Lappeenranta
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CROSS-BORDER TRANSMISSION CAPACITY DEVELOPMENT – EXPERIENCES FROM THE NORDIC ELECTRICITY MARKETS

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ABSTRACT

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The liberalisation of the wholesale electricity markets has been considered an efficient way to organise the markets. In Europe, the target is to liberalise and integrate the common European electricity markets. However, insufficient transmission capacity between the market areas hampers the integration, and therefore, new investments are required. Again, massive transmission capacity investments are not usually easy to carry through.

This doctoral dissertation aims at elaborating on critical determinants required to deliver the necessary transmission capacity investments. The Nordic electricity market is used as an illustrative example. This study suggests that changes in the governance structure have affected the delivery of Nordic cross-border investments. In addition, the impacts of not fully delivered investments are studied in this doctoral dissertation. An insufficient transmission network can degrade the market uniformity and may also cause a need to split the market into smaller sub-markets. This may have financial impacts on market actors when the targeted efficient sharing of resources is not met and even encourage gaming. The research methods applied in this doctoral dissertation are mainly empirical ranging from a Delphi study to case studies and numerical calculations.

Keywords: *electricity market, congestion management, transmission capacity development*

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Lappeenranta, 2015

Mari Makkonen

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I. Makkonen, M., Pätäri, S., Jantunen, A. Viljainen, S., (2012), "Competition in the European electricity markets – outcomes of a Delphi study," *Energy Policy 44 (2012)*, pp. 431–440.

II. Makkonen, M., Viljainen, S., Nilsson, M., (2015), "All quiet on the western front? Transmission capacity development in the Nordic electricity market," *Economics of Energy and Environmental Policy*, Vol. 4, No. 2, pp. XX–XX, accepted for publication.

III. Viljainen, S., Makkonen, M., Gore, O., Spodniak, P., (2012), "Risks in Small Electricity Markets: The Experience of Finland in Winter 2012," *The Electricity Journal*, December 2012, Vol. 25, Issue 10, pp. 71–80.

IV. Makkonen, M., Viljainen S., Spodniak, P., (2013), "Economic impacts of price spreads in the Nordic electricity markets", in *proceedings of European Energy Market Conference*, EEM13, Stockholm, Sweden.

Nomenclature

Roman letters

D	Demand
MC	Marginal cost
MR	Marginal revenue
*P*m	Monopoly price
*P*c	Competitive price
*Q*m	Monopoly quantity
*Q*c	Competitive quantity

Acronyms

AC	Alternating current
ACER	Agency for the Cooperation of Energy Regulators
CBA	Cost Benefit Analysis
CBCA	Cross-Border Cost Allocation
CO_2	Carbon dioxide
CWE	Central-West European electricity market
DC	Direct current
EC	European Commission
ENTSO-E	European Network of Transmission System Operators for Electricity
HVDC	High-voltage direct current
NIMBY	Not-in-my-backyard
NWE	North-Western Europe

TSO	Transmission System Operator
TYNDP	Ten-Year Network Development Plan

1. Introduction

The electricity market liberalisation started on a worldwide scale in the late 1980s and the early 1990s in the UK, Chile and Norway. After that, many countries have restructured their electricity markets; for example the rest of the Nordic countries, Europe, some states of the US, Australia, New Zealand and Russia. In the process, electricity generation and sales have been liberalised, in other words, they have been opened up to competition. Transmission and distribution network operations, however, have retained their natural monopoly positions.

The objective of this doctoral dissertation is to investigate transmission capacity development in the Nordic electricity market that applies the zonal pricing method as the congestion management method to resolve temporary bottlenecks in the transmission network. While a special focus of the study is on the Nordic market, a wider European perspective is also taken into account.

The doctoral dissertation aims at evaluating the critical factors affecting effective transmission capacity development and consequences for an integrated electricity market if the targets are not met. The Nordic electricity market is used to provide examples of successful network investments and failures. Moreover, an obvious change in the Nordic transmission capacity development can be seen in the early 2000s. In addition, the financial effects of imperfectly accomplished transmission capacity plans are calculated.

The research methods applied in this doctoral dissertation are both qualitative and quantitative. The Delphi method is adopted to identify the main issues hampering market integration in Europe. Case studies are used to assess the risks of small electricity markets and the change in governance, and thereby, the changed investment pattern in the Nordic electricity markets. A quantitative approach is taken to study the financial impacts of delayed network investments by introducing a calculation method to estimate the effects for different market participants. To sum up, by applying multiple research methods (quantitative and qualitative) and diverse data from a variety sources and a large group of experts in the surveys, the research limitations associated with a study based on a single method or a source can be compensated for. This is discussed for instance in Denzin (1978): “no single method can ever completely capture all the relevant features of that reality; consequently [we] must learn to employ multiple methods in the analysis of same empirical events."

1.1 Restructured electricity markets

The electricity pricing model as such is not enough to define the electricity market model. The reason for this is that the electricity market model should cover all operation principles of the electricity wholesale market. In some publications (e.g., Joskow (2006a)), also the term 'market design' has been used to describe the principles of the markets. However, in this doctoral dissertation, market design is understood as a term referring to the structure of the markets as a whole including for instance the ownership of power plants. A market model is used to describe the actions in the markets, and especially, how the transmission network congestion is managed. There are two basic models: zonal and nodal pricing, and several kinds of applications of both market models. In this doctoral dissertation, the focus is on the zonal market model in the wholesale electricity markets. Moreover, the transmission capacity development in this zonal model is investigated.

The main goal of the electricity market liberalisation was to promote competition in the markets, reduce governments' role and strengthen the role of consumers in short- and long-term demand management, thereby making the market more efficient (Harris, 2006). Competition can provide cost-minimising incentives and "hold price down to marginal cost" (Stoft, 2002), and even lower the prices for end-users (Haas and Auer, 2006). Competitive markets are also an efficient way to share the scarce resources (Joskow, 2010).

The early stages of the electricity market deregulation and competition issues in the new markets are studied for instance in Joskow (2009), who argues that deregulation and competition in the electricity markets as such are not the goals of the liberalised electricity markets. Instead, competition is the way to achieve the "long-term net benefits to society by increasing the efficiency with which electricity is produced and consumed in ways that are consistent with environmental goals and policies." Newbery (2002) mentions sustainable competitive prices, meaning that liberalised electricity markets should provide efficient and reliable electricity supply by guaranteeing the security of supply in competitive markets that have enough independent generators, transmission capacity and a sufficiently well-developed market structure.

Newbery (2009), again, has stated that the design of the liberalised electricity market "should be tailored to the circumstances of each country." He especially refers to the ownership structure of the power plants and generation types. Hogan (1999), has reviewed electricity market models. He compares zonal and nodal market models and highlights the consequences of transmission network congestion. The nodal pricing model is found more suitable to handle network congestion than the zonal pricing model. Green (2007) also compares the nodal and uniform pricing models. He develops the nodal model for the transmission system in England and Wales and ends up in the result that nodal prices could increase welfare, would be less vulnerable to market power and send better investment signals than uniform pricing. However, the nodal model would "create politically sensitive gains and losses." Neuhoff et al. (2011) discuss the challenges of the congestion management schemes (e.g., zonal and nodal pricing models) in Europe and compare different methods, for example, in the light of transparency.

Electricity differs from most other commodities in that it cannot be stored in an economically viable way (at least not yet), consumption and generation must be balanced all the time for technical reasons, and the demand is mostly quite price inelastic. In addition, the electricity system is characterized by the fact that customers and suppliers are physically connected. Therefore, electricity market restructuring has posed a much greater challenge compared for instance with telecommunications (Borenstein and Bushnell, 2000). Basically in the competitive markets, no market participant is able to take action that would affect prices in the markets (Borenstein, 2000). A small market size can be mentioned as a factor that may hamper competition (too few generators in the market area). Market integration has been seen as a solution to this as it increases the number of market participants, reduces concentration and makes the sharing of resources more efficient. To integrate the markets, sufficient transmission between areas is needed for the electricity to flow freely (usually) from a surplus area to a deficit area (Bergman, 2003; Haas and Auer, 2006; Jamasb and Pollit, 2005).

1.2 On competition

Perfect competition is the optimal case for the markets; nevertheless, it requires many buyers and sellers in the market, product homogeneity, free entry and exit and price-taking sellers and buyers (Pindyck and Rubinfeld, 2005). Moreover, Porter (1980) lists forces that affect the competition of the branch: a threat of potential competitors outside the market, possible substitute products as a necessity for competitive markets and bargaining power from buyers and suppliers. In other words, if the markets work properly, a single market participant cannot affect the prices. However, perfect competition is not always achieved, but there are also imperfect forms of competition, such as monopoly and oligopoly. Reasons for imperfect competition could be the benefits of large-scale production, and thus a natural monopoly, too small markets or legislation protecting firms from competition (e.g. by licensing or patents).

In a monopoly there is only one seller that can decide upon the price for the product. Alternatively, the seller can decide on the amount of production, which can be less than the needs of the buyers. This means that the monopoly produces less with higher prices than in the competitive markets. Usually, a monopoly is inefficient and causes welfare losses for society (except for some regulated natural monopolies, for instance transmission and distribution networks, the operation of which is based on the benefits of the large scale). In Figure 1, the welfare losses are explained.

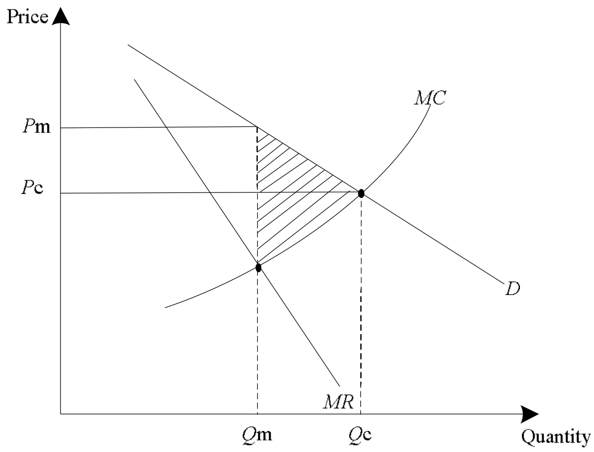

Figure 1. Deadweight loss from monopoly power (Pindyck and Rubinfeld, 2005 p. 360). *P*m = monopoly price and *Q*m = monopoly quantity, *P*c = competitive price and *Q*c = competitive quantity, *MC* = marginal cost, *MR* = marginal revenue, *D*= demand. The shaded area indicates the deadweight loss.

In the competitive markets, the price of a product equals the marginal costs of production. However, in a monopoly situation it is most profitable for the seller that the price is higher than the marginal costs and there is less production than in a competitive situation. Thus, the marginal cost equals the marginal revenue, and the sellers benefit more from the higher price than they suffer from the lower quantity. Nevertheless, from the consumer's viewpoint, this is not an optimal situation; the consumers pay more and get less. As a summary, the deadweight loss can be calculated. This is illustrated in Figure 1 with the patterned area. For instance, even if the monopoly revenue is under taxation, which will be distributed to the consumers, or the monopoly is regulated, there will be inefficiency in the markets because of the lower output. From the viewpoint of electricity markets, the monopoly theory is presented for instance in Stoft (2002). Correspondingly, the monopoly power causes higher market prices than in the competitive situation.

