BLOWING IN THE WIND?

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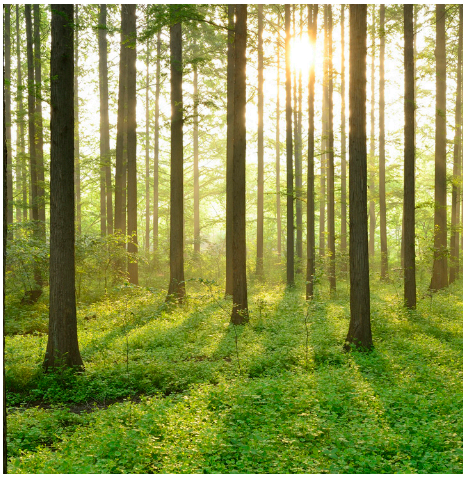

EFORIS

ELMARKNADENS FUNKTION
OCH ROLL I SAMHÄLLET

Energiforsk

Blowing in the wind?

On the future design of the Nordic electricity market

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Foreword

EFORIS, Function an role of the electricity market in society, is a research program on electricity market design. The program was initiated by Energiforsk and involves dozens of highly reputable Swedish and international researchers.

These are the results and conclusions of a study on the future design of the Nordic electricity market carried out by Lars Bergman and Chloé le Coq at Stockholm School of Economics. The authors are responsible for the content.

Sammanfattning

Elförsörjningssystemet i Europa blir allt mer integrerat, fysiskt och institutionellt. Således är ”den svenska” elmarknaden nu en integrerad del av den nordiska elmarknaden som i sin tur blir allt mer integrerad med den europeiska kontinentens elmarknader. Parallellt med denna integrationsprocess håller det europeiska elförsörjningssystemet på att förändras, med ökande andelar icke planeringsbar vind- och solkraft som det mest framträdande draget. Dessa förändringar kommer att ha konsekvenser både för driften av elsystemet och organisationen av handeln med el.

Syftet med denna studie är att identifiera den organisation av elhandeln och den relevanta politikens utformning som bäst främjar samhällsekonomisk effektiv produktion, transmission, distribution och konsumtion av el ett par decennier fram i tiden. Vi har ett i huvudsak svenskt perspektiv, d.v.s. vi diskuterar vad som är den mest ändamålsenliga utformningen av den framtida elmarknad där svenska producenter säljer el och svenska konsumenter köper el. Rapporten riktar sig till en bred läsekrets utan expertkunskap om elmarknaden. Nyckelgruppen bland de tilltänkta läsarna är de som fattar beslut om inriktning och finansiering av elmarknadsforskning i Sverige.

Det som vanligen kallas ”den nordiska elmarknaden” är egentligen en sekvens av gemensamma nordiska terminsmarknader och nationella realtidsmarknader för grosshandel med el. Genom att handla på terminsmarknaderna kan producenter, större konsumenter och elhandlare utforma och gradvis anpassa sina framtida timvisa produktions-, inköps- och leveransplaner. Även om en del av handeln med el sker bilateralt sker det mesta på två flernationella organiserade marknadsplatser, ”dagen-före” marknaden Elspot och ”intra-dag” marknaden Elbas, som drivs av företaget Nord Pool.

Jämfört med andra teknologier för kraftproduktion har vind- och solkraft två särskiljande drag. Ett är att produktionen är intermittent och beroende av vindförhållanden respektive solstrålning. Det andra är att den rörliga produktionskostnaden är i stort sett noll och därmed lägre än motsvarande kostnad i alla andra kraftslag. Beroende på andelarna vind- och solkraft i den samlade elproduktionen kan dessa särskiljande drag ha betydande konsekvenser både för elsystemets och elmarknadens sätt att fungera. Speciellt kan både frekvensen och amplituden i elprisets kortsiktiga variationer och risken för kapacitetsbrist under höglastperioder öka. I rapporten analyseras dessa drag i den framväxande elmarknaden och behoven av en s.k. kapacitetsmekanism diskuteras. Vidare diskuteras marknadsaktörernas möjligheter att med hjälp av finansiella derivat gardera sig mot ökande prisrisker.

Under de senaste åren har man introducerat kapacitetsmekanismer i flera europeiska länder. Jämfört med resten av Europa är emellertid de nordiska länderna unika med sin stora tillgång på vattenkraft. Vattenkraftens flexibilitet gör den idealisk för att balansera vind- och solkraftens kortsiktiga variationer. Det betyder att en nytto-kostnadsanalys av en kapacitetsmekanism ser annorlunda ut för de nordiska länderna än för resten av Europa. Det är också möjligt att

marknadsaktörerna hinner skapa en marknad för kapacitet innan en kapacitetsmekanism baserad på en reglering av elmarknaden ter sig nödvändig.

Omvandlingen av elförsörjningssystemet och elmarknaden ger upphov till en rad frågor som i många fall är lämpade för forskning av nationalekonomer eller elsystemspecialister. Av dessa frågor är det särskilt två som vi vill lyfta fram. Den ena rör den finansiella handeln med el. Såvitt vi har funnit har det bedrivits mycket lite forskning om hur dessa marknader fungerar. Samtidigt är det utomordentligt viktigt att det finns väl fungerande finansiella marknader om och när elpriserna blir mer volatila och amplituden i elprisvariationerna större. Det andra området rör elnätsföretagens framtida roller i ljuset av framväxten av ”smarta” elnät och stora lokala elkonsumenter som serverhallar och ansamlingar av elbilar som skall laddas samtidigt.

Elförsörjningssystemets framtida utveckling, i såväl de nordiska länderna som i Europa som helhet, är en komplex process som drivs av teknologisk och institutionell utveckling i förening med ny lagstiftning. Inom ramen för denna process kommer de incitament som investerare, producenter, elhandelsföretag och konsumenter att ställas inför spela en stor roll för vilka utfall som realiseras. Ämnet nationalekonomi handlar till mycket stor del om att kartlägga och förstå hur ekonomiska incitament bildas och påverkar beteendet under olika teknologiska, institutionella och regulatoriska förhållanden. Således kan ekonomisk forskning med inriktning på elmarknadens institutionella utformning och reglering ge värdefull vägledning till beslutsfattare inom såväl politik och förvaltning som i näringslivet och enskilda hushåll.

Summary

The electricity supply system in Europe is becoming increasingly interconnected, physically and institutionally. Thus the "Swedish" electricity market is now part of an integrated Nordic electricity market which more and more is integrated with the continental European electricity markets. Parallel to this integration process the European electricity supply system is in a state of transition, with increasing shares of non-dispatchable wind and solar power as the key feature. The changes underway will have consequences for the technical operation of the system but also for the electricity trading arrangements.

The purpose of this study is to identify trading arrangements and policy designs that are likely to foster socially efficient production, transmission, distribution and consumption of electricity a couple decades ahead. We primarily adopt a Swedish perspective, discussing the most appropriate design of the electricity market on which Swedish power producers could sell and Swedish consumers could buy electricity in the future. This report is targeted at a general audience without expert knowledge of the electricity market. However, the key target group consists of those deciding about the focus and funding of electricity market research in Sweden.

What is commonly denoted "the Nordic (wholesale) electricity market" is a sequence of common forward markets and a set of national real time markets. By trading on the forward markets, producers, major consumers and retailers can form and gradually adjust production and delivery plans for specific future hours. Although part of the forward trading is bilateral most of it takes place at two organized multi-country markets operated by the company Nord Pool, namely the day-ahead market Elspot and the intra-day market Elbas.

Compared to other technologies for power production wind and solar power have two distinguishing features. One is that production is intermittent and depending on wind speed and solar radiation conditions, respectively. The other is that short run variable costs are close to zero and thus lower than the variable cost of all types of conventional power plants. Depending on the shares of wind and solar power in the generation mix these features may have significant implications for the functioning of the electricity supply system and the market for electricity. In particular both the frequency and amplitude of electricity price variations and the risk of power shortage during peak demand periods may increase. In the report these aspects of the emerging electricity market are analyzed, and the need for a capacity mechanism is discussed. Moreover, the possibilities to hedge increasing price risks by means of financial derivatives trade is discussed.

During the last few years several European countries have introduced capacity mechanisms. However, compared to the rest of Europe the Nordics are unique by having a very significant amount of hydro power. The flexibility of hydro power makes it ideal for balancing the short-term variations of wind and solar power production. This means that the cost-benefit analysis of capacity mechanisms looks different in the Nordics than in the rest of Europe. Moreover, a "market solution", i.e. a market for capacity created by the market participants, may develop before a

capacity mechanism based on further regulation of the electricity market is conceived to be warranted.

The transformation of the electricity supply system will give rise to several issues, many of which are suitable for research by economists and electricity system specialists. Of these issues we want to especially point out two areas. One is the financial electricity trade. We have learned that very little has been done in terms of research on the design and functioning of these markets. At the same time efficient financial markets are extremely important when electricity price volatility, and the amplitude of price variations, increase. The other area is related to the future role of the DSOs in the light of "smart" networks and large local consumers such as server farms and numerous electric vehicles.

