donc engagés à agir en accord avec l'acquis communautaire sur le marché commun de l'énergie. Par ailleurs, la Suisse, qui est au cœur du système électrique, est en négociation bilatérale avec l'UE concernant sa participation au marché commun.

En pratique, le droit européen en place en 2012 offre tout d'abord un cadre à la libéralisation des marchés de l'électricité et un droit de la compétition commun. En outre, l'acquis communautaire concerne aussi les objectifs de sécurité d'approvisionnement

¹¹Dans les limites conférées par les traités dont le traité sur le fonctionnement de l'Union européenne et le traité sur l'Union Européenne (EU, 2010d).

et de développement durable. Par exemple, le système communautaire d'échange de quotas d'émission permet l'émergence d'un prix des émissions de gaz à effet de serre commun pour les principaux producteurs d'électricité européen.

Le rôle des initiatives supportée par l'UE

Plusieurs initiatives supportées par l'UE depuis la libéralisation des marchés de l'électricité forment un terreau pour de nouveaux accords permettant l'amélioration future de la coordination aux frontières. Pour coordonner l'action des régulateurs sur les questions transfrontalières, une agence européenne, l'ACER, a été créée et financée par l'UE en complément de l'association des régulateurs européens de l'énergie. Par ailleurs, la coordination à l'échelle de régions européennes a été favorisée depuis 2005 via des Initiatives Régionales (Everis and Mercados EMI, 2010).

Pour préparer de nouveaux accords entre les parties prenantes, plusieurs lieux et processus de discussions entre acteurs ou représentants des acteurs ont été ouverts. Depuis 1998, les "Forums de Florence" sur la régulation européenne de l'énergie ont lieu périodiquement et permettent à un large panel de parties prenantes de discuter de manière plutôt informelle des dernières évolutions et projets d'évolution de la coordination aux frontières. Depuis plus récemment, une sélection restreinte de représentants des parties prenantes¹² est régulièrement invitée à participer à divers comités très fortement impliqués ou consultés dans des processus de décisions. Par exemple, en 2009, un "Project Coordination Group" a posé de manière publique des options qui ont été suivies dans les années suivantes.

De plus, la rédaction d'orientations cadres et de codes réseaux européens tel que défini dans une régulation européenne de 2009 (EU, 2009d) offre une occasion de faire évoluer les règles communes pour le bon fonctionnement du système électrique européen. Ce processus porté par l'ACER et les GRTs met l'accent sur la consultation des parties prenantes et les versions finales seront soumises à un processus dit de comitologie afin d'être ajoutées à l'acquis communautaire.

¹²Parmi les associations représentées se trouvent l'association des GRTs (ENTSO-E), des associations de producteurs (Eurelectric), de grands consommateurs (IFIEC), l'association des entités de trading (EFET) et celle des bourses d'électricité (Europex).

L'UE a aussi supporté financièrement et orienté des projets de recherches communs autour des métiers des GRTs tels que PEGASE, OPTIMATE, UMBRELLA et iTESLA¹³. Ces projets doivent apporter non seulement des innovations pour le système électrique européen telles que des outils ou des méthodes, mais aussi une meilleure connaissance des pratiques de chaque GRT par ses homologues et par les milieux académiques impliqués. Ces initiatives portées ou initiées par l'UE ont en commun de favoriser la rencontre, la compréhension mutuelle entre acteurs et l'identification des points de vue divergeant. Ce sont des conditions nécessaires à l'émergence d'une confiance réciproque entre acteurs et à l'action de médiation qui peut permettre l'émergence de nouveaux accords pour une amélioration des mécanismes de coordination européens.

5. Les modes de coordination entre Gestionnaires de Réseaux de Transport

Les GRTs sont au cœur de beaucoup des solutions de coordination décrites dans la section 2. Cependant, du point de vue institutionnel, les modes de coordination entre les différents GRTs ont été peu analysés dans la littérature économique. Cette section propose donc d'analyser deux dimensions de ces modes de coordinations, à partir de l'observation empirique d'une sélection de mécanismes de coordination sur deux grandes régions européenne en 2012 : la région CWE et la région nordique. Il s'agit d'un résumé de l'étude ([Janssen and Trotignon, 2012](#)).

La première dimension vise à identifier l'utilisation de trois formes institutionnelles particulières pour la réalisation concrète de la coordination : (a) Les GRTs se coordonnent entre eux principalement à l'aide d'un accord privé ; (b) Un fournisseur de service ou une association liée aux GRTs a un rôle majeur pour la coordination ; (c) Une règle publique contraignante assure la coordination.

La deuxième dimension évalue l'extension géographique de la coordination en utilisant les régions CWE et nordique comme référence intermédiaire entre trois niveaux : (1) La coordination couvre quelques zones à une échelle plus petite que les régions européennes

¹³Les descriptifs de ces projets, dont les objectifs, participants et budgets, sont décrits sur le site du CORDIS : http://cordis.europa.eu/home_en.html.