In the electricity markets there are natural monopolies in distribution and transmission networks. A sufficient transmission network provides potential entry opportunities for new market participants (a larger market area) (Bergman, 2009). On the other hand, a congested network can limit the market area so that there are only one or a few generators, and thus, even affect the competition. According to Cardell et al. (1997) and Newbery et al. (2004) the dominant generator may even (theoretically) enhance the uncompetitive market situation by increasing its production in one location and thereby affect generation, network constraints and prices in other location. These situations can be modelled by for example game theory, as discussed in Borenstein et al., 2000; Metzler et al., 2003 and Neuhoff et al., 2005.

1.3 Congestion management method

An integrated competitive electricity market area is the initial target in the European electricity market development. It is assumed that trade and larger markets is more efficient from the viewpoint of competition (more market participants), and the sharing of resources is efficient. However, a large market area requires a strong electricity transmission network; without adequate network connections within the market area, a free flow of electricity cannot be guaranteed, and in reality there would be no common market. In addition, the existing transmission network capacity has to be exploited efficiently by the market (to be efficient, the flows have to be from surplus areas to deficit areas). Transmission congestion is mainly thought of as a temporary situation in the zonal pricing model, and in the case of congestion in the market area, a few predefined price zones are used. Countertrading is used to alleviate internal congestion within the zone. The reduction of congestion is based on a buy-back principle so that the system operator trades against the flow of congestion (Amundsen et al., 2006; Bergman, 2009; Bjørndal and Jörnsten, 2007; Creti et al., 2010; Glachant and Pignon, 2005; Haas et al., 2006; Jamasb and Pollitt, 2005; Küpper et al., 2009).

In the zonal pricing model, the electricity exchange is responsible for the electricity price calculation. The Transmission System Operators (TSO) monitor the availability of transmission capacities and offer the available capacity to the power exchange. Based on the transmission capacity available, and bids and offers from the market participants, the power exchange calculates the electricity price. If there is enough transmission capacity, a single price holds for the whole market area. In the case of congestion, zonal prices are calculated. This is referred to as an implicit auction method, in which the electricity and transmission capacities are calculated simultaneously; it is not allowed to reserve transmission capacity before the electricity trading (unlike in the explicit auctions). There are both market splitting and coupling methods, which basically differ from each other by the order of the price calculation of the common and zonal prices in a single or many power exchanges.

The model relies on a non-congested network and a large market area, and therefore, if this requirement is not met, competition in the markets may suffer (Bergman, 2009). Especially, if the network congestion is repeated and predictable, it can provide opportunities for gaming by the market participants. In addition, the need for countertrading (or redispatching) will increase. Market monitoring procedures can be added to limit the market power abuse but surveillance is a difficult task, as discussed in Newbery et al., (2004).

1.4 Outline of the work

There are two parts in this doctoral dissertation; the first part gives an overview of the dissertation and delineates the research objectives and results, and the second part provides the research papers that address the research questions within the scheme and objectives of the study. In the first part, Chapter 2 introduces the Nordic electricity markets. The history of the Nordic electricity markets and transmission capacity investments are elaborated upon in brief. Three cases of capacity investments are presented. The objectives of the research approach and the motivation for the research are given in Chapter 3. Chapter 4 summarises the research publications and the key findings. Chapter 5 provides a discussion on the topic and the main conclusions from the work presented in the dissertation.

The doctoral dissertation consists of four original refereed articles. One of the articles was presented in an international conference; three of them have been/will be published in scientific journals. The articles and the author's contribution to them are summarised next.

Publication I *Competition in the European electricity markets – outcomes of a Delphi study (2012)*

Publication I identifies the factors affecting the European electricity market integration. The Delphi method was used to gather opinions on electricity market integration from selected European electricity market specialists. In the study, transmission network development was recognised to be necessary to further the market integration in Europe, yet it was also identified to be the most challenging target to achieve. The author of the doctoral dissertation carried out the Delphi study and analysed the results, wrote more than half of the paper, and was the principal author in the publication.

Publication II *All quiet on the western front? Transmission capacity development in the Nordic electricity market (2015)*

Publication II evaluates the development and impact of the governance structure in the Nordic electricity market, with the focus on the change in the governance structure (with a special reference to the change in the outlet for local political commitment). Further, the paper analyses the impacts of this change on the transmission capacity development. In this publication, the author has collected almost all data underlying the analysis and contributed essentially to the analysis presented in the publication. The present author was the corresponding author in the publication.

Publication III *Risks in Small Electricity Markets: The Experience of Finland in Winter 2012 (2012)*

Publication III illustrates the risks of small electricity markets[1]. The analysis presented in the publication is based on an empirical case in the Finnish electricity market in winter 2012. In that winter, Finland was repeatedly separated into a price zone of its own in the Nordic market area.

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[1]In this case, small from the competition viewpoint. ‘Small electricity market’ refers to a situation in which the transmission capacity is limited and the market decouples into a (geographically small) price zone of its own. In addition, if there are only a few market players in the decoupled zone, the market can be called ‘small’.

One main reason for this was that Russia limited its electricity export to Finland, which increased the need to export electricity from Sweden to Finland to cover the consumption. The present author made the numerical analyses and wrote about half of the paper. The author acted as a co-author in the publication.

Publication IV *Economic impacts of price spreads in the Nordic electricity markets (2013)*

Publication IV presents the distributional effects of electricity market decoupling in the Nordic electricity markets. Delayed transmission capacity investments hamper market uniformity, which, again, may have financial impacts for market actors. The empirical study has been carried out for the years 2010–2012, and it covers Finland, Sweden, Denmark and Norway. The present author was responsible for the analysis and calculations and wrote almost all the text in the paper. The author was the corresponding author in the publication.

In addition, the author of this doctoral dissertation has studied the topic in other publications, for instance in Makkonen and Viljainen (2012).

2. Nordic electricity markets

The Nordic electricity market was the first integrated regional electricity market in Europe. The transmission capacity investments were chosen as the method to solve the structural bottlenecks of the grid in the long term: investments are necessary to guarantee a well-functioning Nordic electricity markets.

2.1 History of the Nordic electricity markets

The Nordic electricity market has been set up gradually since the 1990s. The target of the electricity power system integration in the Nordic countries was initially to ensure a more efficient sharing of resources (e.g. hydro power). In addition, strong political support has promoted the establishment of a Nordic electricity market (Amundsen et al., 2006). First, after the liberalisation of the national markets, Norway and Sweden constituted a regional market (1996), and later on, Finland (1998) and Denmark (2000) joined the market. The Baltic countries have also entered Nord Pool Spot, the Nordic marketplace.

The roots of the Nordic electricity markets lie at the beginning of the 20th century when small local electricity companies built a few interconnections between the Nordic countries, after which the Nordic co-operation organisation Nordel was founded in the 1960s. Nordel had historically focused on the system operation function, but in the late 1990s it expanded to cover the transmission capacity development. In 2000, Nordel changed its statutes to be the cooperation organisation of the TSOs only (Nordel, 1978–2008), and it played the key role in the planning of transmission capacity investments. Following the European Union’s changes in governance, Nordel was dismantled in 2009, and it was replaced by the European organisation ENTSO-E (European Network of Transmission System Operators for Electricity). Table 1 summarises the main steps of Nordel’s capacity development initiatives. The history of Nordel and the Nordic electricity markets is also outlined in Publication II.

Table 1. Nordic transmission capacity development initiatives (Energinet.dk, 2009; Fingrid, 2012; Montel 2013b; Nordel 1978–2008; Nordel Grid Plan, 2004; Nordel Grid Plan, 2008; Nordic Grid Development Plan (2012, 2014); Nordic Grid Code, 2007; Nordic Grid Master Plan, 2002; Statnett, 2013a; SvK, 2009; SvK, 2013; Swedish-Norwegian Grid Development, 2010; TYNDP (2010, 2012, 2014)).

Year	Nordic transmission capacity development initiatives (1/2)
1963	Nordel was founded, cooperation organisation of Nordic electricity companies (Nordic Grid Code, 2007).
1978	Nordel identifies the need for more interconnector capacity at the Hasle cross-section between southern Norway and Sweden (Nordel, 1978).
1980	The Swedish-Norwegian cooperation results in interconnector capacity increases at the Hasle cross-section (Nordel, 1980).
1987	The Nordel Planning Committée drafts a "proposal for the transmission capacities on the interconnecting links at the 1995 stage" based on e.g. the expansion plans for the generation and transmission system (Nordel, 1987).
1992	Nordel highlights the importance of cross-border cooperation in developing transnational electricity markets (Nordel, 1992).
1993	Nordel changes its statutes to distinguish between the grid functions and the generation functions (Nordic Grid Code, 2007).
1998	Nordel transforms into a peer group organisation of the Nordic TSOs (Nordic Grid Code, 2007).
1999	The tasks of the revised Nordel organisation are presented to "fall mainly into the following categories: - system development and rules for network dimensioning; - system operation, reliability of operation and exchange of information; - principles of pricing for network services; - international co-operation; - maintaining contacts with other actors, organisations and the authorities within the power sector. The results of Nordel's work are to be public and its operations are to be neutral" (Nordel, 1999) .
2000	Nordel becomes a formal cooperation organisation of the Nordic TSOs (that is, the TSOs as companies now become the members of Nordel instead individual persons working for the TSOs) (Nordic Grid Code, 2007). Nordel's goals are defined as "to create the conditions for, and to develop further, an efficient and harmonised Nordic electricity market". Correspondingly, a new task of "preparing and disseminating neutral information about the Nordic electricity system and market" is added to Nordel's task list. Dialogue with the market actors is to be carried out through Nordel's Market Committée (Nordel, 2000).
2001	Preparation of a Grid Master Plan is set to be a strategic project of Nordel. The common grid plan will be the first of its kind, and it aims to identify and prioritise the important transfer corridors in the Nordic electricity markets (Nordel, 2001).
2002	The Nordel Planning Committée drafts its first Grid Master Plan. The goal of the report is to "ensure that the infrastructure is present which is necessary for the smooth operation of the market and to ensure the supply of electricity to the entire Nordic area". The plan identifies in total nine "important cross-sections within the Nordel area". The Hasle cross-section is listed amongst the important cross-sections (Nordic Grid Master Plan, 2002).

Table 1. Nordic transmission capacity development initiatives (Energinet.dk, 2009; Fingrid, 2012; Montel 2013b; Nordel 1978–2008; Nordel Grid Plan, 2004; Nordel Grid Plan, 2008; Nordic Grid Development Plan (2012, 2014); Nordic Grid Code, 2007; Nordic Grid Master Plan, 2002; Statnett, 2013a; SvK, 2009; SvK, 2013; Swedish-Norwegian Grid Development, 2010; TYNDP (2010, 2012, 2014)).