The future development of the electricity supply system, in the Nordics as well as in Europe as whole, is a complex process in which technological and institutional development coupled with legislation are driving forces. Within this process the economic incentives faced by investors, producers, retailers and consumers will play an important role and, in the end, largely determine the actual outcomes. Economics is essentially about understanding how economic incentives are formed and affect behavior under different technological, institutional and regulatory conditions. Thus, economic research with a focus on electricity market design and related topics has the potential to provide useful insights and guidance both to decision makers in government, industry and finance, and to individual households.

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List of content

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1 Purpose and scope of the study

The electricity supply system in Europe is becoming increasingly interconnected, physically and institutionally. While electricity markets used to be national they now are organized regionally with the geographical extension of the regions constantly growing. Thus the "Swedish" electricity market is now part of an integrated Nordic electricity market which is increasingly integrated with the continental European electricity markets.

Parallel to this integration process the European electricity supply system is in a state of transition, with increasing shares of non-dispatchable wind and solar power as the key feature. In this process Sweden is unique in the sense that a sizable amount of nuclear capacity will be phased out during the next couple of decades and most likely will not be replaced by new nuclear power. Instead there is an ambitious program aimed at very significantly increasing the share of wind and solar power in the Swedish power generation mix. Thus the 50-50 nuclear-hydro system in place since the early 1980s is about to be replaced by a system dominated by wind and hydro power. The target is to have 100 percent renewable energy by 2040 and net-zero carbon emissions by 2045.

The transition of the electricity supply system is driven by increasingly ambitious climate policies and is taking place in a rapidly changing technological environment. Thus, technological developments together with "learning-by-doing" are changing relative cost conditions in power generation and opening new possibilities for electricity storage. At the same time digitalization is about to enable consumers to actively participate, directly or indirectly through so called "aggregators", in the electricity market in real time.

The changes underway will have two related yet distinct sets of consequences. The first relates to the electricity system operation and the need to manage the technical and operational complexities created by increasing shares of non-dispatchable wind and solar power.[1] The second relates to the trading arrangements and the electricity market rules and regulations, i.e. the "electricity market design". In this study we focus on the market design aspects of the emerging electricity supply system.[2]

1.1 PURPOSE OF THE STUDY

The purpose of this study is to identify trading arrangements and policy designs that are likely to foster socially efficient production, transmission, distribution and consumption of electricity a couple decades ahead. We primarily adopt a Swedish perspective, discussing the most appropriate design of the electricity market on

[1] See Svenska kraftnät (2015) for a discussion of these issues as well as a presentation of system operation reforms that have recently been implemented or are under way.
[2] See De Vries and Verziljbergh (2018) and Newbery et.al (2018) for a general discussion of the market design issues raised by the large-scale introduction of wind and solar power in the European electricity supply systems. See Grubb and Newbery (2018) for a discussion of electricity market reforms in the UK.

which Swedish power producers could sell and Swedish consumers could buy electricity in the future.

It is commonly expected that increasing shares of intermittent power, i.e. wind and solar power, will be accompanied by more volatile electricity prices and increased risks of capacity shortage during peak demand periods. So, the need for a revised electricity market design will crucially depend on the answers to the following two questions:

- Given the current market design, will the emerging electricity supply system be flexible enough to maintain security of supply?
- If not, how can the security of supply issue be dealt with in the most efficient way?
- Given the current market design, will market participants be able to hedge emerging price and quantity risks at a reasonable cost?
- If not, how can the issue of price and quantity risk be dealt with in the most efficient way?

The answers to these questions depend, among other things, on the technologies that are available in the future. Especially, the spread and implementation of technologies enabling consumers to participate in real time trading is likely to increase the short run price sensitivity of electricity demand, which, in turn, may reduce demand peaks. Moreover, the development and deployment of cost-efficient storage technologies will affect the possibilities to provide power when capacity shortage is imminent and to absorb power at times of power surplus. There are also issues regarding the incentives to build and maintain transmission and distribution networks and the role of the distribution system operators (DSOs).

This report is targeted at a general audience (policy makers, policy analysts, students…) without expert knowledge of the electricity market. However, the key target group consists of those deciding about the focus and funding of electricity market research in Sweden. Thus, in addition to providing an overview of the market design consequences of large-scale introduction of wind and solar power the report aims to propose guidelines and topics for future electricity market research in Sweden. Given these aims the report is written in non-technical language, and key concepts, well known to electricity market specialists, are explained.

Our analyses and conclusions about the future market design are a mixture of recommendations and predictions. On the one hand we will point out markets design features which we believe will foster a socially efficient electricity supply and demand system. On the other hand, we will speculate about the outcome of the interplay between policy makers, regulators and market participants in an environment of rapid technological change and ambitious climate policy.

The report is organized in the following way. In Section 2 we discuss some key points of departure for our analysis and in Section 3 we briefly discuss the current design of the Nordic electricity market. In Section 4 we give a brief description of the current and expected electricity supply and demand conditions in the Nordics, with a special focus on Sweden. In Section 5 we discuss and illustrate the case of the Swedish electricity supply system with large shares of wind and solar power.

This is followed up in Section 6 where we discuss the implications of these properties for the functioning and role of the day-ahead and intra-day markets. In Section 7 we discuss the need for a new or revised electricity market design and in Section 8 we summarize our conclusions and suggest directions for future research on electricity market design.

2 Changing or revising the market design: Some points of departure

Our analysis has two key points of departure. One is that, despite the continuing integration of European electricity markets, both the Nordic countries as a group and Sweden remain relevant objects of study from an electricity market point of view. The other is that future changes of the electricity market design will be the result of an interplay between legislation, regulation and initiatives by the market participants. In the following we will elaborate on these points.

2.1 WILL THE RELEVANT FUTURE ELECTRICITY MARKET BE A SWEDISH, NORDIC OR EUROPEAN MARKET?

A key feature of the current Swedish electricity supply system is that trading and price formation at the wholesale level take place within the frame of a fully integrated multi-country market. This market was created as a common Norwegian-Swedish electricity market in the middle of the 1990s and expanded into a Nordic market when Finland and Denmark joined a few years later. Since then the market has continued to expand and currently encompass the Baltic countries, i.e. Estonia, Latvia and Lithuania. Moreover, via the single price coupling algorithm EUPHEMIA system day-ahead electricity prices across large parts of Europe are coupled.

What, then, is the "relevant" electricity market from the point of view of producers and consumers in Sweden? Is it European, Nordic or Swedish? The answer depends on which perspective one wants to focus on. One obviously very important perspective is competition and price formation at the wholesale level. The key implication of the above-mentioned developments is that future electricity prices in Sweden will be affected by supply and demand conditions in a much wider geographical area than the Swedish and even the Nordic territory. The question then is to what extent supply and demand conditions in Sweden, or in the Nordic area, will determine the electricity prices faced by Swedish power producers and electricity consumers during the next couple of decades.

The answer depends on the capacity of future cross-border transmission capacities and congestion management practices in the Nordics and in northern Europe. If cross-border transmission capacities will be practically unlimited most of northern Europe will be one single price area. The cost of producing electricity in Sweden would then determine whether Sweden would be a net exporter or a net importer of electricity, but the prices would be determined by supply and demand conditions in Europe as a whole.

However, we do not envisage that this kind of situation will emerge within the coming decades. Although cross-border transmission capacities between the Nordics and continental Europe will increase they will be far from unlimited. On the other hand, the transmission capacities within the Nordic area are quite significant and will continue to increase. It is therefore likely that the supply and demand conditions in the Nordic area will remain the key determinants of the electricity prices faced by producers and consumers in Sweden during the next decades.

However, the geographical extension of the electricity market may also be defined with respect to system operation and the existing regulatory framework. Indeed, there is, still, a Swedish TSO (Svenska kraftnät) running the national real-time market and being responsible for the real-time balancing of the system. It also controls the strategic reserve, i.e. the capacity which is held available for use in situations of imminent capacity shortage. Moreover, the power producers, the distribution network owners and the power exchange in Sweden are subject to Swedish laws and overseen by Swedish regulatory agencies.

Against this background the relevant electricity market from the point of view of Swedish producers and consumers is both Nordic and Swedish. It is Nordic, while increasingly Northern European, when it comes to wholesale price formation and competition in the generation segment of the market. But it is largely Swedish when it comes to short time adjustments related to the system control, real-time pricing and issues about generation and network capacity adequacy. Thus, both the Nordic countries as a group and Sweden appear to be relevant objects of study from an electricity market point of view.

2.2 REVISING THE MARKET DESIGN

“Market design” commonly refers to the organization of the market place, involving decisions such as between a mandatory pool and a voluntary exchange, gate closure times (when trading must stop), treatment of start-up and stop costs, as well as on balancing mechanism design and congestion management. With a somewhat wider definition the market places and trading rules, as well as the design of renewable energy support systems, are elements of the overall electricity market design.