; (2) La coordination couvre l'équivalent d'une région européenne ; (3) La coordination dépasse l'échelle régionale.

Observations empiriques

Les observations, résumées dans le Tableau D.4, sont brièvement résumés dans la liste suivante et pour aider la compréhension, leur fonction est liée à l'analyse fonctionnelle faite dans la section 2 :

- La détermination des capacités d'échanges aux frontières sous forme de NTC par accord bilatéral entre GRTs (Tache correspondant au module A.2).
- L'allocation des capacités d'échange à long terme par des enchères explicites coordonnées (module B.2). Ces enchères sont opérée sur la région CWE, ainsi que plusieurs pays voisins comme l'Italie, par un acteur unique, CASC-CWE.
- L'allocation des capacités d'échange à l'horizon journalier par des enchères implicite (module B.2). Plusieurs opérateurs de bourses d'électricité assurent ce service à l'échelle des régions. Il s'agit par exemple de Nordpool spot dans la région nordique.
- L'allocation des capacités d'échange à l'horizon infra-journalier par des enchères implicites (module B.2). En 2012, ce service est assuré par des opérateurs de bourses d'électricité à l'échelle régionale dans la région nordique et de manière bilatérale dans la région CWE.
- L'utilisation des capacités disponibles en temps réel pour coordonner l'activation des réserves secondaires (module B.2). Des accords entre GRTs permettent cet usage des capacités d'échange sur des frontières internes et externes de l'Allemagne.
- La production d'analyse de sécurité à l'échelle de plusieurs aires de contrôle (module C.1). Les entreprises Coreso, SSC et TSC offrent par exemple ce service à l'horizon journalier.
- La coordination des réponses des GRTs lorsqu'une situation critique est anticipée (module C.2). Les entreprises Coreso, SSC et TSC sont en mesure de proposer des solutions coordonnées aux GRTs qui ont une totale responsabilité sur leurs actions et peuvent aussi se coordonner plus directement entre eux.

- La distribution d'un mécanisme de compensation pour les pertes et pour la fourniture de l'infrastructure d'accueil de flux transfrontaliers d'électricité (module D.1). Une décision de la Commission Européenne fixe de manière détaillée les modalités de cette compensation (EU, 2010a).

Par ailleurs, deux taches pour plus d'intégration sont analysées, les projets de recherches communs et la rédaction des codes réseaux européens introduits tous deux dans la section 4. Pour ces deux taches, l'ENTSO-E joue un rôle central. Il s'agit d'une association composée par 42 GRTs européens.

Sélection de mécanismes de coordination	Mode			Extension		
	(a)	(b)	(c)	(1)	(2)	(3)
Détermination bilatérale des capacités	x			x		
Allocation explicite à l'horizon long terme		x				x
Allocation implicite à l'horizon journalier		x			x	x
Allocation implicite à l'horizon infra-journalier		x		x	x	
Coordination de l'activation des réserves secondaires	x			x		
Analyses de sécurités multizones		x		x	x	x
Réponse coordonnée à une situation critique	x	x		x	x	
Redistribution d'un mécanisme de compensation			x			x
Rédaction de nouveaux codes réseaux européens		x	x			x
Projets de recherches communs		x	x		x	x

TABLE D.4: Observation de deux dimensions des modes de coordination entre GRT dans les régions CWE et nordique en 2012. La coordination peut être réalisée principalement par a) un accord entre GRTs, b) l'implication de fournisseur de service commun ou d'une association commune et c) une règle publique contraignante. La coordination peut s'étendre sur 1) deux ou trois pays, 2) l'équivalent d'une région européenne, 3) plusieurs régions.

Analyse de la forme institutionnelle utilisée pour la coordination

L'utilisation de fournisseurs de services, souvent une filiale de GRTs, ou d'une association commune, l'ENTSO-E, apparaît intéressante pour le bon fonctionnement du système et pour l'amélioration de la coordination. En effet, ce mode peut permettre : de mutualiser des coûts, de partager et confronter des pratiques différentes au sein d'une entité commune, d'offrir un intermédiaire qui peut agir comme médiateur dans la construction de décisions communes et de créer des entités qui, selon leur gouvernance, pourront être incitées à proposer de nouveaux services pour une bonne coordination transfrontalière.

En plus des cas existants, ce mode peut être adéquat pour la réalisation de nouvelles tâches transfrontalières. Par exemple, une nouvelle entité pourrait héberger la coordination de l'activation des réserves secondaires entre plusieurs GRTs. En outre, les filiales Coreso, SSC et TSC pourraient être amenées à offrir de nouveaux services autour de leurs fonctions actuelles sur les analyses de sécurité.