Year	Nordic transmission capacity development initiatives (2/2 continued)
2004	Nordel publishes its second Grid Master Plan, the Priority Cross-sections Report. The plan lists five prioritised projects that are expected to improve the functioning of the Nordic electricity markets and enhance the security of supply in the Nordic countries (Nordel Grid Plan, 2004).
2008	Nordel publishes its third Grid Master Plan to promote new cost-efficient Nordic grid enforcements. In the plan, Nordel puts forward a recommendation for "Statnett and Svenska Kraftnät to start the planning process for strengthening the grid between Sweden and Norway". The benefits of the promoted project for Norway and Sweden are expected to be "reduced bottlenecks and improved security of supply" (Nordel Grid Plan, 2008).
2009	Nordel as an independent organisation is dissolved and the cooperation of the Nordic TSOs continues in the European-level organisation ENTSO-E that hosts a Baltic Sea Regional Group. Svenska Kraftnät and Statnett start "a strategic collaboration with the aim, among other things, of producing a Norwegian-Swedish network development plan" (SvK, 2009). Danish Cable Action plan for 132–150 kV grid is published. It contains analysis of the existing grid and especially cable undergrounding (Energinet.dk, 2009).
2010	Svenska Kraftnät and Statnett publish a joint report on grid development. The purpose of the report is to meet "the goal of Nordic Council of Ministers which aims for a Nordic perspective in the grid development planning". Svenska Kraftnät and Statnett note the report to be "one of the planning tools of our common power systems, disregarding national borders". However, the report also stresses its role as "a supplement to Statnett's national grid development plan" (Swedish-Norwegian Grid Development, 2010). First TYNDP report is published by ENTSO-E. European grid investments are evaluated at a regional level (TYNDP, 2010).
2012	The Nordic TSOs publish a common report on grid development. The report is written as "a response to the request from the Nordic Council of Ministers". The report is based on the work done in two regional groups of ENTSO-E where a larger area has been the focus of the study. The report "contains no new information compared to the ENTSO-E TYNDP 2012 package" (Nordic Grid Development Plan, 2012; TYNDP, 2012). Fingrid publishes its own ten-year grid development plan, in which national grid investments have been evaluated. Some investments outside of Finland are also analysed (Fingrid, 2012).
2013	Statnett and Svenska Kraftnät cancel the Westlink project that had aimed at relieving a bottleneck at the Hasle cross-section between southern Norway and Sweden, identified as a problem already in the 1970s, and having been included in Nordel's grid development plans for many decades (Montel, 2013b; Nordel, 1978). Svenska Kraftnät publishes "Perspektivplan 2025" grid development plan, which widely evaluates the future electricity needs and transmission capacity investments in Sweden but also cross-border line investments (SvK, 2013). Statnett publishes grid development plan, in which mainly national grid investments are evaluated but also interconnectors e.g. to Great-Britain and Germany are analysed (Statnett, 2013a).
2014	European-wide grid development plan TYNDP 2014 is published (TYNDP, 2014). Nordic Grid Development Plan 2014 is published; it is an extract from the TYNDP 2014 report (Nordic Grid Development Plan, 2014)

The Nordic electricity market applies the implicit zonal market model in the day-ahead electricity markets, in which the common system price is calculated for the whole market area by assuming an unconstrained network. The prices for each pre-defined bidding zone are then calculated based on real constraints, resulting in price zones in accordance with the infrastructure and the underlying production and consumption structure. Currently, there are 15 bidding zones in the Nordic market[2], Figure 2. The zonal prices differ from the system price (and of course from each other) if the grid is congested. In that case, the TSOs receive congestion rents, that is, the product of the price difference and the capacity of the transmission line. Currently, the congestion rents are divided equally between the affected TSOs. At the beginning of the 2000s instead, there was a different rule dividing all the collected congestion rents between all the Nordic TSOs according to Nordel Committée (2005); not only between the affected TSOs. Between 2001 and 2005, the congestion rents were divided based on the reimbursement model and the countries' share of the total Nordic electricity consumption. Between 2006 and 2011, again, the rents were distributed partly based on the country's proportion of the total costs of the five prioritised cross-sections and partly equally between the affected TSOs (Nord Pool Spot, 2015). This was made to promote common Nordic grid investments by rewarding for example investments within Sweden that would affect the neighboring countries.

[2]The bidding zones are referred to as NO1-NO5, SE1-SE4, DK1-DK2, FI, EE, LT, LV.

Figure 2. Nordic electricity markets: bidding zones and the main cross-border connections (Nord Pool Spot, 2014a).

There has been cooperation between different systems in electricity transmission issues far before trade between regions was considered (see for example Joskow, 2005). For instance, power systems may trade to equalise differences in winter and summer peaks. However, in the Nordic countries, common trading may have been driven by differences in generation capacity as there are distinct hydro and thermal power regions (e.g. Swedish bidding zone 1 is a hydropower area, and Finland is dominated by thermal electricity production). Thermal power plants may have to run constantly to exploit economies of scale whereas hydro power plants can be used in times of scarcity and high prices. As shown in Thema (2012), the trade between the Nordic countries and also with Continental Europe follows such a pattern, both on a day-to-day basis (exports daytime and imports night-time) but also by importing electricity in dry years.

2.2 Transmission capacity investments

Historically, in vertically integrated utilities, the transmission function was responsible for system operation. The system operation concerns maintaining reliable electricity supply; this naturally continued to be the core task of the TSOs also in the deregulated electricity market. “The system operation is mainly an informational business as it has to gather information about the inflows and demand, respecting the constraints of the physical systems” say Pineau and Hämäläinen (2000). The coordination function, according to Hogan (2002), is not optional; in every electricity system, there is always a system operator. However, the definition of a well-functioning electricity market is, to some extent, less clear.

After the restructuring of the markets, the establishment of the electricity market became one of the Nordic TSOs’ tasks. The TSOs that had competence in making decisions from the system operation point of view were on a less familiar ground when forecasting the long-term development of demand and supply. The operational culture of the parts of the vertically unbundled companies that later came to be the TSOs was also historically heavily focused on reliability (Brunekreeft and Newbery, 2006; Meeus et al., 2006).

Prior to the market liberalisation, the Nordic TSOs shared a concern of long-term energy balances, and the common capacity development was seen as a way for the TSOs to share risks and reduce the likelihood of energy shortages in dry years. The optimal capacity development was not an independent task but depended essentially on the forecasted need for electricity in society. Furthermore, the common capacity development was to contribute to the development of the Nordic electricity markets, an essential prerequisite of which was adequate transmission capacity within the Nordic countries and between them. On the other hand, market players (i.e., non-regulated entities betting their money on the future) may acquire and use knowledge differently than TSOs, which are regulated entities. For instance, if the goal of the TSO is to keep the transmission tariffs as low as possible, it has a strong incentive to forecast as small changes as possible. Therefore, it is difficult to choose which projects should be executed when regulated entities and market players have different viewpoints. This is one reason leading to the need for transparent planning procedures (this topic is also discussed in Publication II).

Transparency is critical for an appropriate planning procedure, that is, the procedure should be open enough to guarantee that the right people and information are available when the grid investments are decided upon. In addition, the common international objectives have to be defined to carry out the planned cross-border investments. However, some governance structure is also required to push investments through. In the Nordic countries, apparently, there was such a governance structure: the Nordic Council of Ministers and the Energy Market Group played an important role in the development of the Nordic electricity markets. In the yearly meetings at the beginning of the 2000s, they followed and steered the deeper integration of the Nordic electricity markets (EMG 2006; 2008–2009). Especially, they instructed Nordel to enhance the Nordic cross-border grid planning. As a response, Nordel produced three grid plans in years 2002, 2004 and 2008 to further the Nordic grid development[3]. In the 2002 plan, potential line reinforcements were presented, although it was not considered to be an investment plan as such. In the 2004 plan, five new interconnectors were proposed. All lines were assumed to be implemented by 2010. The total costs were estimated to be about 940 M€ (Nordel Grid Plan, 2004). The basic scenario in 2004 was that six years later there would be an energy deficit situation. In addition, the analysis included the effects of dry and wet years on generation, the options to import electricity from the Continental Europe or Russia, and the overall robustness of the electricity system.

In plan 2008, three new lines were proposed. In addition, one new line between Sweden and Finland was suggested. The critical lines were chosen from the group of different investments by using the socio-economic criteria defined by Nordel’s Missing Link Group in 2002 (Nordel Grid Plan, 2008). These criteria covered technical aspects ranging from production optimisation and reduction of power losses to mitigation of the risks of power shortages. Although a better-functioning market (especially reducing the risk of market power abuse if the “market area”[4] grows as a result of grid investments) was considered important by the TSOs, its value was found difficult to quantify (Nordic Grid Development Plan, 2012; Nordel Grid Plan, 2008).

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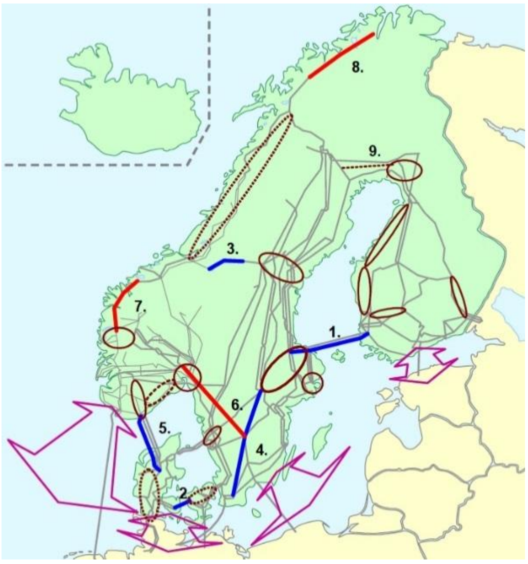
[3]The cross-border investment plans have also been introduced in Publications II and IV. Table 1 summaries the investment plans in the Nordic market.

[4]This is more of a technical issue as there were no plans to merge bidding zones. Rather, the hope was that the increasing transmission capacity would make prices converge and be more uniform across the Nordic zones.

The recommended line investments presented in the plans of 2004 (1–5) and 2008 (6–9) are shown in Figure 3 (Nordel Grid Plan, 2008).



1. Fenno-Skan 2, Finland–Sweden
2. The Great Belt, Denmark
3. Nea-Järpströmmen, Norway–Sweden
4. Southlink, Sweden
5. Skagerrak IV, Norway–Denmark
6. South-West Link (Westlink/Hasle), Norway–Sweden
7. Ørskog-Fardal, Norway
8. Ofoten-Balsjord–Hammerfest, Norway
9. North, Finland–Sweden

Figure 3. Nine prioritised transmission line investments in the Nordic countries presented in the Nordel grid master plans of 2004 (lines 1–5) and 2008 (lines 6–9), (Nordel Grid Plan, 2008).

In 2009, Nordel disbanded. After that, TSOs are individually responsible to follow the previous grid plans. Next follows a discussion on the realisation of these plans. Three of the cases are studied in more detail.