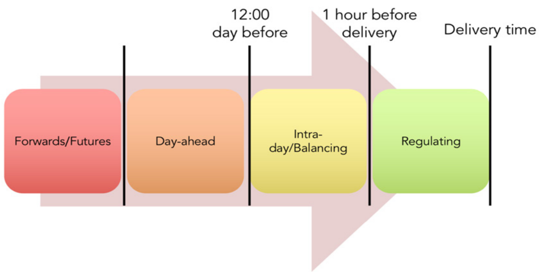
To a large extent a given market design reflects legally based regulations, including binding instructions to the system operator. Other elements are decided by the system operator within the frame of the legally based regulatory framework. However, the establishment of market places and trading rules are often initiated and further developed by the market participants to serve their interests by reducing information and transaction costs. If the external conditions change, the market participants are likely to push for an adjustment of the market design.

Thus, the revision of the market design will be driven by two types of processes. One is new legislation and initiatives by the system operator, while the other is changes in the set of trading arrangements on the initiative of the market participants. Moreover, along the road there will be interplay between these two processes. Changes in the legal and regulatory framework will induce certain changes on the part of the market participants. At the same time the changes implemented by and for the market participants will have an impact on the timing and content of changes in the legal and regulatory framework. This means that our conclusions will be a mix of recommendations to the legislators and the system operator, and predictions about market design changes initiated by the market participants.

3 Current design of the Nordic electricity market

What is commonly denoted "the Nordic (wholesale) electricity market" is a sequence of common forward markets[3] and a set of national real time markets. By trading on the forward markets producers, major consumers and retailers can form and gradually adjust production and delivery plans for specific future hours. Although part of the forward trading is bilateral most of it takes place at two organized multi-country[4] markets operated by the company Nord Pool, namely the day-ahead market Elspot and the intra-day market Elbas. The sequence of markets is illustrated in Figure 1 below.

Figure 1: Sequence of markets



Source: IAE 2016

3.1 SEQUENTIAL MARKETS

More than 95 percent of the produced electricity in the Nordic and Baltic countries is traded at the day-ahead market Elspot. For each hour during which electricity is produced and delivered, a (wholesale) price is calculated. Elspot runs an auction that define the system price for delivery each hour the following day. During this trading period sellers and buyers place hourly bids, in terms of quantity and price, for the following day. For each delivery hour, these bids are then matched to find an equilibrium price, i.e. a price at which the quantity supplied is equal to the quantity demanded. The result of the day-ahead trading is a set of hourly equilibrium prices and corresponding production and delivery plans for the next day.

The contracts traded on Elspot are standardized hourly contracts defined in terms of MWh/h, and the hourly equilibrium prices are made public. In principle there could be a single hourly price for the entire Elspot area, i.e. the Nordic and Baltic

[3] A forward market is a market where products are traded for delivery at a future point in time.
[4] The "Elspot area" covers the Nordic countries (except Iceland), the Baltic countries and UK, whereas Elbas also covers major parts of central Europe.

countries, but due to transmission constraints the prices often differ between countries and between “electricity areas” (i.e. bidding areas) within each country.[5]

However, Elspot also determines a “system” price which is the price that would prevail if there were no transmission constraints. This is an important price as it is often used as the reference price in the financial contracts signed by the market participants to hedge price risks[6].

The trade on the intra-day market (Elbas) is continuous and enables the market participants to adjust their plans for each trading hour. Like on Elspot the traded products are hourly contracts (MWh/h). However, while the accumulated trade on Elspot in 2017 was 394 TWh the corresponding figure for Elbas was only 5.5 TWh. The drivers for Elbas trading are new information that relates to (expected) supply and demand conditions during “the hour”. Elbas is open until one hour before “gate closure”, i.e. one hour before “the hour”. During “the hour” the Swedish TSO, i.e. Svenska kraftnät, manages the Swedish system to maintain frequency and voltage in real time within predetermined narrow limits.

Each market participant is required to attain balance between available power resources, owned or contracted, and hourly delivery obligations. Each producer or consumer must either assume the role of a “Balance Responsible Party” or transfer that obligation to another market participant by means of a contractual arrangement. There are penalties to be paid by a Balance Responsible party in case of imbalances between expected and actual generation (or consumption) during “the hour”.

3.2 REAL TIME TRADING IN SWEDEN

Finally, to ensure continuous balancing between actual production and consumption, the “Regulation Market” allows for real time trading. It is operated by Svenska kraftnät, who buys or sells “regulation power” from/to producers and major consumers within the framework of the “Balance Service”. Currently regulation power is an hourly product (MWh/h), but within a few years there will be a shift to 15-minutes trade.

The market for regulation power is based on offers from producers and major consumers. Thus, producers make offers, in terms of price and quantity, to increase or reduce production in response to calls by the system operator, while major consumers in the corresponding way make offers to reduce or increase consumption. The TSO accepts the set of bids that minimizes the cost of balancing the system.

The (equilibrium) price of regulation power is equal to the marginal accepted bid. Thus, the real time price of electricity is equal to the marginal cost of producing power (or reduce the use of power) in real time. Currently the volume of traded

[5] In Sweden there are four electricity areas, SE1-SE4. They are defined by a geographical division of the country into four geographical areas based on bottlenecks in the north-south transmission grid.
[6] As forward or futures contract only provide a hedge against this system price the market participants are faced with the basis risk. The basis risk refers to the risk of an area price being different from the system price, resulting in imperfect hedges for the market participants.

regulation power is small, only around 1 600 GWh in 2017, and the real time price does not play any significant role for the consumers. However, new technologies could enable the consumers to be active in real time trading (to be discussed in Section 6).

In theory there would be no transactions on the Regulation Market during a specific hour if each Balance Responsible Party had a balanced portfolio for that hour. However, this is seldom the case and even if it were there is most likely a "structural" reason for the system operator to buy or sell electricity on the Regulation Market. This is because production and delivery plans are hourly, while maintaining frequency and voltage in the electricity supply system requires continuous balance between injections to and withdrawals from the system.

3.3 FINANCIAL MARKETS AND HEDGING OF PRICE RISKS

Unpredictable electricity price variations represent financial risks for power producers, retailers and major consumers of electricity. Consequently, they are willing to pay for measures that provide protection against the financial impact of adverse price movements. A "hedge" is an investment in a security that reduces the exposure to the risk of a specific adverse price movement, while a "derivative" is a security whose value moves in relation to a reference, or "strike", price. Options, futures, swaps and forwards are examples of financial derivatives. Market for derivatives play an important role in modern economies where very large portfolios of financial assets are managed.

The basic idea of hedging is very simple: If the value of a financial derivative is negatively correlated with the price of electricity, i.e. increases when the price of electricity goes down and vice versa, a market participant can reduce the financial impact of electricity price variations by investing in such a derivative. However only in the case of perfect negative correlation, holding such a derivative completely eliminates the financial risk.

The market participants' urge to hedge price risks has led to the development of "financial power exchanges". The company Nord Pool established a financial power exchange in parallel to the establishment of the common Norwegian-Swedish day-ahead market in the middle of the 1990's. A key feature of the derivatives traded on the Nord Pool financial power exchange is to have the day-ahead "system price" as the reference price. Thus, holding financial derivatives allows market participants to hedge market risks and thus reduces the effect of system price fluctuations. Nord Pool also offers clearing services, i.e. assumes the role of (reliable and liquid) counterpart to both buyers and sellers of the derivatives.

The Nord Pool financial power exchange, including its clearing function, has played an important role for the successful development of the Nordic electricity market. In 2008 the company was sold to Nasdaq Commodities (without any major change of the trading rules). At that time electricity market related derivatives trading in the Nordics had grown to 2 500 TWh per annum. Since then, however, the volume of trade has gone down and in 2017 it was only 1 059 TWh. The possible reasons for this, and consequences of reduced liquidity, will be discussed later in Section 7.

There are two types of trading with derivatives. One is trading by power producers, retailers and major consumers of electricity wanting to hedge electricity price risks. The other is so called proprietary trading by market participants, normally without direct connection to power production or electricity intensive industries, wanting to benefit from electricity price volatility. One reason for this is that the movement of electricity prices may be negatively correlated with the prices of some other assets, and thus electricity derivatives help to stabilize the value of certain portfolios of financial assets. The proprietary trading is important as it adds liquidity to the market for electricity related derivatives.

The financial products traded at Nasdaq Commodities are System Futures[7], European Options[8] and so called EPADs (Electricity Price Area Differentials). While forward or futures contracts provide a hedge against the system price, EPADs are designed as futures and allow the market participants to hedge against differences between the System Price and Electricity Area prices. Of these the System Futures, with the Elspot System Price as reference price, account for around 75 percent of the trade. The volume of EPADs trade is rather small, and most of the trade is related to the areas SE3 (in Sweden) and Finland.

By means of System Futures, market participants can hedge price risks up to ten years into the future, while the corresponding horizon is four years for EPADs. However, the liquidity of instruments with maturity more than two years into the future is rather limited. Thus, market participants wanting to hedge long term risk must resort to various kinds of bilateral agreements. These agreements are commonly structured as forwards[9] with expiration dates up to 20 years into the future. One example is "Power Purchase Agreements" (PPA's) which are forwards used in connection with investments in wind power plants.