L'utilisation de règles publiques pour assurer ou améliorer la coordination est une option qui a été en partie analysée dans la section 4. Ce mode permet en particulier de gérer de manière acceptable certaines externalités transfrontalières sur un système électrique intégré comme illustré par les transferts financiers dans le cadre du fond de compensation entre GRTs (EU, 2010a).

En fonction de l'aboutissement du processus de rédaction et d'adoption des codes réseaux européens, les règles publiques vont probablement définir plus précisément certains mécanismes de coordination. Néanmoins, ce mode peut présenter des coûts de transactions élevés et une inertie forte qui pourrait limiter la capacité d'adaptation à une évolution du système électrique intégré. C'est pourquoi, il est important que le résultat offre une flexibilité suffisante à l'évolution continue de la coordination transfrontalière.

Analyse de l'extension géographique de la coordination

L'observation de la diversité des aires géographiques couvertes par les mécanismes de coordination renforce la modularité de la coordination de l'exploitation au sens où les différentes tâches peuvent être définies et mises en place relativement séparément comme introduit dans l'analyse des solutions (section 2).

Une observation plus précise révèle une corrélation inverse entre la taille de la coordination et l'impact potentiel sur la sécurité d'approvisionnement à court terme. Par exemple, concernant les mécanismes d'allocation des espaces de possibilité d'échanges transfrontaliers, il apparaît que plus l'horizon de temps est proche du temps réel, plus la coordination se fait à une petite échelle. Ce lien peut s'expliquer par au moins trois hypothèses. Il peut simplement s'agir d'une coïncidence sur les quelques éléments observés. Cela peut aussi être un effet transitoire. En effet, le temps de négociation et de mise en place est peut être plus élevé quand le sujet est plus complexe et sensible pour les GRTs. Cette observation peut enfin être le signe d'une question plus fondamentale,

à savoir qu'il peut être intéressant de garder une échelle régionale ou sous-régionale pour la coordination de certaines tâches.

Derrière cette dernière hypothèse se pose la question de l'optimalité d'une extension géographique. L'objectif politique est un marché unique de l'électricité à l'échelle de l'Union Européenne et de certains pays fortement liés à ce bloc. Au-delà de cette ligne directrice, la réalisation pratique devra viser les objectifs finaux d'efficacité, de sécurité d'approvisionnement et de respect de l'environnement. Dans ce cadre, la dimension régionale peut apparaître comme une dimension optimale pour certains mécanismes de coordination dans le processus de décision en cours.

Conclusions

La coordination transfrontalière de l'exploitation est une solution pour utiliser au mieux les ressources d'un système électrique intégré comme le système Européen. En pratique, la coordination est réalisée par un ensemble de mécanismes assurant deux grandes fonctions économiques : déterminer et allouer une ressource rare, l'espace des possibilités d'échanges, et gérer les externalités transfrontalières générées par l'interconnection et les flux résultants.

D'un point de vue technique, il existe en 2012 plusieurs solutions pour la coordination transfrontalière de l'exploitation du système électrique (ex. calcul des capacités d'échanges en flow based ou ATC based, allocation implicite/explicite, price & volume coupling)¹⁴.

Du point de vue des surplus économiques, les coûts du processus d'amélioration apparaissent supportables comparés aux bénéfices potentiels, même si les études d'impacts se heurtent à de nombreuses inconnues. Ces études tendent aussi à révéler qu'il peut y avoir de forts effets re-distributifs.

La dimension politique du problème est donc très importante dans l'évolution de la coordination de l'exploitation. En complément de l'implication volontaire de certains acteurs, l'émergence d'accord est en pratique favorisée par plusieurs processus initiés ou supportés par l'Union Européenne.

¹⁴Ces solutions techniques font l'objet de focus dans le chapitre II.

Par ailleurs, concernant plus précisément la coordination entre GRTs, il est intéressant de noter que des filiales communes assurent en 2012 plusieurs fonctions clés. Ce mode de gouvernance présentant de nombreux bénéfices semble être une option adaptée à plusieurs tâches clés.

L'analyse économique de ces mécanismes de coordinations montre donc qu'au-delà des limites techniques, concernant par exemple des algorithmes, et des coûts économiques, l'amélioration de la coordination pose avant tout des problèmes d'économie institutionnelle. Cela se vérifie par l'observation d'effets redistributifs potentiellement importants, par l'analyse des externalités transfrontalières et la forte composante nationale des politiques pour le secteur énergétique en particuliers en dehors du droit de la concurrence. Il ressort de l'analyse que l'économie institutionnelle a donc encore beaucoup à apporter au processus continu d'amélioration de la coordination aux frontières internes d'un système électrique intégré.

Par ailleurs, même si cette étude a été centrée sur le cas des frontières intérieures au système électrique de la région CWE autour de 2012, les cadres d'observations ont été construits de manière à pouvoir être appliquée à d'autres frontières. Il sera donc intéressant de confronter les résultats aux autres régions européennes, aux frontières extérieures de l'Europe et à d'autres continents.

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