2.2.1 Cases of Nordic transmission capacity investments

The three first lines (Fenno-Skan 2, The Great Belt and Nea-Järpströmmen) of the Nordel 2004 grid plan were commissioned between years 2009–2011, Skagerrak IV was completed at the end of 2014, and Southlink is expected to be completed in 2015/2016, Figure 3. Ørskog-Fardal of the Nordel 2008 plan is also under construction and expected to be commissioned in 2016. In addition, the investment decision concerning Ofoten-Balsjord–Hammerfest has been made, and the line is expected to be in use by 2020. As to line 9 (North), both Fingrid and Svenska Kraftnät have incorporated the line in their long-term grid development plans (i.e., Fingrid 10-year network development plan (Fingrid, 2012) and Svenska Kraftnät Perspektivplan (SvK, 2013)). In addition, the Finnish Government has proposed this North-Sweden–North-Finland line into the European Priority Investment Plan 2015–2017 in the end of year 2014 (Investment Plan, 2014). Line 6 (Westlink) was cancelled in 2013. Next, three of the Nordel projects of 2004 and 2008 plans are elaborated further. The cases selected for consideration are line 3 (Nea-Järpströmmen), line 1 (Fenno-Skan 2), and the abandoned line 6 (Westlink). These lines are chosen for different reasons; Nea-Järpströmmen between Sweden and Norway is of interest because the benefits are asymmetrical between the affected countries. Fenno-Skan 2, on the other hand, is an example of a project that was considered beneficial for the Nordic market integration regardless of the small price differences in the zonal prices between Finland and Sweden. Finally, Westlink is a transmission project that was deemed important in different guises already in 1978 and as late as in February 2013, and was nevertheless abandoned in late spring 2013.

Nea-Järpströmmen

According to NVE (2013), the Nea-Järpströmmen line was built in 1960 as the first regularly used transmission line between the two countries (with 75 km of the line in Sweden and 25 km in Norway). It soon became evident that the capacity of the line was insufficient, and in 1976 the voltage level of the line was upgraded from 220 to 300 kV. In the 1990s, the upgrading of the line became topical again amidst the discussion of establishing a deregulated Nordic electricity market. Finally, in June 2004, Nea-Järpströmmen was defined as one of Nordel's priority projects. The expected benefits of the line reinforcements were, for example, the improvement in trading capacities and the robustness of the Nordic grid. In February 2005, Statnett and Svenska Kraftnät signed a contract for building of a new 420 kV transmission line (Nordel, 2009). The building of the line started in 2007 and was completed in 2010. Since then, Mid-Norway has seen some new investments in industrial facilities, thus highlighting the importance of Nea-Järpströmmen (Meeus and He, 2014). However, regardless of the commissioning of the new line and the introduction of the fourth and fifth bidding zones in Norway in 2010, there is still tightness in energy supply within the connected zones especially in Norway.

The project of upgrading the Nea-Järpströmmen line had strong political support. The line was upgraded from 300 kV to 420 kV with the maximum capacity of 750 MW. However, only about

200 MW of the total line capacity has been in use in the first step. After the line reinforcements in Mid-Norway (Ørskog-Fardal, presented in the Nordel grid plan 2008) are completed, the maximum capacity can be given for use in the markets (Nordel, 2009). Thus, these two line investments should be seen as a unity to secure the supply in Norway and reduce the congestion also within Sweden and Norway (north-south flows). However, the Ørskog-Fardal line investment seems to be more challenging (e.g. because of landowner opposition), and the estimated implementation date has been postponed from the planned 2013 to 2016 at the earliest (Energimarknadsinspektionen, 2008–2009; Meeus and He, 2014; Montel, 2013i; Nordel, 2009).

The benefits of the Nea-Järpströmmen line lie mostly on the Norwegian side although the main part of the line is located in Sweden (75 %). The line seems to have been a priority to Statnett, and "the financing of the Swedish part of Nea-Järpströmmen involved [even] a payment from Statnett to Svenska Kraftnät" (NordREG, 2010). The total investment cost of the Nea-Järpströmmen line was finally about 116 M€, of which almost one half was paid by Statnett. Compared with the other grid investments of the Nordel 2004 plan, the financing arrangements of Nea-Jäpströmmen seem to have been unique. In other Nordel projects, the costs of the interconnectors were equally divided between the TSOs involved: the costs of Fenno-Skan 2 were divided between Fingrid and Svenska Kraftnät, and the costs of Skagerrak IV between Statnett and Energienet.dk (Nordel Committée, 2005; Nordel, 2009). National regulatory authorities can approve contracts (e.g. Cross-Border Cost Allocation, or CBCA, agreements) aiming to improve the stakeholders' commitment to cross-border projects that have a positive impact on total welfare (Meeus and He, 2014; Nordel, 2009; NordREG, 2010).

The Nea-Järpstömmen line seems to have been built to remove one structural bottleneck in the Nordic power system. The zonal price differences are fairly insignificant as the zonal prices in the interconnected Elspot zones NO3 (Nea) and SE2 (Järpströmmen) almost always converge. Over the past couple of years, prices in the two zones have differed by more than 2 €/MWh only for less than 10 % of the time (Nord Pool Spot, 2014a). However, one striking fact about the Nea-Järpströmmen case is the extent to which the line still remains underutilised: because of the inability to complete the internal network enforcements in Norway, only a fraction of the line capacity is actually available for the markets.

Fenno-Skan 2

The Fenno-Skan 2 line between Finland and Sweden was introduced in the common Nordic transmission network investment package in 2004, along with the other four lines considered critical for the Nordic electricity market integration. Fenno-Skan 2 was the second DC link to be constructed between southern Finland and central Sweden. In addition, there are two AC lines connecting the two countries in the north. Fenno-Skan 2, 800 MW capacity, added 40 % to the total interconnector capacity (Fingrid, 2011).

Even before the investment, the Swedish and Finnish electricity markets were well integrated: the Finnish and Swedish price zones already merged regularly for over 90 % of the time. The new line was expected to result in uniform prices in Finland and Sweden for 98 % of the time. Especially on the Finnish side, the Fenno-Skan 2 project received strong political support; when granting the license in 2007, the then Minister of Energy of Finland Mauri Pekkarinen stated that the new line was expected to improve the Nordic markets, enhance the security of supply, mitigate the risk of a serious power system failure, reduce power losses, lower the redispatching costs caused by the internal North-South bottleneck in Finland and limit the number of price spikes in Finland (Ministry of Trade and Industry, 2007).

The direct annual benefits of Fenno-Skan 2 to the Finnish economy were expected to be 30 M€. When taking into account the multiplier effects, the annual benefits were expected to be 100 M€. The total costs of the project were estimated to amount to 290 M€ (the project was eventually completed at the total costs of approximately 315 M€). The project was finally carried out in 30 months, which was 12 months faster than indicated in the initial plan (ABB, 2012; Ministry of Trade and Industry, 2007; Nordel, 2009).

In retrospect, Fenno-Skan 2 has turned out to be a successful investment. For example, in the winter of 2012, Jukka Ruusunen, the CEO of Fingrid pointed out that with Fenno-Skan 2 out of service, the Finnish prices were as much as 10 €/MWh higher than the Swedish prices (ABB, 2012). He further continued that at an annual level this would mean an additional cost of one billion euros for the Finns compared with the situation in which the Finnish and Swedish prices would converge. In addition, Fenno-Skan 2 can be seen important from the reliability perspective. The importance of Fenno-Skan 2 has recently been emphasised by the reductions in the Russian electricity exports to Finland (since 2012); the deficit has mainly been managed by increasing electricity imports from Sweden (Fingrid, 2014; Nord Pool Spot, 2014a). Without the Fenno-Skan 2 line, the risk of a total blackout would probably have been higher for example in a cold winter day, and according to Ruusunen, the costs of a total blackout would have been around 100 M€ in one hour for the Finnish society (ABB, 2012).

The importance of the Fenno-Skan 2 line can be illustrated by the data collected from the occasion of a fault in the newly built line (Fingrid, 2014; Nord Pool Spot, 2014a). In total, Fenno-Skan 2 was out of service for the entire period of 17 Feb.–25 Apr. 2012 because a ship anchor broke the sea cable. By comparing the same dates in 2012 and 2013, the significance of the line investment can be estimated. In the period of 17 Feb. 2012–25 Apr. 2012, the Finnish and Swedish zonal price difference was over 6 €/MWh on average (average of all hours' price differences over the period). Over a comparable time period in 2013, the prices were nearly uniform with only 0.25 €/MWh average price differences between the Elspot FI and SE1/SE3 market prices on the Nordic power exchange. Furthermore, during the outage of Fenno-Skan 2 in 2012, the lines between Finland and Sweden were congested for 62 % of the time. With Fenno-Skan 2 fully in service in winter and spring of 2013, the lines between Finland and Sweden were congested only for 3.4 % of the time. Based on the observed price difference between the Finnish and Swedish Elspot prices, the additional cost for the Finnish electricity users resulting from the Fenno-Skan 2 fault can be estimated to be around 100 M€ in a couple of months. Table 2 summarises the state and conditions of Fenno-Skan 2 in spring 2012 and compares them with the normal situation in spring 2013.

Table 2. Effects of a fault situation in Fenno-Skan 2 line between Finland (FI) and Sweden (SE1/SE3 bidding zones) in 2012 and a comparison with the normal situation in 2013. The electricity flow is mainly from Sweden to Finland (Fingrid, 2014; Nord Pool Spot, 2014a).

Fenno-Skan 2	**17 Feb. 2012–25 Apr. 2012**	**17 Feb. 2013–25 Apr. 2013**
Capacity, MW	0 MW (out of service because of a fault)	800 MW
Average price difference FI-SE1/SE3, all hours €/MWh	6.32 €/MWh	0.25 €/MWh
Price difference hours, % of time, FI-SE1/SE3	62 %	3.4 %
Average electricity consumption in Finland, MWh/h	9962 MWh/h	10387 MWh/h
*Additional cost to Finnish consumers, sum of (hourly price difference*hourly electricity consumption), M€*	108 M€	4.7 M€

The fault situation in spring 2012 indicates that without the Fenno-Skan 2 line investment between Finland and Sweden, the Finnish consumers would likely have had paid much more for the electricity they consumed. The capacity of the Fenno-Skan 2 line is quite small compared with the average electricity consumption in Finland, but it seems to have a great impact on the Finnish zonal price. In Publication IV, the costs of insufficient transmission network investments in the Nordic electricity markets have also been estimated.

Westlink

The structural bottleneck in the Hasle cross-section between Sweden and Norway was identified already in Nordel’s grid plan of 2002. To remove the bottleneck, network investments would be needed both between Sweden and Norway and within Sweden (later, the bundle of these network reinforcements became known as the South-West Link project). The western part of the network reinforcements was considered important especially in dry years (with a power deficit in southern Norway resulting from low hydro power reservoirs). Nevertheless, only the southern part of the investment (i.e., the Southlink connection within Sweden) was introduced in the Nordel grid plan of 2004. Finally, however, also the Westlink connection was put forward in the Nordel grid plan

2008. The South-West Link project was seen important for both the power system operation and the security of supply in the Nordic market. The estimated total costs of the project were around 702 M€ (over half of those allocated to Sweden). Initially, the Westlink connection was expected to be ready around 2015/2016. Later, the estimated commissioning time was first postponed to 2018–2022. The Southlink connection in Sweden is currently under construction and expected to be commissioned in 2015/2016 (Nordel Grid Plan, 2004; Nordel Grid Plan, 2008; Nordic Grid Development Plan, 2012).