3.4 SECURITY OF SUPPLY

"Security of supply", which is a key aspect of any electricity supply system, can be divided into two parts. One depends on the reliability of transmission and distribution networks while the other depends on the availability of capacity in relation to peak demand in the power generation segment of the system. First, we discuss the second part, i.e. the rules, regulations and incentives which are intended to ensure that the available generation capacity is enough to serve peak demand.[10] We later comment on the current design of network regulation and the

[7] A "futures" contract is a standardized forward contract giving the holder the right and obligation to buy, or sell, a certain product (physical or financial) at a given price at a certain future date.
[8] An "option" is a standardized financial contract giving the holder the right, but not an obligation, to buy, or sell, a product (physical or financial) at a given price. The option is "European" if that right refers to a future point in time.
[9] The key difference between "forwards" and "futures" is that forwards are tailor-made agreements while futures are standardized. Thus, forwards are suitable for bilateral trading, while futures can be priced and traded at organized markets.
[10] To be precise the aim is to keep the probability of power shortage at a very low yet positive level.

role of the network companies, commonly called "distribution system operators" (DSOs). Note that we only focus on the situation in Sweden.

Like many other electricity markets the Nordic electricity market is a so-called energy-only market (EOM). This means that the producers are paid for the energy (MWh) they deliver, but not for the capacity (MW) they keep available. But for physical reasons the injections to and withdrawals from the system must balance in real time, and to safeguard this it is necessary that enough capacity (MW) and/or demand flexibility is always available.

In Sweden, as in the other countries in the Elspot area, there is no regulation of (minimum) available capacity (MW), neither at the level of individual generators nor at the level of the system. Instead it is assumed that scarcity prices in peak periods, together with the risk of having to pay penalties for not being in balance in peak hours, will provide incentives for generators to keep enough amounts of capacity available[11].

So far, this mechanism has worked well and there has been no problem with security of supply in the generation segment of the electricity market. There are primarily three reasons for this. The first is the significant expansion of nuclear power in the 1980´s, which to a large extent relieved the hydro power plants from the task of providing base load power. The second is the significant amount of hydro power capacity in the country, combined with the inherent flexibility of hydro power. The third is the significant capacity of the interconnections with Norway, Finland and Denmark, which makes it possible to import electricity at times of imminent capacity shortage in Sweden.

A side effect of the ample supply of capacity and the flexibility of hydro power is that the electricity prices have exhibited rather limited short-term volatility. The variations between years, reflecting the yearly differences in precipitation, have been larger than the seasonal variations. It is however unclear whether the actual economic incentives to build and maintain the desired peak capacity are enough. Without such incentives peak capacity may not be enough to safeguard security of supply in the long term. This last point leads to an important question: Does the replacement of nuclear power with wind power make it necessary to establish a (generation) capacity mechanism in Sweden? This issue is discussed in Section 7.

3.5 NETWORK REGULATION AND THE ROLE OF THE DSOS

Like in other countries both transmission and distribution companies in Sweden are natural monopolies, i.e. they do not face competition but are subjected to regulation. Svenska kraftnät is the single owner and operator of the transmission network, while power companies, municipalities and pension funds own the regional and local distribution networks. The regulation of these distribution companies, i.e. the DSOs, is designed as a revenue cap system. Thus, based on estimates of capital and operating costs, in conjunction with incentives to improve quality, a revenue cap for each DSO for a period of four years is determined by the

[11] Based on legal requirements, however, Svenska kraftnät finances a so-called strategic reserve, "Effektreserven", to be used in the case of immediate risk of capacity shortage.

regulator (Energy Market Inspectorate). The key aspect of "quality" is security of supply.

A discussion of the details of the system are beyond the scope of this study. The important point, however, is that the DSO has a relatively passive role in relation to the users of electricity in the area. Thus, whatever the level and time-profile of electricity demand in the area the DSO in question has an obligation to serve the demand for network capacity. Yet the DSO can affect the electricity demand in the area by designing peak-load pricing schemes.

However, due to the legally imposed separation between distribution and retailing the DSO is currently not allowed to take actions which implies that the DSO in effect acts as a retailer. But if local electricity demand is going to be dominated by large customers such as server farms and large numbers of electric vehicles, the vertical separation between distribution and retailing may have to be reconsidered. We will briefly discuss this issue in Section 7.

3.6 RENEWABLE ENERGY SUPPORT SYSTEM

Like in many other countries there is a support system for some renewables in Sweden. Renewable (often called "green") energy sources are hydro, wind, sun, wave, peat and biomass. Each MWh "green" electricity generated, i.e. electricity based on renewable energy sources, is subsidized. In some countries there are so called feed-in tariff systems where the subsidy is fixed and independent of electricity market conditions. In Sweden, however, the subsidy is determined on a market for so called electricity certificates and varies as electricity market conditions change.

Given that some electricity consumed must be "green", electricity retailers need to buy electricity certificates in a fixed proportion to the electricity sold. The demanded certificates are supplied by the producers of "green" electricity. The price of the certificates, and thus the per MWh subsidy to green electricity, depends on the interplay between supply and demand conditions on the certificate market. As there is a fixed relation between total electricity demand and the demand for certificates the certificate prices also depend on supply and demand conditions on the electricity market.

A discussion of the details of the system and how it works[12] is beyond the scope of this study. The important point, however, is that the system is designed to support production of "green" electricity (MWhs), not investments (MWs) in hydro, wind-, solar, wave-, peat or biomass power plants. It is not obvious that this design is the most efficient one. We will come back to this issue later in this report.

[12] One consequence of the design of the system is that day-ahead prices may be negative. This is because the sum of the positive per MWh subsidy and the market price may be positive and thus induce the producers of "green" electricity to continue producing despite the market price being below zero.

4 Current and future supply and demand conditions: Some numbers

As a background for the ensuing discussion on the future market design it is useful to summarize some data about current and expected future electricity supply and demand conditions in the Nordics. The future is represented by projections of the situation in 2030 and 2045. The latter year is a point in time when all the nuclear power plants in Sweden (but not in Finland) are expected to be phased out. Table 1 below presents aggregated data for the Nordic countries, i.e. Denmark, Finland, Norway and Sweden[13], while Table 2 presents the corresponding data for Sweden. Year 2015 is our reference year, as most of the nuclear power plants in Sweden were still in operation at that time[14] and the scale of wind and solar power introduction was still rather modest. In other words, the 2015 electricity supply system in the Nordics, and Sweden, relatively well depicts the situation prior to the transition to a system with large amounts of wind and solar power and not so much nuclear power. However, to have the more recent data we have added the corresponding numbers for 2017.

Table 1. Aggregate production and consumption of electricity in the Nordic countries

	2015 (IEA)		2017 (ENTSOE)		2030 (ENTSOE)[15]		2045 (ENTSOE)[16]	
	TWh	%	TWh	%	TWh	%	TWh	%
Hydro	230,7	57,1	220,6	54,9	222,4	48,7	223,2	49,2
Nuclear	79,6	19,7	84,6	21,0	72,7	15,9	18,3	4,0
Fossil	28,1	7,0	26,4	6,6	44,2	9,7	4,3	0,9
Biomass, peat, waste	29,8	7,4	30,2	7,5	30,6	6,7	42,0	9,3
Wind	35,2	8,7	39,5	9,8	85,2	18,7	144,3	31,8
Solar	0,7	0,2	0,8	0,2	1,8	0,4	21,5	4,7
Aggregate production	404,1	100,0	402,1	100,0	457,0	100,0	453,4	100,0
Net export	-1,3		-1,2					
Final consumption	345,3		393,1					

Source: IEA, ENTSOE

[13] Given that the electricity supply system in Iceland, the fifth Nordic country, is entirely independent of the other Nordic countries, we do not consider this country.

[14] Of the twelve nuclear reactors built and taken into operation in Sweden ten were in use in the beginning of 2015. Later that year one reactor (Oskarshamn 2) was closed, followed by the closing of another one (Oskarshamn 1) in 2017. In 2019 and 2020 two reactors (Ringhals 1 and Ringhals 2) are scheduled to be closed.

[15] *2030EU* scenario in ENTSOE (2018).

[16] *2040GCA* scenario in ENTSOE (2018).

The projections for 2030 and 2045 reflect current policy objectives about the future electricity supply system as well as the conditions expected to affect the future demand for electricity. If these objectives are attained around 85 percent of power generation in the Nordics will be based on renewable energy sources in 2045. However, given the very significant share of hydro power non-dispatchable wind and solar power will account for only around 35 percent of the generated power. It is an open question whether 35 percent non-dispatchable power is enough to significantly affect the properties of the electricity supply system. As shown in Table 2 below the corresponding number for Sweden alone is around 40 percent, which, as shown in Section 5, does have such an impact.

Note that 2015 was a "wet" year with large hydro power production, while 2030 and 2045 are projected to be "normal" years with respect to precipitation. Therefore, the hydro power production, in Sweden as well as in the Nordics as whole, declines between 2015 and 2030. The difference between aggregate production and gross consumption (i.e. consumption including network losses) corresponds to the net export to countries outside the Nordic area.