However, in spring 2013, the TSOs in Sweden and Norway (Svenska Kraftnät and Statnett) jointly cancelled the Westlink investment. It was declared that the investment was no longer beneficial: the expected price differences between the Elspot zones NO1 and SE3 were too low to make the project viable, and the security of supply could be ensured by the line reinforcements within the countries (Montel, 2013 a–b). Moreover, the Westlink reinforcement had also become too expensive given the chosen technical solutions: the investment costs had more than doubled in the TSOs' new calculations compared with the situation in 2008/2009 (Montel, 2013c).

After Westlink was cancelled, the question about the consequences for the electricity prices in Norway and Sweden became topical (Montel, 2013 d–g). For example, Statnett and the independent Norwegian service provider Markedskraft see the impacts differently. Markedskraft has analysed that the electricity prices in Norway will be 3–10 €/MWh higher than in Sweden in 2020–2030. Statnett does not reveal the figures that they have used in their cost-benefit analyses, but claims that the price differences between Swedish and Norwegian price zones will be low (Statnett, 2013b), (discussed also in Publication II). However, some price estimations used by the TSOs can be obtained from Svenska Kraftnät's Perspektivplan 2025 (SvK, 2013). In Perspektivplan's base case, had the Westlink connection been built, the zonal prices in SE3 and NO1 would have converged. This would not have generated any congestion rent but is aligned with the old target of striving for price convergence. On the other hand, in all the analysed cases, the flows between Sweden and Norway are not trivially small, and from that perspective, the decision to abandon the project may seem surprising.

The cancellation of the Nordic Westlink project is accompanied with plans to build new interconnectors from Norway to Germany and Great Britain. According to Markedskraft (Montel, 2013d; Montel, 2013f–g), in the absence of the Westlink connection, Norwegian generators could save their hydro power at night-time and sell it to Germany, the Netherlands and Great Britain at higher prices during daytime hours. This could result in higher electricity prices in Norway than in Sweden. Statnett and Svenska Kraftnät, on the other hand, do not assume notable price differences between Sweden and Norway even after the cancellation of Westlink as long as the national grid reinforcements are carried out as planned. The latter conclusion coincides with that of Pöyry Consulting, lending support to the forecasts of negligible price differences (Montel, 2013d).

The cancellation of Westlink has triggered some political reactions mainly in Norway. For example, a Progress Party representative has commented that Statnett is more interested in making money with new cable connections from the Nordic countries than ensuring the security of supply and the lowest possible price for the Norwegian consumers. On the other hand, the representative of a Conservative Party noted that, to some extent, it is good to aim at uniform prices in the Nordic market, but this should not be at any cost (referring to the high costs of the Westlink investment), and added that the value of the connections from Norway is large (Montel, 2013h). In Sweden, the cancellation has mainly been treated with silence.

2.2.2 Conclusions on the Nordic cases

The cross-border transmission capacity investments are challenging. The countries have to plan the necessary investments, get permission and agree upon how the costs should be divided. In the Nordic countries, Nordel took care of the planning so that the common socio-economic benefits and well-functioning electricity markets could be achieved. In addition, the regional regulatory institution NordREG supported the national regulators. Above all, the Nordic Council of Ministers and the Energy Market Group instructed the Nordic market operators for establishing the common electricity market. Three transmission grid plans in total were drawn up in Nordel's era. In addition, some investments were decided upon before Nordel disbanded in 2009. Five years after the abolition of Nordel, the Swedish and Norwegian TSOs cancelled the long-planned and critical Hasle (Westlink) reinforcement between the countries.

In the rest of Europe, the challenges in the transmission network capacity development have been similar to those in the Nordic countries. For example, the cost allocation of new investments between the TSOs has been one of the problems. However, according to the EU targets, a common electricity market has to be established, and it requires cross-border transmission capacity investments. As shown in the Nordic examples, planning the grids is not enough, but they have to be built as well. In addition, harmonisation of the TSO instructions and governance is needed to carry through the cross-border capacity plans in a socio-economically acceptable manner. These issues are discussed in detail in Publication II.

2.3 European electricity markets

In the European Union (EU), the free movement of goods and services is one of the fundamental elements of the common market (Treaty of Maastricht, 1992; Treaty of Rome, 1957). Internal markets have been established in the EU area for many goods; Directive 1996/92/EC provides the first commitment to set up internal markets also for energy. After that, new directives (e.g., 2003/54/EC, 2009/72/EC) and regulations (e.g., 1228/2003, 714/2009) have been issued, in which the rules and orders have been specified. Free movement of goods is considered important from the consumers' perspective; consumers have more choices, and they can find products at the lowest price. In addition, efficient companies benefit from free trade.

2.3.1 Internal European electricity markets

The cornerstones of the European Union energy policy are security of supply, competitiveness and sustainability ("An Energy Policy for Europe", COM 2007). Common internal electricity markets have been seen as the instrument to reach these targets. The security of supply is improved with shared resources, competition can be more intense when there are more companies, and the exploitation of low-carbon generation is more likely with increased trade (EC, 2007). However, problems of market concentration in electricity markets and the lack of cross-border interconnectors were already recognised in the EC (2007).

The establishment of the internal electricity markets can be divided into three phases: first, the member countries liberalised their national electricity markets (by 2007), after which seven regional electricity markets were set up (e.g. Haas et al., 2006), and finally, a common internal market will be provided by integrating the regional markets. In 2011, the European Council set a target for establishing a common electricity market by 2014 in Europe (European Council, 2011); this was partly achieved in February 2014 when the North-Western Europe (NWE) market coupling was set up covering 75 % of electricity consumption in Europe (Nord Pool Spot, 2014b). High-level coordination of the integration process is carried out by ACER (Agency for the Cooperation of Energy Regulators) and ENTSO-E (European Network of Transmission System Operators for Electricity).

To efficiently integrate the electricity markets, both an efficient use of the existing network and sufficient interconnector capacities are required (ACER, 2013). A strong network has risen into a fundamental position to achieve the aims of the EU energy policy (Kapff and Pelkmans, 2010). In the EU, three ten-year network development plans (TYNDP, 2010, 2012, 2014) have been prepared, in which environmental aspects (e.g., curbing CO_2 emissions), security of supply and competition have been emphasised. The commissioning of the strategic investments should be carried out gradually by 2020 at the latest.

In 2015, European Commission (EC) launched an “Energy Union Package” in which the ways to achieve “the goal of a resilient Energy Union with an ambitious climate policy at its core is to give EU consumers—households and business—secure, sustainable, competitive and affordable energy” (Energy Union, 2015). It has been recognised that there are the European Union energy rules but at the same time there are 28 national regulatory frameworks. For example, generation and transmission capacity investments are needed together with a more transparent course of actions between the Member States to achieve the goal of the Energy Union. Moreover, “the Energy Union also needs an integrated governance and monitoring process, to make sure that energy-related actions at European, regional, national and local level all contribute to the Energy Union’s objective” (Energy Union, 2015).

In addition, the European Union has adopted a 20–20–20 target program, the roots of which lie in the international Kyoto Protocol. The EU target program includes a 20 % decrease in greenhouse gases, a 20 % increase in energy efficiency and a 20 % share of renewable energy sources[5] in the energy consumption by year 2020 (Council of the European Union, 2007). The member countries have agreed upon mutual sharing of responsibility to meet the targets. In 2014, the European Commission set new climate targets for the period 2020–2030. The new target for cutting greenhouse gas emissions was suggested to be 40 % (reduction to the 1990 level) by year 2030. Yet another new target was to increase the proportion of renewable energy to at least 27 % of the energy consumption (without specified national targets) and increase the energy efficiency at least by 27 % (European Council, 2014; COM, 2014). According to the National Renewable Energy Action Plans (2010), the member countries will make significant investments in renewable electricity generation in 2015–2020. As mentioned by VTT (2011), renewable electricity generation will almost double from the 2010 level, from 653 TWh to 1217 TWh by 2020; this accounts for 34 % of the total electricity consumption in the EU[6]. This usually involves investments in intermittent generation types, that is, wind and solar power, which are primary energy resources (at least the large-scale ones) typically far away from the existing transmission network. As a consequence of the massive generation investment program, also significant new investments and reinforcements in the transmission network will be required. Roughly over 52 000 km of line investments within and between countries are needed in Europe in the coming years[7]. 80 % of transmission network bottlenecks are related to the RES integration, but investments are also needed to enhance market integration and security of supply (ACER, 2012; TYNDP, 2012).

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[5]According to Directive 2009/28/EC, " 'energy from renewable sources' means energy from renewable non-fossil sources, namely wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases."

[6]There was 329 GW renewable electricity generation capacity (including 119 GW hydropower capacity) in the EU in 2012 (Renewables, 2013).

[7]In the TYNDP (2012), 52300 km of new or refurbished high-voltage lines were presented with a total cost of 104 billion €. 76 % of the investments written into the TYNDP (2012) were already introduced in the plan of 2010. About 20 % of the investments suggested in the TYNDP (2010) had been made either partly or in full or were expected to be commissioned by 2012 (TYNDP, 2012). In TYNDP (2014), the proposed line investments cost 150 billion €, and the total length of all investments is around 50 000 km.

2.3.2 Transmission capacity development

In the EU, the transmission capacity investments are necessary to establish the targeted common electricity markets. In addition, investments are required to replace an ageing network and to integrate new RES generation into the grid (Energy Union, 2015). If the transmission network is too congested, a common market area cannot be formed, which can be harmful to the efficient sharing of resources and competition. Obviously, investments are also needed for the sake of reliability. To extend the market area, reinforcements are required within and between the price zones, and even across national borders. The national TSOs mainly take care of the grid investments and grid operations in Europe.

Many directives and regulations guide the development of the internal electricity markets in Europe. For instance, the EU has set Regulations 1228/2003 (incl. Annex 2006/770/EC), 714/2009, 347/2013, which, among other issues, define how the common European electricity markets are to be established through national and regional electricity markets, how the number of cross-border transmission investments is to be increased, and how the TSOs should use the congestion incomes. ACER (2011–2012), stated that the integration between the established regions is low, although full price convergence within each region may occur frequently (e.g., full price convergence in the Central-West European (CWE) region took place 65 % of the time, in the Nordic region 26 % of the time, but between these regions only 6–14 % of the time in 2011 (a full convergence means a price difference ≤ 1€/MWh in this case).

To ensure efficient cross-border investments, ENTSO-E has made European-wide TYNDP (ten-year network development plan) plans, in which the important cross-border network investments have been recognised. However, it is yet uncertain if the national TSOs will carry out the investments as planned. There seems to be lack of high-level governance to push the investments through. In addition, long permitting procedures, uncertain financing of new investments and regulatory issues hinder the investments (Roland Berger, 2011). Further, issues such as NIMBY (not-in-my-backyard), lack of social acceptance and the problem of land-use are common (TYNDP, 2010).

Regulation 347/2013 states that projects of common interests in Europe have to be listed ("Union list"), and they "should comply with common, transparent and objective view of their contribution to the energy policy objectives." In addition, Regulation 347/2013 obliges ENTSO-E to develop the Cost Benefit Analysis (CBA) methodology to estimate the pan-European transmission network investments. Meeus at al. (2013) have studied the CBA method to estimate the costs and benefits of the planned investments; they point out that the ranking of the projects should be based on the monetised net benefit ("mean value of the net benefit distribution of a project"). In the method, technical aspects, costs and environmental/societal impacts, the security of supply, socio-economic welfare, market integration and sustainability are taken into account (Meeus at al., 2013). The aim is to determine the most important investments, that is, projects of common interests (ENTSO-E, 2014).

The cost allocation of investments is also an important issue. An investment may be beneficial only to some of the market participants (e.g. consumers but not producers), or the benefits are collected in a different state/country than where the investment is located (MIT Study, 2011). For example, the costs of cross-border investments can be divided based on the expected benefits or equally between the builders (i.e., the TSOs, Nordel Committée (2005)). In some cases in Europe, the Cross-Border Cost Allocation (CBCA) method has been suggested and even used to finance certain cross-border investments that are built in one country/state while the benefits of the line are harvested in another one (see e.g., Meeus and He (2014)). In that case, the TSO that benefits from the investment pays some compensation to the other TSO in whose region the line investment is located. This was used in the above-discussed Nea-Järpströmmen investment. Merchant transmission network investments could also be one way to increase the number of investments in Europe (discussed e.g. in Brunekreeft et al., 2005; Brunekreeft and Newbery, 2006; de Hauteclocque and Rious, 2011 and Supponen, 2011). Typically, cross-border investments have been made by TSOs, but there are also a few of examples in Europe where merchant investors have financed the investment (for example Estlink between Finland and Estonia and BritNed between the UK and the Netherlands (de Hauteclocque and Rious, 2011)).

In Europe, the use of collected congestion rents is defined in Regulations 1228/2003 and 714/2009. It is stated that the rents should be used to reinforce the grid; however, the rents can be used also to lower the grid tariffs. According to the ERGEG (2010) report, about half of the reported congestion incomes were used to lower the tariffs in Europe in 2009 and, in 2013, about 30 % of these incomes were used for that purpose (ACER, 2013). Joskow (1999) highlights the need to sufficiently compensate “the efficient operation and expansion of the transmission networks”. According to Joskow (1999), it is more important to be worried about underinvestments in the transmission network than overinvestments: “the societal costs of underinvestments in transmission are much larger than the societal costs of overinvestments”. For example, an ideal level of transmission capacity (investment) decreases the losses and congestion costs, whereas an insufficient transmission capacity increases these costs (Kwok, 2010). However, external factors (such as licencing requirements) limit the number of new capacity investments and thus, the risk of overinvestments is low.

To sum up, there are many problems related to new transmission network investments. They lead to a situation in which the investments are either lagging significantly from the planned timetable or they have not even been decided upon. Some governance and binding commitments are needed to supervise that the TSOs/SOs will implement the planned investments.

3. Research design

This doctoral dissertation is an empirical study on the transmission network development in the Nordic electricity markets. The objective is to study how governance, planning and operations of the infrastructure can affect the functioning of the market. The main target and scientific contribution of this dissertation is to shed light on the determinants causing the breakdown of the "Nordic transmission capacity development machine", discuss the threats of network congestions to the market dynamics on the basis of empirical findings, and analyse the financial impacts of network congestions on market actors. The latter is achieved by using numerical data from the Nordic electricity markets. In order to achieve the research target, different research methods are applied. The research approach in Publications I and III–IV is mainly empirical, whereas Publication II provides critical discussion on the topic, Table 3.

Table 3. Research objectives and methods.

Objective	**Research method**	**Research strategy**
Identification of the transmission network affecting market integration in Europe (Publication I)	Delphi study.	Qualitative methods.
Identification of critical pillars required to develop the transmission network efficiently (Publication II)	Case studies.	
Illustration of the impacts of small electricity markets (Publication III)		
Financial impacts of insufficient transmission networks (Publication IV)	Calculation-based analysis.	Quantitative methods.

The results of these research objectives have been published in three scientific journals (Publications I–III) and in a scientific conference (Publication IV).

The detailed research design of the dissertation is presented next.

3.1 Research questions and objectives

This doctoral dissertation is the result of research at the Laboratory of Electricity Markets and Power Systems at Lappeenranta University of Technology. The main focus of this dissertation is on illustrating the transmission network investments in the deregulated electricity markets. Especially, the challenges to achieve the targeted investments are studied. Empirical research has been carried out to determine the effects of delayed transmission capacity investments. The research question of this doctoral dissertation is "What are the ingredients of effective transmission capacity development, and what happens if some of them are distorted?" The research objectives are summarised in Figure 4.

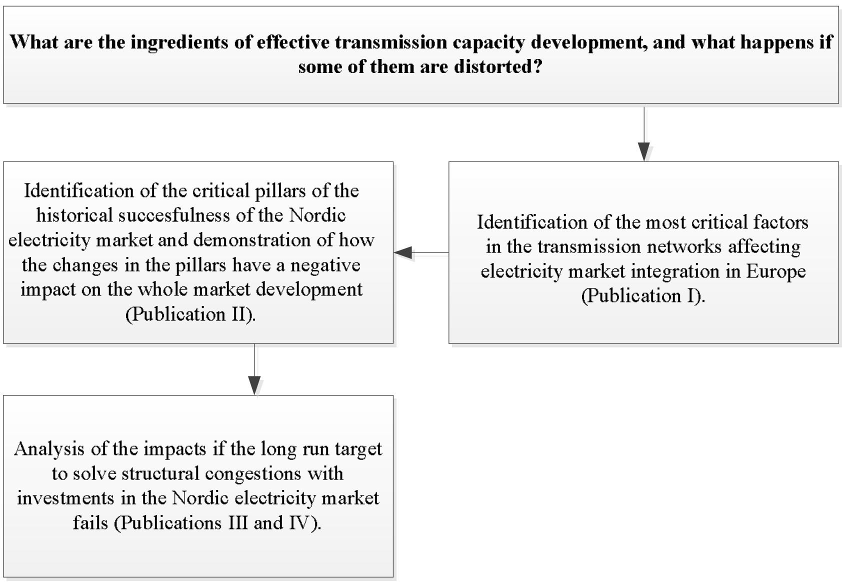

Figure 4. Scheme of the study.

In order to answer the research question, the critical issues affecting electricity market integration are identified. After that, the Nordic electricity market is used as an example of an area where investments have been chosen by the TSOs as the main means to solve the problems of a congested transmission network. For example, the Nordic TSOs stated the target of having a nearly uniform market (price differences less than 2 €/MWh) as one of the rationale for their common investment plans 2004 and 2008 (Nordel Grid Plan, 2008). It is shown that there are certain critical factors affecting the successfulness of the Nordic market and the evident shift in the trend when the structures of market governance were changed. In addition, the financial impacts of this development are analysed.

The research is divided into four more detailed research questions, which are answered in Publications I–IV:

- Which kinds of issues are the most critical ones to further the electricity market integration in Europe?
- Which kinds of circumstances are required to effectively develop the transmission capacity?
- How does an inadequate transmission capacity influence a competitive landscape?
- What are the financial impacts of an inadequate transmission capacity in the Nordic electricity markets?

3.2 Research approach

The objective of the deregulated electricity markets is to develop electricity markets in which competition is a kind of public good; competition should be at least at a workable level to guarantee the benefits for society (Bergman, 2009). In that case, the prices emerge from an equilibrium of supply and demand without market power abuse or high market concentration (workable competition refers to a situation which “is perhaps less perfect than the textbook vision of a competitive market but yet generally free from monopolistic pricing and various forms of collusion and manipulation” (Bergman, 2009)).

Market integration is one way to increase competition in the market. In addition, integration can also make the sharing of resources more efficient. However, to integrate (national) electricity markets into regional ones, a network with sufficient transmission capacity between the areas is a necessity. According to Joskow (2006b), the transmission network allows market participants to trade in the competitive power market, and it can even extend the geographical market area, which provides opportunities for new generators to join the market, and consequently, may even lower the prices. In other words, if a network is constrained, it "fragment[s] the market, reducing the number of generators actively competing in sub-markets" (Newbery, 2002).

In the first place, transmission networks have typically been built according to the national demands, and cross-border connectors have mainly been built for back-up connections (Meeus et al., 2006). When electricity markets are decided to be integrated across national borders (which is the case in Europe), the transmission capacity has to be reinforced. The European electricity market relies on the assumption that the transmission network is adequate, and bottlenecks do not usually hamper free power flow as the zonal pricing model has been chosen as the market model[8].

However, transmission capacity investments especially across the borders are not an easy task. Supponen (2011) has identified that TSOs have national interests in the transmission investments in Europe so that cross-border investments are not often in their main focus. In Frontier (2008), the mismatch in the distribution of costs and benefits of the cross-border investment has been recognised as one of the key problems. In addition, long permitting procedures or land-use issues can be problematic and delay the investments that are crucial important for the market integration (TYNDP, 2010).

Solutions to attract new transmission investments have also been studied in the literature. The need for governance is recognised in Ruostetsaari (2010) and defined as "the need for cooperation between the state, quasi-state, non-state (non-governmental), and private institutions such as corporations to solve collective action problems and to take responsibility for well-being." Regulation or high-level governance should be strong enough to push through the investments that are socioeconomically profitable. Frontier (2008) highlights the transparent supra-national grid planning and discusses the regulatory incentives for TSOs (for instance, uplift the rate of return for TSOs) to increase the transmission capacity investments. Meeus and He (2014) show how the Cross-Border Cost Allocation (CBCA) method can be used to divide the costs of

[8] Another market model is called nodal pricing. In principle, the nodal pricing model allows network congestion and makes the congestion transparent (Joskow, 2006c). Yet, a heavily congested transmission network should be avoided because it hampers the effective sharing of resources, and new investments are necessary to remove bottlenecks.

transmission capacity investments asymmetrically. That is, the beneficiary of the cross-border investment will pay more of the investment even though most of the line is located in another country. On the other hand, Buijs et al. (2011) propose different technical solutions such as high-voltage direct current (HVDC) to increase transmission capacity or undergrounding of cables to avoid bulky overhead cables.