Table 2. Production and consumption of electricity in Sweden

	2015 (IEA)		2017 (ENTSOE)		2030 (ENTSOE)[17]		2045 (ENTSOE)[18]	
	TWh	%	TWh	%	TWh	%	TWh	%
Hydro	75,4	46,6	63,9	40,2	68,4	39,4	68,4	48,8
Nuclear	56,3	34,8	63	39,3	48,6	28,0	0,0	0,0
Fossil	1,9	1,2	2,7	1,7	13,1	7,5	0,0	0,0
Biomass, peat, waste	12,0	7,4	12,2	7,7	7,8	4,5	17,1	12,2
Wind	16,3	10,0	17,3	10,9	35,3	20,4	48,1	34,4
Solar	0,1	0,1%	0	0	0,2	0,1	6,3	4,5
Aggregate production	162,1	100,0	159,1	100,0	173,3	100,0	139,9	100,0
Net export	-3,4		-2,3					
Final consumption	124,9		140,1					

Source: IEA, ENTSOE

Table 2 shows a significant net export of electricity from Sweden both in 2015 and in 2017. For the year 2015, this is mainly due to the excess of hydropower supply. Note that the production during a "normal" year is around 63 TWh. For the year 2030, the big net export comes from the large investments in wind power that is assumed to take place. As wind power production and thus aggregate supply expand in the Nordic area, there is downward pressure on average electricity prices, especially when most of the wind power plants are in operation. As indicated by Table 1 and Table 2 this situation is expected to prevail at least as long as the Swedish nuclear power plants remain in operation, i.e. to 2030 and possibly a few years after.

[17] *2030EU* scenario in ENTSOE (2018).
[18] *2040GCA* scenario in ENTSOE (2018).

Contrary to the situation in the other Nordic countries there is an issue with regard to peak capacity sufficiency in Sweden. Table 3 shows two measures of capacity: installed capacity and capacity expected to be available at peak demand periods in 2018/2019. The difference between the two measures reflects various restrictions on the use of hydro power, statistics on the historical availability of the thermal power plants, and predictions of wind and solar conditions at the time when instantaneous demand is expected to peak. In the case of gas turbines, the reason for the big difference between installed and available capacity is that around 90 percent of the installed capacity in gas turbines is part of the strategic reserve[19] and thus not available under normal market conditions. Note that we disregard the import capacity here.

Table 3. Installed and available peak capacity Sweden 2018/2019

	Installed capacity, MW	Available peak capacity, MW
Hydro	16 301	13 400
Nuclear	8 586	7 727
Wind	7 506	676
Gas turbines	1 577	190
Condensing	1 433	822
Combined heat and power	4 969	1 924
Solar	460	0
Total	40 832	26 279
Peak load reserve		750

Source: Svenska kraftnät, Regeringskansliet

The expected peak demand between November 2018 and March 2019 is 26 700 MW. If there would be a so called ten-years winter[20] the figure would be 27 800 while it would be 28 300 under so called twenty-years winter conditions. Thus, Sweden is already close to becoming dependent on imports to balance the system during peak periods, and the risk of having insufficient peak capacity is likely to increase.

As shown in Table 2 the expectation is that all nuclear power in Sweden, i.e. 7 727 MW, will be phased out before 2045. Parallel to that around 8 000 MW of wind power and around 4 000 MW of solar power are expected to be added to the system. However, in terms of expected peak capacity the new wind and solar power only add around 900 MW. At the same time demand is expected to grow. Consequently, the need for import during peak periods is likely to increase (unless storage and increased demand response create entirely new conditions for peak load management).

The maximum cross-border capacity for import to Sweden currently is around 10 000 MW. However, for various reasons the actual capacity is usually much lower, and the four so called electricity areas in Sweden (SE1 – SE4) differ considerably both in terms of the production-consumption balance and with respect to the

[19] The “strategic reserve” is capacity held available to be used only when capacity shortage is imminent.

[20] By a ten-years (twenty-years) winter is meant a winter which, based on historical data, is expected to be experienced only once in ten (twenty) years.

capacity of cross-border connections for import. From this point of view the situation is least favorable in the southern part of the country (SE3 and SE4). Moreover, the existence of physical import capacity does not mean that enough supply of imports from other countries will be available when it is needed.

The conclusion of this review of current and future supply and demand conditions is that Sweden is facing a delicate dilemma. A key policy objective is to replace nuclear power with wind and solar power as soon as possible. But an equally important objective is to maintain security of supply, which in practice means, at the regional level, a reasonable margin between available domestic peak generation and import capacity and peak demand. In theory these two goals do not need to conflict with each other. But given the current situation in the Nordics and Sweden, they appear to be.

This is because the successful subsidy-driven expansion of wind power, in Sweden and the other Nordic countries, has led to overcapacity and low prices. For reasons to be elaborated below this means that the incentives to invest in new dispatchable power are weak. Consequently, there is an emerging risk for capacity shortage leading to reduced security of supply when the nuclear power plants are phased out. Thus, in the context of exploring a suitable future design of the Nordic electricity market the design of mechanisms for safeguarding security of supply in Sweden is a key issue.

To shed some more light on the security of supply issue we will present some simulations showing the impact on the Swedish electricity supply system of high shares of wind and solar power.

5 The impact of high shares of wind and solar power

Compared to other technologies for power production wind and solar power have two distinguishing features. One is that production is intermittent and depending on wind and solar radiation conditions, respectively. The other is that short run variable costs are close to zero and thus lower than the variable cost of all types of conventional power plants. Thus, whenever wind and solar power plants operate, they will be the least-cost alternative. Depending on the shares of wind and solar power in the generation mix these features may have significant implications for the functioning of the electricity supply system and the market for electricity.

5.1 SOME ILLUSTRATIVE DATA

The changes induced by a large-scale introduction of intermittent power can be illustrated by the figures below, showing current (2017) and future (2045) supply and demand conditions in July and January in Sweden.[21] As shown in Table 2 above around 40 percent of the produced electricity in Sweden is expected to be generated by wind and solar power in 2045. We use ENSTOE data and TYNDP scenarios developed by ENTSOE for the year 2040 to simulate the supply and demand conditions in July and January 2045. Note that the time pattern of demand in year is used for all four figures and is represented by the dark line. The colored areas show the hourly production levels for each technology.

Figures 1a and 1b show the supply and demand conditions in July and January 2017, i.e. in a year when hydro and nuclear power still dominated electricity production in Sweden. Thus, the production in hydro and nuclear plants supplied most of the load, while the contribution by wind power was quite small. The category “other” includes solar power and CHP plants. As always demand varied significantly, and systematically, between day and night, between workdays and holidays and between summer and winter.

[21] This assumption is justified by different prospective analyses showing that demand in Sweden is likely to be constant until 2045 (NETP, 2016).

Figure 2. Actual electricity supply and demand in July 2017

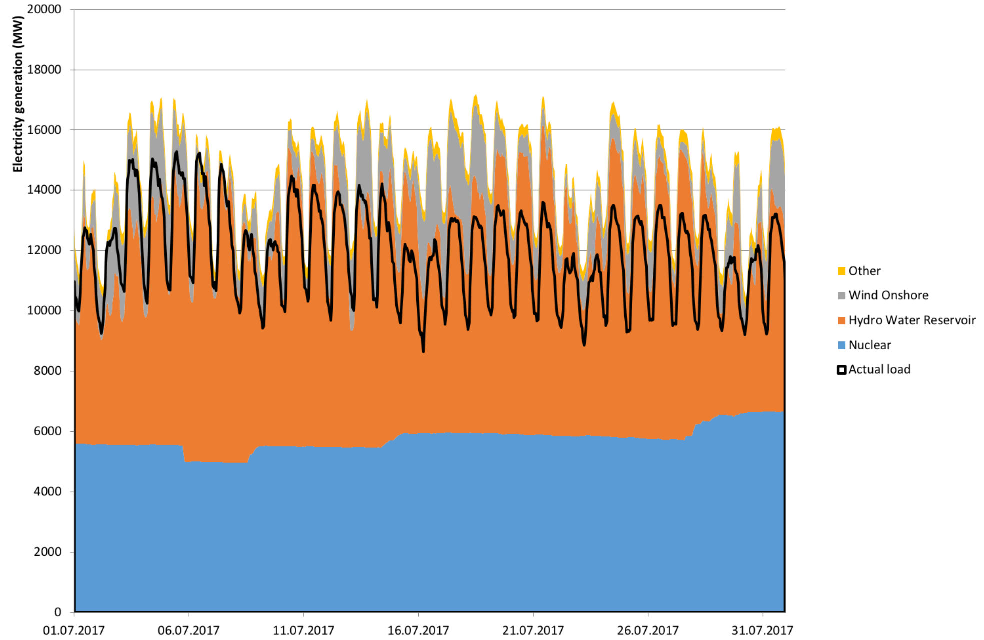
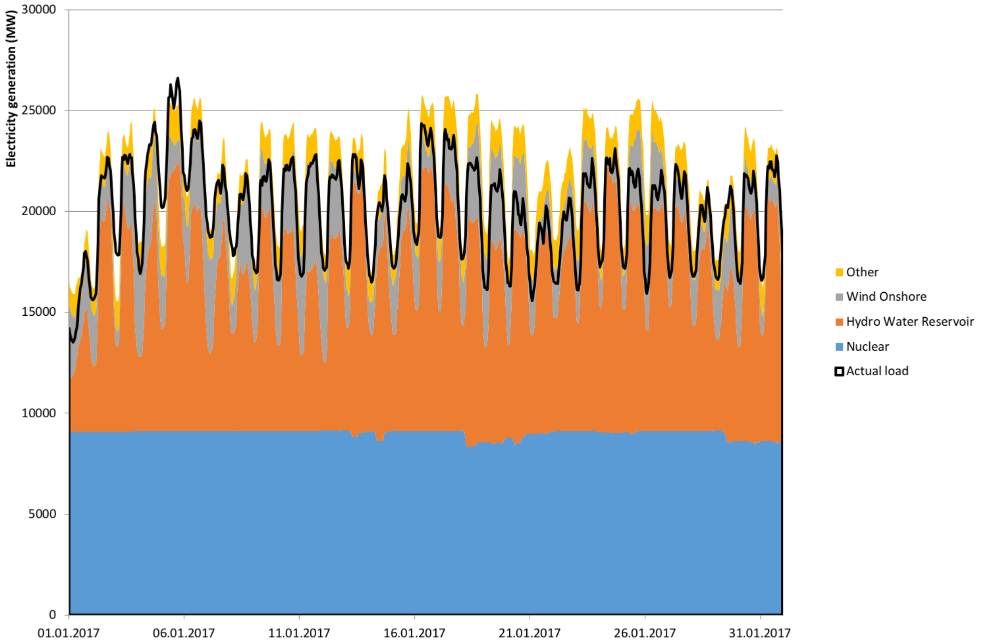