To sum up, the delayed transmission capacity investments are challenging for the European electricity market integration, and it is not straightforward to promote these investments. These issues are studied widely in the literature. However, there is a lack of empirical research on the effects of insufficient transmission capacity investments. Especially, there is a gap in the evaluation of changes in the competitive landscape of the electricity markets if the required transmission capacity investments are not carried out. This doctoral dissertation aims at bridging this gap. The Nordic electricity market is used as an illustrative example: the cross-border capacity investments before and after the abolition of the regional TSO cooperation entity are observed, and the financial consequences of an inadequate transmission network for market participants are evaluated. It is also studied which factors lead to a failure in implementing the required network investments. In Figure 5, the research platform is shown.

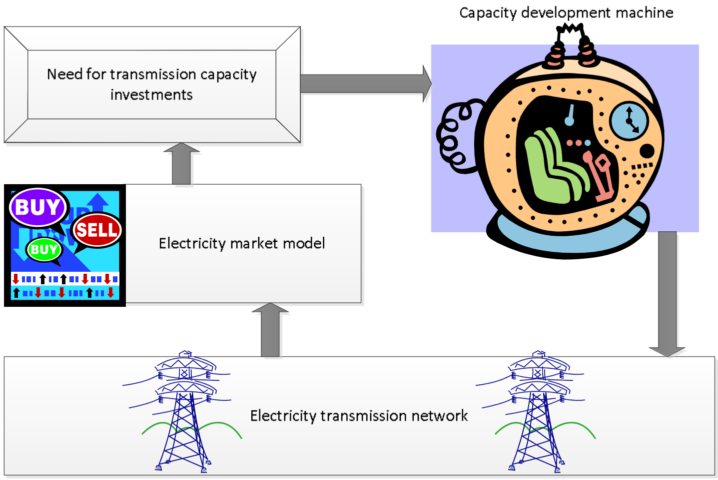

Figure 5. Research approach and platform.

In Figure 5, the transmission network is the foundations for the electricity market model. However, to establish a competitive electricity market and guarantee the efficient sharing of resources, transmission capacity investments are needed. To draw up investment plans and execute them effectively, a “capacity development machine” is required. This “machine” covers issues from the transmission network planning to the execution of the plans. If this machine is not working properly, the foundations (transmission network) of the electricity market model will suffer. Again, this will change the competitive landscape of the electricity markets and have financial impacts on the market participants.

3.3 Research data

The research data used in the calculations to show the risks of small electricity markets and the financial impacts of delayed transmission network investments have been gathered from the web pages of the power exchange Nord Pool Spot (2014a) and the Finnish TSO Fingrid (2014). The research data used in analysing the critical factors in the electricity market development were collected by applying the Delphi method. The respondents of the study were European electricity market specialists. In addition, literature reviews have been carried out to study the electricity market development in the Nordic countries. Finally, a set of qualitative data were collected and used in the discussion on the institutional differences between the Nordic countries.

3.4 Limitations of the study

The research problem in this dissertation has been observed from different angles. In other words, the research approach is wide while the aspects of infrastructure, market actions and policy have taken into account. In the course of the research, literature reviews from a variety of sources have been prepared. Part of the data have been collected from separate sources, and thus, it has been possible to confirm the validity. Moreover, the Delphi method has been used to collect opinions of electricity market specialists in Europe, and a calculation method to estimate the distributional effects for market participants because of insufficient transmission investments.

The Delphi method itself helps in pinpointing the relevant issues because participants can add their own statements at each point of the study (not only evaluating the statements provided by the researcher). However, in the Delphi study (Publication I), the number of panellists was 30, and they represented 15 different nationalities. From some countries there was only one respondent and from others two or more, and thus, some countries were overrepresented in the final results. In addition, the viewpoints of some groups may be overrepresented in the results. Finally, we are all biased by the current context that we are acting in, and the issues relevant in 2011 are different from those in 2015. For example, issues such as the reliability of the power system with a large amount of wind and solar production might be perceived differently today than they were a few years ago. Thus, a more in-depth study would provide more knowledge and give more specific results about the challenges of the electricity market integration in Europe.

The financial impacts of delayed transmission capacity investments have been studied in Publication IV. It applies a data set collected especially to highlight the distributional effects for different market participants. In the analysis, the hourly prices for each bidding zone and the hourly sell and bid volumes in the power exchange were used. Part of the electricity trading is carried out in the bilateral markets, but those price data are not publicly available[9]. Therefore, the calculation results presented in the publication do not cover all electricity trading in the Nordic market. Moreover, in Publication IV, it is assumed that in an ideal situation, there would be the same (system) price in the whole Nordic market all the time. In reality, some degree of grid congestion is acceptable in the electricity markets (e.g. because building a copper plate would be costly). Further studies in this field would adopt exact uniformity targets (that is, some grid congestion would be acceptable), and also include the bilateral trading results to assess the real-life impacts of insufficient transmission capacity more accurately.

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[9]About 88 % of electricity trading was made through Nord Pool Spot in the Nordic countries in 2013 (NordREG, 2014). Nord Pool Spot price probably provides an important reference for bilateral contracts; however, the prices in the bilateral trades are not public information.

4. Summary of the results and publications

An overview of the publications is presented in Table 4. It summarises the objectives, research questions, methods and findings of the papers included in this dissertation.

Table 4. Summary of the papers.

	Publication I	**Publication II**	**Publication III**	**Publication IV**
Title	Competition in the European electricity markets – outcomes of a Delphi study	All quiet on the western front? Transmission capacity development in the Nordic electricity market	Risks in small electricity markets: The experience of Finland in winter 2012	Economic impacts of price spreads in the Nordic electricity markets
Objective	Identify the most critical factors affecting market integration and competition in European electricity markets.	Evaluate how the transmission capacity investments depend on the different institutional requirements and governance structure.	Illustrate the risks of small electricity markets.	Calculate the distributional effects of market decoupling.
Research question	Which kinds of issues are the most critical ones to further the electricity market integration in Europe?	Which kinds of circumstances are required to effectively develop the transmission capacity?	How does an inadequate transmission capacity influence a competitive landscape?	What are the financial impacts of an inadequate transmission capacity in the Nordic electricity markets?
Method	Qualitative. Delphi study.	Qualitative. Literature review and case study.	Qualitative. Case study.	Quantitative. Cost-based analysis.
Findings	Network expansions are necessary to further the integration, and also one of the primary means to promote competition, but they are also the most challenging to achieve.	Appropriate planning procedures, political commitment, governance, transparent cost benefit analysis and harmonised investment criteria are necessary to carry out congestion management through investments.	Structural bottlenecks leading to predictable market splitting may encourage gaming and reduce transparency.	Delayed transmission network investments hamper market uniformity and have distributional effects.

4.1 Publication I: Competition in the European electricity markets – outcomes of a Delphi study

This paper draws on the results of a Delphi study conducted during the research project "Vision for European electricity markets in 2030." The main target of the study was to identify the critical factors affecting the electricity market integration in Europe, and moreover, to suggest solutions to promote the common electricity markets and competition in the markets. The main objective of the paper was to introduce the key factors raised by the Delphi study and compare the results with the current development of the European electricity markets.

Interview methods assisted with information technology are nowadays often used to gather expert opinions. The Delphi method is one of such methods involving a certain future-oriented aspect, and it enables the collection of data on a research topic with scarce data. In addition, it is possible to gather information from a large group of specialists from different countries and organisations. Anonymity of information is also preserved, and thus, opinions can be expressed freely. The Delphi technique is based on iteration. First, a list of statements is sent to the panellists, who can both rank the given statements on a defined scale and add their own suggestions for new statements. At least two rounds are required to reach the consensus among the panellists. Between the rounds, the respondents are provided with a summary of the results of the previous round. In addition, different rounds can be organised, in which, for instance, the panellists are asked to tackle certain statements in more detail and give more specific suggestions on how the issue should be solved in the future.

The Delphi study presented in the paper was a three-round survey. The first part was organised for 11 Finnish electricity market specialists at Lappeenranta University of Technology to identify the factors affecting competition in the electricity markets. After that, a two-round electronic survey for European electricity market specialists was conducted. In the latter part of the survey, the European specialists evaluated statements on factors having an impact on the development of the electricity market. In addition, they evaluated the relevance and likelihood of competition in certain statements. In the second survey round, the same panellists suggested ways to influence the critical factors.

To sum up the results of the study, the insufficient transmission network capacity was raised as the most worrying factor for the electricity market integration in Europe. However, the challenges of achieving these investments was also recognised. In certain circumstances, the inadequate transmission network capacity may cause market power problems if large market areas have to be split into smaller bidding zones. Network reinforcements were seen the primary means to promote competition in the European electricity markets. In addition, massive investments in networks are also required quite quickly to increase the use of renewable energy resources. On the other hand, if the transmission network enhancements are not carried out in time, the nodal pricing principle might be a better solution for the European electricity markets. However, trading issues such as harmonisation of the calculation procedures in the electricity exchanges and time schedules were not considered to pose similar problems to the markets as the transmission network issues. In addition, these matters have already been solved to some extent.

The main finding of the paper is that the transmission capacity investments play a critical role in the establishment of a common European electricity market. In addition, new transmission investments can also promote competition because market fragmentation can be reduced and there can be more market participants in the market area. However, it is also recognised that transmission investments may be challenging to carry out.

4.2 Publication II: All quiet on the western front? Transmission capacity development in the Nordic electricity market

This study aims at investigating how the transmission capacity development depends on the governance and other institutional settings in the electricity market. The Nordic electricity market has been used as an illustrative example to discuss experiences on how the change in the outlet for local political commitment impacted on the transmission capacity development. The main focus is on the 2000s, when three Nordic transmission capacity development plans were drawn up and also partly implemented. The main objective of the paper is to study the history of the Nordic electricity market through transmission capacity investments, governance and national investment criteria.

In the Nordic countries, investment plans have been prepared, although the planning procedures have not been very transparent. Planning procedures have been mainly managed by TSOs, which are regulated entities. However, other market participants, for example generator investors, have not been able to participate in the discussion of future scenarios exploited in the grid plans. For that reason, it is possible that all relevant information has not been utilised in the plans. In addition, it is not possible to assess and compare the investment plans afterwards because data used in the calculations are not publicly available. Later on, the implementation of the plans has, to some extent, been lagging behind the original schedule, and one planned (evaluated to be critical) investment between Sweden and Norway (Westlink) has even been cancelled altogether. The TSOs have argued that the investment is not considered beneficial anymore.

Moreover, the Nordic investment criteria are national and not harmonised to further the development of the Nordic market (i.e., national benefits are emphasised, not the common Nordic market perspective). One main reason for the delays and cancellations may also be that the governance structure was changed in the Nordic market. The outlet for political commitment may have been lost in the Nordic market when the regional entity for TSO cooperation (Nordel) was dismantled in 2009. Initially, there was a quite direct governance model from the Nordic Council of Ministers through Nordel to the national TSOs. Now, this kind of a chain seems to be missing. After the Nordel era, the implementation of investments that were considered critical from the viewpoint of the Nordic market seem to have decreased even further, which indicates some division among the TSOs.

Considering the Nordic experiences, we may sum up that transmission capacity development plays a critical role in acquiring the benefits of electricity market integration. The planning procedure should be transparent and open to public debate, and all relevant market actors should be represented. This provides a good basis for network reinforcements. However, this is not enough, and also the investment criteria have to be harmonised so that the benefits of investments are observable from the perspective of the whole market area, not only from a national viewpoint. In addition, political commitment and governance are required to push investments through.