Figure 3. Actual electricity supply and demand in January 2017



Source: Own calculations using ENTSOE data

Except for the level of demand the general pattern did not differ very much between July and January: There was an almost constant level of nuclear power production, while hydro power production was following the load to balance the system. Note that the conventional power production[22] was never below 9 000 MWh/h in July and never below 14 000 MWh/h in January.

When the nuclear power plants are phased out and wind and solar power capacity continues to grow the situation becomes much different. Figures 2a and 2b shows the projected situation in July and January 2045, i.e. a point in time when all the Swedish nuclear power plants are expected to have been shut down. As in Figures 1a and 1b the dark line represents demand while the orange and blue areas represent conventional power generation and the grey area represents the wind power production. The key assumption here is that nuclear power is fully phased out, while significant additions of wind and solar power capacity have been added as indicated by Table 2. Moreover, we assume that the institutional arrangements are the same by 2045.

As can be seen in Figures 2a and 2b the production of wind and solar power varies significantly but is not very systematic. During a couple of days in early July there is almost no solar and wind production and imports are needed to serve the load. On the other hand, production in excess of demand will lead to exports during other days. The common feature of both months is that production in conventional power plants must vary a lot to compensate for the variations wind and solar power production. This is in sharp contrast to the situation in 2017 when conventional power production in July was quite stable. However, security of supply can be maintained without any apparent problem.

However, the situation in January (when there is essentially no solar power production) is quite different from the security of supply point of view. As shown by Figure 2 b the level of wind power production varies between approximately 2000 MWh/h and 15000 MWh/h. Thus, the production in conventional power plants will have to vary equally much in the opposite direction to balance the system. Yet there are several days when production in Sweden is less than the domestic load and imports from neighboring countries would be needed. Alternatively, more domestic production and/or storage capacity could be added and/or demand response could increase.

[22] The ”conventional power plants” are hydro, nuclear and fossil fueled power plants.

Figure 4. Projected electricity supply and demand conditions in July 2045

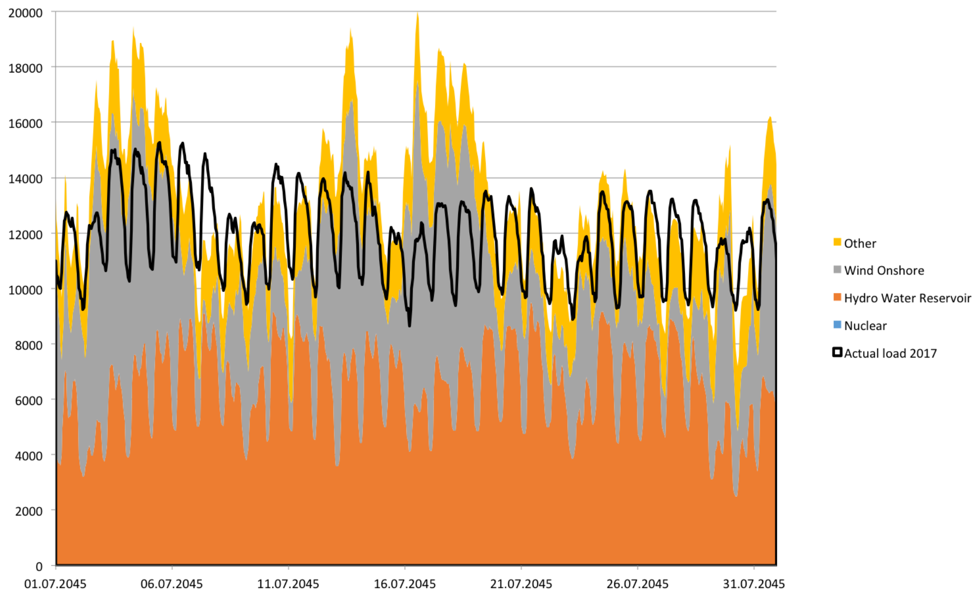
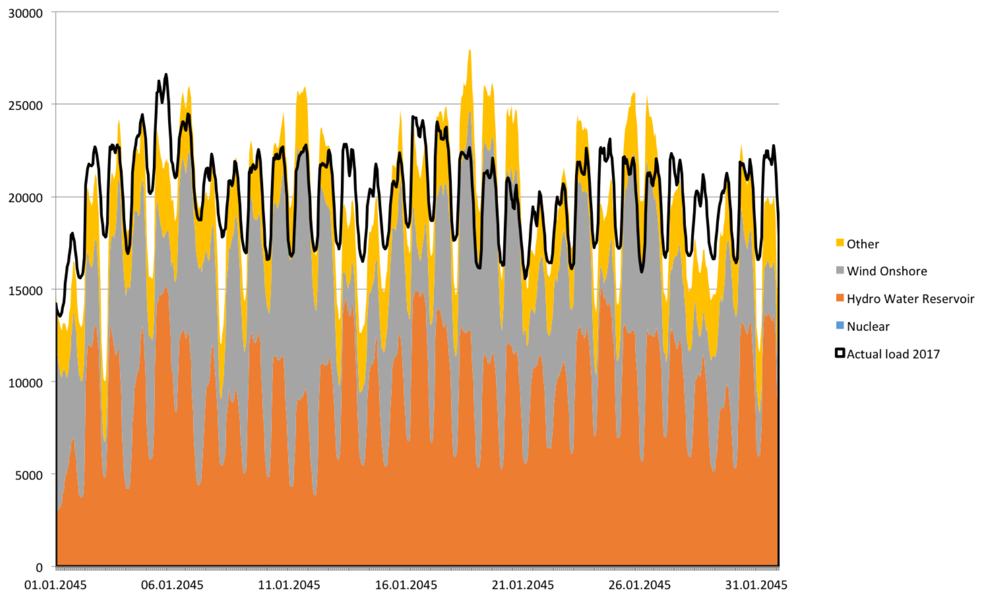


Figure 5. Projected electricity supply and demand conditions in January 2045



Source: Own calculations using ENTSOE data and TYNDP 2018 scenarios.

The figure also shows that wind power production can be quite low during several days in a row. As demand response primarily has the function of shifting demand a couple of hours or so the safeguarding of security of supply would have to be based on imports, storage or additional domestic production capacity. The question then is through which mechanisms the needed extra MW's would be supplied. This brings us to the question about "the missing money problem" and the possible need for a "capacity mechanism". As elaborated below this problem is closely related to the price variations associated with the short-term variations in conventional power production.

5.2 "MISSING MONEY" AND SECURITY OF SUPPLY[23]

The short-term balancing variations in conventional power production must be induced by corresponding variations in electricity prices. The more inelastic the short run electricity demand is the higher the amplitude of electricity price variations will be. Moreover, the resulting electricity price volatility may not be systematic as it has been historically, but may rather reflect variations in wind conditions. In other words, with high shares of wind and solar power, the electricity price volatility will be higher and more unpredictable than it currently is (at least, in the short term, which is the focus of this analysis).

As mentioned, one feature of so called "energy only" markets is that financial incentives rather than regulations are assumed to induce market participants to keep enough peak capacity available. Whether that mechanism will ensure capacity adequacy when the shares of wind and solar power are high is a much-debated issue. The discussion is focused on the "missing money problem" and it often implicitly assumes that all conventional power plants are thermal. In short, the "missing money problem" is the following:

An increase in wind and solar generation (with zero marginal cost) is likely to reduce the yearly number of operating hours in thermal power plants. The peak plants may however be called into operation more frequently and on shorter notice. Unless prices are sufficiently high during these hours the annual revenues of thermal power plants will not be enough to cover their capital costs. But due to regulations and lack of public acceptance peak period prices[24] may not be allowed to be high enough to compensate for the lower number of operating hours. Thus, from the point of view of investments in peak capacity the increased shares of intermittent power will be associated with increased risk for capacity shortage during peak demand periods.