The main finding of the paper is that certain circumstances are required to guarantee sufficient transmission capacity investments, and thus, the proper functioning of the chosen electricity market model. In the rest of Europe, similar challenges are faced as in the Nordic electricity market. Transmission investment plans have been compiled, and even a cost benefit analysis has been made; nevertheless, only a few (cross-border) investments have been made. The key finding of the paper is that based on the experiences of the Nordic electricity market, transmission investment plans do not suffice to establish common electricity markets, but governance to impose investments is required. Local political commitment and practical cooperation are required to put Nordic and European interests above the national interests.

4.3 Publication III: Risks in small electricity markets: The experience of Finland in winter 2012

This paper describes the risks of small electricity markets. The main objective of the paper was to study empirically the situation in the Finnish electricity market in winter 2012. The import from Russia has traditionally covered at least 10 % of the Finnish electricity consumption per hour. In 2012, the amount decreased significantly to 0–400 MWh/h on average. Reductions in the Russian electricity produced pressure to increase the import from Sweden to Finland. This led to a situation where Finland was more often decoupled as a price zone of its own because of congested lines between Finland and Sweden. Therefore, the Finnish electricity generators were in the margin to set the price for Finland. However, market surveillance in the Nordic market was based on the assumption that the market is uniform as a whole. At the same time, the market structure was quite concentrated in Finland. Two large generators held more than 6000 MW of the generation capacity while the average trading (sell) volume in Nord Pool Spot was 6000 MW. These factors potentially increased the risk of market power abuse in the zonal pricing markets.

The main findings of the paper are that structural bottlenecks leading to predictable market splitting may encourage gaming and reduce transparency. There is a risk of market manipulation in a small market area, and the limited market surveillance in the Nordic markets is not capable of handling changes in the competitive landscape. More transparent markets can provide one solution to this so that individual players are not able to abuse market power. On the other hand, more detailed market surveillance or regulation methods can be introduced, but these can, however, increase the risk of “government failures”.

4.4 Publication IV: Economic impacts of price spreads in the Nordic electricity markets

This paper introduces an approach to calculate the financial impacts of the price spreads in the Nordic electricity wholesale markets. The main objective is to calculate the financial impacts of not perfectly integrated electricity markets. There are plans in the Nordic countries on how the transmission network should be reinforced, but the implementation of the investments is delayed. The price convergence rates have been quite low over the period 2010–2012 (about 20 % of the time for the whole market area).

The financial impacts of price spreads are calculated for Norway, Denmark, Sweden and Finland for the years 2010–2012. Surpluses for electricity buyers and generators in the power exchange are calculated, and further, the congestion incomes for the TSOs are taken into account. A theoretical case in which all the electricity traded in the power exchange would have been traded at the system price is compared with the actual situation in which all the electricity is traded at the zonal prices. The buyers' surplus is the difference between the system and zonal price multiplied by the buy volume in the exchange. Similarly, the generators' surplus is the difference between the zonal price and the system price multiplied by the sell volume in the exchange. Always when the price differences occur in the markets, the TSOs earn congestion incomes. In the calculations, the congestion incomes for the TSOs resulting from price spreads are taken into account. The economic impact is the sum of these components: the surpluses for buyers and generators and the TSOs' congestion incomes.

In Finland, for example, the results of the calculations reveal distributional effects among electricity market participants during the observation period. Moreover, the congestion incomes for the TSOs have increased almost in each country during the period. The financial impacts have been negative in Denmark (2010–2012) and in Finland (2011–2012). In Norway, the financial impacts have been positive for the whole period and in Sweden for the years 2011–2012.

The first key finding was that the price spreads have financial impacts on the surpluses of the generators and buyers. One main reason for the price spreads is the inadequate transmission network. The impacts of price spreads are considered to increase, yet some of the critical transmission network investments are still lagging behind the original investment schedule. The initial target of the zonal pricing model was to establish a large competitive market area. If the network congestion repeatedly splits the market into small price zones, the risk of market power abuse may increase. More transparent markets are thus required. The REMIT Regulation (1227/2011) by the EU is a step towards more detailed market surveillance, but the regulation has not yet been fully implemented.

5. Discussion and concluding remarks

The target set by the EU is to establish a common internal electricity market in Europe. A lot of progress has been made towards this goal although the implementation of the third energy package is not fully completed yet (SWD, 2014). Environmental issues also play an important role in the EU, not least when considering electricity production. However, investments in renewable energy generation also call for transmission capacity expansions to guarantee that renewable energy sources can be effectively integrated into the electricity system (Huppmann and Egerer, 2014). It has also been recognised that delayed transmission capacity investments hamper the markets: there are extra costs for electricity users, and the targeted integration is not achieved. For example, Shrestha and Fonseka (2004) have shown that a congested transmission network prevents perfect competition between market participants.

The Nordic electricity market is one of the first regional electricity markets in Europe. The first steps of electricity market integration in the Nordic countries can be considered successful: according to Amundsen and Bergman (2006), for instance based on the experiences of the whole and retail sales markets, competition has squeezed the profit margins. Later on, the targeted market uniformity (that is, the price zones merged in daily price calculations) has not been fully met, which may have had an effect on the success of the market. In Nordel Grid Plan (2008), the targeted market uniformity level was 65 % of the time (price difference <2 €/MWh) for year 2010 after the five prioritised line investments in the Nordic countries. It was seen important that the uniform market would allow more cross-border trading and thereby more efficient sharing of resources. However, the uniformity levels have varied between 10 to 30 % in the period from 2010 to 2014 (Fingrid, 2014). This can be partly explained by the fact that some of the Nordic transmission network investments are lagging behind of the original planned timetable.

In this doctoral dissertation, the Nordic electricity market is used as an example to demonstrate the critical role of transmission capacity investments for the market integration. The study is empirical, and both qualitative and quantitative research methods are applied. In Publication I, a Delphi study is conducted to demonstrate the factors affecting electricity market integration in Europe. In addition, some suggestions are made on how to ensure the integration. Publications II and III provide case studies on the Nordic electricity market landscape. Especially, the change in the governance structure in the Nordic electricity markets as well as the risks of small markets in the case of inadequate transmission capacity are discussed. Publication IV represents a quantitative research approach: a numerical analysis is performed to determine the effects of delayed transmission network investments for market participants in the Nordic electricity markets.

5.1 Contributions of the study

In this doctoral dissertation, the consequences of insufficient transmission capacity to the market participants were researched. To sum up, the contributions of this dissertation are:

1. Identification of critical factors affecting electricity market integration.
2. Elaboration on the possible impacts that different governance regimes may have on the delivery of cross-border infrastructure projects.
3. Analysis of possible risks in isolated electricity markets.
4. Development of a method to tentatively estimate the financial impacts of delayed transmission investments for electricity market participants.

Electricity markets have been restructured for example to enhance competition and thus make the market more efficient. Transmission capacity investments, again, are seen as a way to further the electricity market integration, although the investments procedures are typically challenging in nature. In particular, TSOs play a critical role in transmission capacity expansions.

In the Nordic electricity markets, the transmission capacity investments were also considered critical to enhance the market uniformity. However, the completion of the planned transmission investments has partly been lagging behind the targeted schedule. This study suggests that changes in the governance structure have affected the delivery of Nordic cross-border investments. Notably, the outlet for local political commitment has changed as the regional organisations (viz. the Nordic Council of Ministers, the Energy Market Group, Nordel and NordREG) have been replaced by European-level organisations (ENTSO-E and ACER). In addition, varying investment criteria (for cross-border transmission investments) between the countries may have influenced final investment decisions.

Based on the study of the Nordic electricity markets, a "Nordic transmission capacity development machine" can be delineated. In other words, there have to be certain determinants to guarantee the effective transmission capacity development, which, in turn, supports the proper functioning of electricity market as it was targeted in the first place, Figure 6.

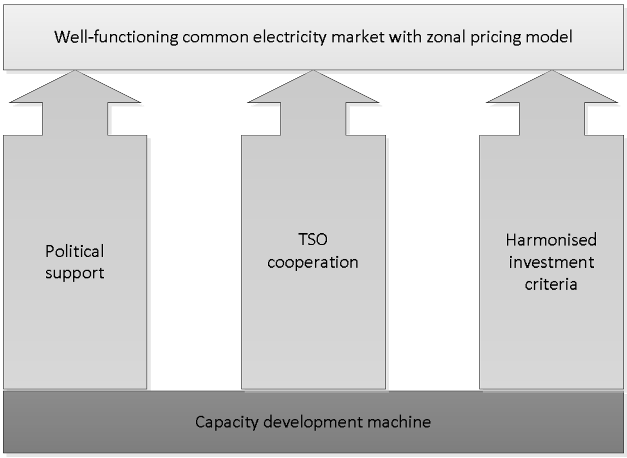

Figure 6. "Capacity development machine" in the Nordic electricity markets.

In the Nordic electricity markets, there are some positive experiences of the functionality of this machine, although there have also been challenges such as non-harmonised investment criteria. However, it can be argued that after the changes in the outlet for political support and the TSO cooperation in the Nordic electricity markets, the enthusiasm to commit to common Nordic projects seem to have decreased.

The financial impacts can be significant for the market participants if the transmission network is not adequate; for instance, the goal of efficient sharing or resources may not be met. In addition, frequent network congestion that can be anticipated may give rise to gaming possibilities. In this doctoral dissertation, an empirical study on the distributional effects of electricity market decoupling has been made. The impacts for the electricity generators, buyers and TSOs have been calculated.

5.2 Other findings and future work

Establishment of the common electricity market is a topical issue also at the European level. Transmission capacity investments are of key importance in the market integration and needed also to guarantee the functioning of the electricity markets. There are certain ways (e.g. ten-year network development plans, TYNDPs) to instruct and further the transmission network investments in Europe. Also elsewhere in Europe, the challenges in the transmission network capacity development have been similar to those in the Nordic countries. Projects can be delayed because the TSOs cannot agree upon the sharing of costs, or the permitting procedures are time consuming. The new methods to solve these problems (e.g. a list of projects of common interest and the cross-border cost allocation method) have been introduced, but currently, there is no wide experience of the viability of these methods. (There are some exceptions, e.g. the Nea-Järpsrömmen investment, where the asymmetrical cost allocation method was applied successfully.) In addition, there seems to be the same missing piece as in the Nordic electricity markets; the local and direct dialogue between regulators and TSOs. When this element disappeared from the Nordic market, the investment plans were not followed as before.

As a part of future work, the ways to promote the transmission capacity development in Europe should be analysed. In particular, the focus should be on the effects of a new cost benefit analysis and listing of projects of common interest. For example, merchant investments and the idea of a regional system operator model in Europe could be studied in more detail. A regional system operator could be a solution to enhance the development of a common electricity market, and it could take care of grid operations and planning. Finally, the effects of the REMIT Regulation and market transparency should be evaluated at the whole European level.

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