The "missing money problem" is the key argument for adding a so-called capacity mechanism, i.e. a mechanism for paying generators to keep capacity available during peak demand periods. The mechanism may also include operators of storage facilities and major consumers being prepared to reduce their consumption when capacity shortage is imminent. Thus, in a market design with a capacity mechanism the generators are being paid not only for the MWh's they deliver but also for the MW's they keep available.

As will be elaborated in Section 7 a capacity mechanism can be designed in many ways. The key question, however, is how serious the "missing money problem" will be in the Nordics where there is plenty of flexible hydro power resources, and

[23] There is also reason to expect electricity prices to be very low in certain periods. This is because the dependence on common natural conditions implies that many of the wind power plants, like the solar power plants, will be producing at the same time. Moreover, wind and solar radiation conditions may be favorable during periods when the demand for electricity is low. Thus, a significant part of the electricity generated in wind and solar power plants will be supplied at times when prices are very low, while very little or no power will be generated when prices are high. Consequently, the output-weighted average price of electricity from wind and solar power plants will be lower than the time-weighted average market price of electricity. For analyses of the impact of wind power on electricity prices, see Hirth (2015) and Hirth (2018).

[24] Even if public acceptance may be more related to electricity bills, i.e. average prices, than short-term peak prices.

technological development may open new possibilities for storage and demand response. These issues will be discussed in some detail in Section 7. Before that, however, we will discuss the functioning of day-ahead and intra-day markets in electricity supply systems with high shares of intermittent power.

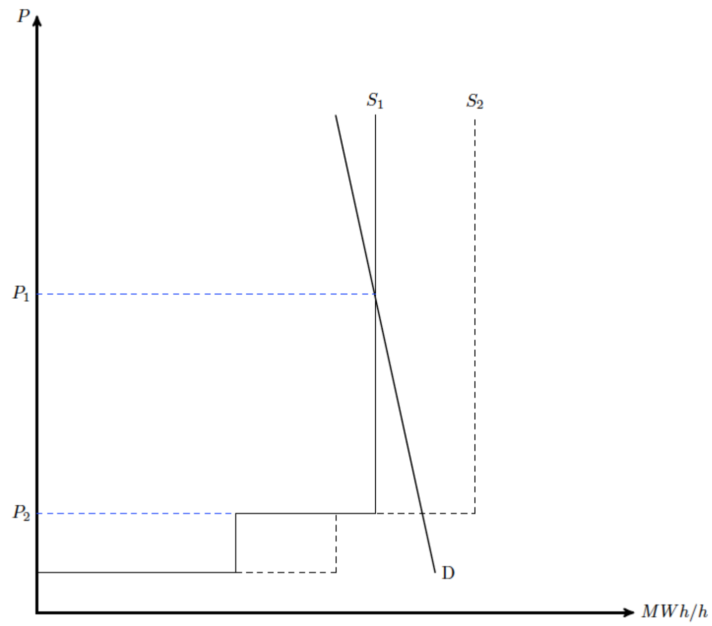
6 The future functioning and role of the day-ahead and intra-day markets

The day-ahead (whole-sale) market plays a very crucial role in the Nordic electricity market. It is the key vehicle for production planning, and the day-ahead prices to a very large extent determine the (pre-tax) electricity prices faced both by large and small consumers. Furthermore, the "system price" is the reference price in the financial contracts used for hedging of price risks. Thus, it is important to explore how this market is likely to work when the shares of wind and solar power are high, and to what extent the day-ahead market will retain its current role in the electricity supply system. We also need to understand the interplay between the day-ahead market and the intra-day market given this change in energy supply conditions.

6.1 THE FUTURE DAY-AHEAD MARKET?

To shed light on these issues we will use a series of supply-demand diagrams of a day-ahead market. The first, Figure 3, depicts the situation in an electricity supply system with some dispatchable power, assumed to be thermal power, and a substantial share of (non-dispatchable) wind and solar power. As demand exceeds the supply of dispatchable power it is necessary to produce at least some wind and/or solar power to supply all the electricity that is demanded.

Figure 6. Electricity market dominated by wind and solar power



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The figure refers to one specific hour during the next day. The (aggregate) supply curves S1 and S2 depict the price-quantity bids by the generators if expected wind and solar production is small or large, respectively. The increasing part of the curves represents the capacity limit of the whole set of power generation plants. If the market is competitive the bids by the wind and solar power producers are essentially zero-price bids, while the bids by the thermal producers reflect the variable cost in thermal power production. The demand is relatively inelastic so the day-ahead demand curve (D) is quite steep.

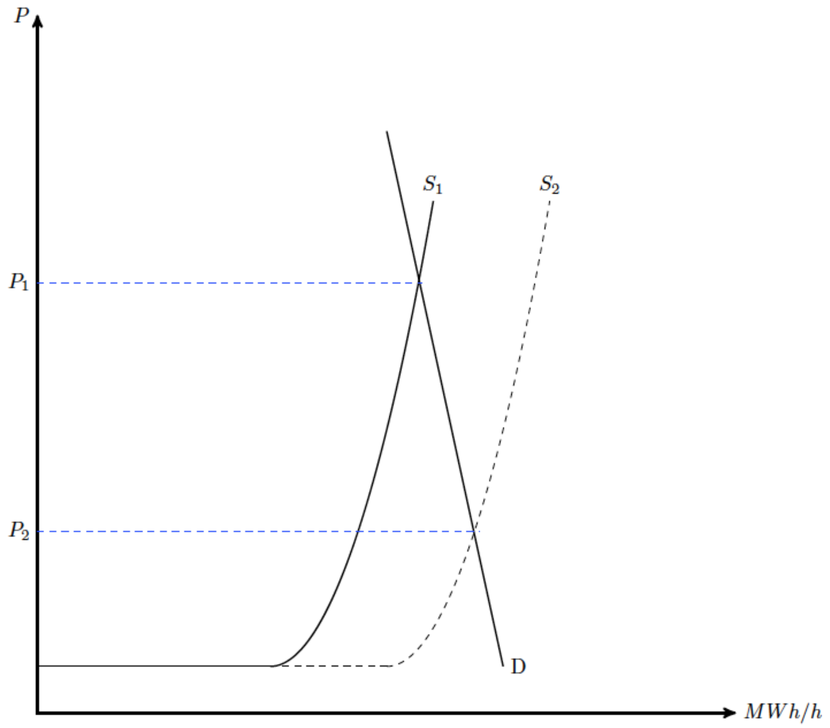
When the supply of wind and solar power is expected to be small the market price is P1, while it is P2 when there is plenty of wind and solar power. Since the demand curve is very steep and the supply curve is vertical at the capacity limit even small variations in expected wind and solar power production lead to very significant variations in equilibrium prices.[25] Moreover, the price will either be close to zero or very high.[26] If wind and solar power supply is considerably less than the supply S1, there may not even exist an equilibrium price.

Since a transition from thermal to wind and solar power is under way in many countries the situation depicted in Figure 3 has attracted quite a lot of attention in the electricity market literature[27]. The question is whether the day-ahead market can function and maintain its current role if equilibrium prices are either very low or very high in an unpredictable way. A tentative answer is that the day-ahead market may not provide the right signals for an optimal production planning. However, we do not believe that Figure 3 provides a realistic picture of the electricity market in the Nordics a couple of decades into the future.

This is because there will continue to be significant capacity, both in terms of MW and MWh, in hydro power as well as in nuclear power (as shown in Table 1). If we take that into account, the impact on the day-ahead market of high shares of wind and solar power (which in the Nordic context essentially means wind power) is quite different. This is illustrated by Figure 4 below where the slope of the supply curves reflects the opportunity cost of stored water, i.e. the expected value of the water at some other point in time. The vertical part of the curves reflects the capacity limit (MW) in the hydro power plants[28].

[25] Note that the final price will depend on interconnection, storage and demand side.
[26] In Sweden there is maximum allowed day-ahead price, currently equal to 3 000 €/MWh.
[27] See Riesz et. al. (2016) for an analysis of price formation in an electricity supply system based on 100 percent renewables.
[28] For simplicity the thermal power capacity is not included in the figure. Thus, it is implicitly assumed that, on the margin, some hydro power will always be used.

Figure 7. Electricity market with wind power and a large share of hydropower

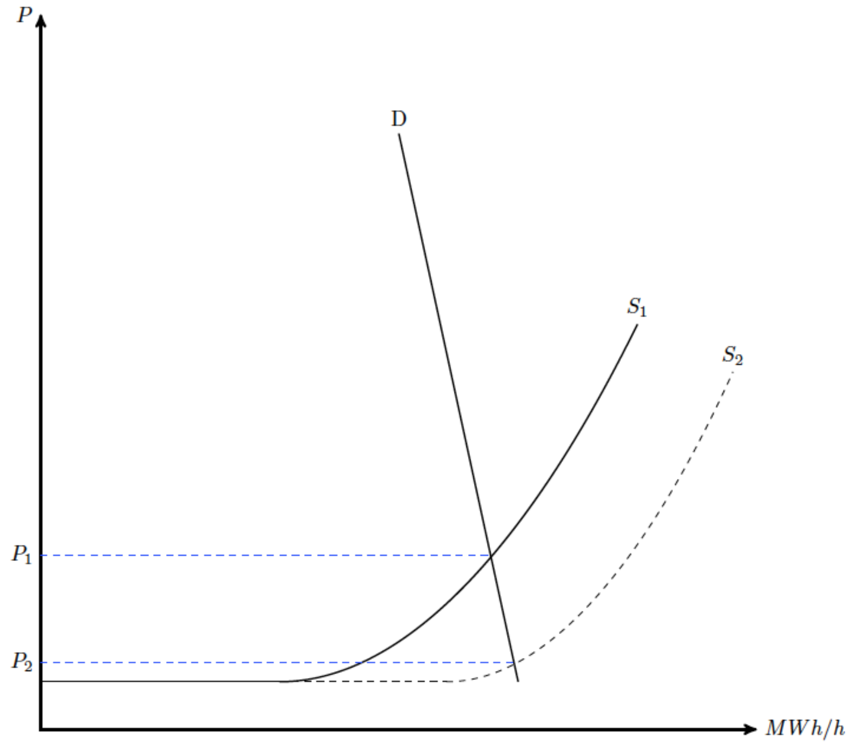


The key difference compared to the situation in Figure 3 is that the prices are not either very low or very high but can attain a range of different values between the two extreme values. However, if the supply of wind and solar power is sufficiently small there is, like in the previous case, no (or a too high) market clearing price.

Under the currently prevailing technological and institutional conditions this is very much the end of the story about the impact of high shares of wind and solar power on the day-ahead market. But a couple of decades into the future these conditions may be much different. Thus, new technologies and new types of contracts between sellers and buyers of electricity may significantly change the situation. The most important novelties are new technologies for storage of electricity, and digital equipment enabling consumers in general to, directly or indirectly, participate in the real time trading of electricity.

In Figure 5 we illustrate the combined impact of new storage technology and demand response. Storage facilities enter the market on the demand side in situations with very low prices, and on the supply side when prices are high and aggregate power plant capacity is getting scare. Figure 5 depicts the second case. The impact of releasing power from storages is that the supply becomes more elastic, and that the vertical part of the supply curve shifts to the right.

Figure 8. Electricity market with storage capacities and demand response



Digitalization enabling consumers to participate in real-time trading potentially has a significant impact on the day-ahead market. That is, if retailers expect consumers to be sensitive to real-time price variations it will affect the bidding behavior on the day-ahead market. More precisely the day-ahead demand curve will become more elastic as depicted in Figure 5. The combined result of power storage and demand response is that the amplitude of price variations becomes smaller, and that the market can clear at a lower level of wind and solar power production.

The conclusion of this discussion is that higher shares of wind and solar power will, ceteris paribus, increase the amplitude of day-ahead price variations. But both new storage technology and increased demand response work in the opposite direction. Whether the net effect is smaller or larger price variation amplitudes is hard to predict without access to a suitable simulation model.

However, the shares of wind and solar power may increase before efficient storage facilities and demand response begin to play significant roles. But the more volatile prices will be, the stronger will be the incentives to develop and deploy efficient storage facilities. In the same way high price volatility is likely to stimulate the use of technologies and contractual arrangements enabling consumers to react on price variations. Thus, in the long-term electricity price volatility may not be much higher than it currently is.

What then are the implications of the increasing shares of wind and solar power for the functioning and role of the day-ahead market? Unless these shares will be very high it is quite likely that the day-ahead market will continue to function essentially as it has in the past. Yet there will be minor changes such as a transition from hourly to shorter trading periods. However, due to the difficulty of planning wind and solar power production many hours in advance day-ahead market trading may decrease.

6.2 THE INTRA-DAY MARKET

While day-ahead trading may decrease in the future intra-day market trading, i.e. trading on Elbas, is likely to increase. So far, the traded volumes at Elbas have been quite small, only around 5 TWh in 2017. But higher shares of wind and solar power in combination with unpredictable weather conditions will most likely make it necessary for market participants to adjust their positions after the closing of the day-ahead market. As indicated above they may also abstain from trading at the day-ahead market. In any case the volumes traded at the intra-day market are likely to increase considerably.

The changing relative roles of the day-ahead and intra-day markets raise several questions. Should we have, on the intra-day market, a 15-minute trading, instead of the current continuous trading? How many markets for intra-day trading will exist a couple of decades into the future, and where will they be located? What will be the most appropriate reference price in the financial trading? A day-ahead price or an intra-day price? Some of these issues are analyzed in a parallel study within the EFORIS program and will only be briefly touched upon in this report.

Moreover, as the geographical extension of the "relevant" electricity market grows the competition between different power exchanges is likely to grow. The outcome in terms of the future number and location of power exchanges, as well as the role of day-ahead and intra-day trading, depends on what the market participants consider most useful and efficient.

7 A new or revised market design

In the previous sections we have described the likely impact of a significantly higher share of wind power on the properties of the electricity supply system. We have also examined the resulting impact on electricity price volatility and the possibility of a "missing money problem". In this section we will focus on what we believe are the key implications of the emerging conditions with respect to the future design of the Nordic electricity market.

7.1 OVERALL TRADING ARRANGEMENTS

The overall trading arrangements can change in different ways. At the highest level there is a choice between bilateral trade and (organized) market-based trade. In the current market design trade on organized markets is completely dominating. This is because the existing set of day-ahead, intra-day and derivatives markets has turned out to offer the market participants attractive trading arrangements with low information and transactions costs. Moreover, the real-time market has been a well-functioning instrument for the System Operator.

However, we do not envisage that increased shares of wind and solar power will fundamentally change the competitiveness of trade on organized markets in relation to bilateral trade and thus induce a major shift from market-based to bilateral trade. In other words, we believe that the future market design will be a revised version of the current market design, not an entirely new one. Yet it is possible that bilateral contracts between wind power producers and peak load thermal power producers will be used for managing the unpredictability of wind power production in peak periods.

At the second level there is an issue about the set of organized markets. Will all the currently existing markets continue to exist? Will more markets be added? Concerning the first question there is, as mentioned, an issue about the future role of the day-ahead market. With very high shares of unpredictable wind and solar power trading 12-36 hours before the "hour" may not help production planning in any significant degree. Thus, it is likely that day-ahead trading will decrease while intra-day trading will increase. However, we do not envisage that day-ahead trading will be reduced to the extent that the day-ahead market will cease to exist.

The second question is whether the set of markets is likely to expand. More precisely, will more products be traded on organized markets? It is likely that we will see a strong demand for products giving some "flexibility", i.e. a commitment to change production or consumption, on short notice. Such products are likely to be promoted by market participants. Another product would be "inertia", one of the so called "ancillary services" which are needed to balance and stabilize the electricity supply system.[29]

[29] Note that technologies such as nuclear, thermal, hydropower require some time to adjust to the new market conditions. See Anaya and Pollitt (2018) for an overview.

To be suitable for being traded on an organized market a product needs to be well defined and easily measurable. Moreover, it must be standardized in terms of quantity and quality. To the extent that these conditions are satisfied for “inertia” and/or other types of ancillary services it is up to the TSO to decide whether such markets would make sense from a system operation point of view. Markets for “flexibility” will emerge only if the products can be properly defined and measured, and the market participants would consider such markets useful and efficient.

7.2 SAFEGUARDING SECURITY OF SUPPLY

However, a new market that certainly needs to be considered is a market for capacity, often called a “capacity mechanism”. As mentioned, the role of a capacity mechanism is to safeguard capacity adequacy and thus security of supply with respect to peak power generation. Security of supply with respect to the capacity and reliability of the transmission and distribution networks would require other measures than a capacity mechanism.

In this section we focus on two issues. The first is whether the future design of the Nordic electricity market should include a capacity mechanism. The other is how such a mechanism, if it is needed, should be designed. To answer the first question, it is useful to consider the numbers in Table 4 below. The table assumes that all nuclear power has been closed. It is also assumed that only 12 percent of installed wind power capacity is available during peak hours (normally in January or February), while the corresponding number for solar power is zero.

The expected capacity deficit is close to the 7 727 MW nuclear capacity currently available (see Table 3). Thus, while the wind and solar power capacities that is expected to be installed during the next couple of decades indeed replace the nuclear power from an energy (MWh) point of view that is not the case from a peak capacity (MW) point of view. The deficit must be covered by a combination of imports, demand response, release from storages, capacity increases in existing hydro power plants, new hydro power and new thermal power.[30] It appears unlikely that the entire deficit could be covered by imports. Thus, a certain amount of demand response and domestic capacity increases (including storage facilities) will be needed.

Table 4. Capacity and demand in the Swedish power system 2045

	Installed capacity, MW	Expected peak capacity, MW
Hydro power	16 200	14 000
Nuclear power	0	0
Wind power	18 800	2 200
Thermal power	8 000	6 000

[30] It is assumed that the currently existing strategic 750 MW reserve,”Effektreserven”, will be phased out by 2040/50.

	Installed capacity, MW	Expected peak capacity, MW
Solar power	12 000	0
Total capacity	55 000	22 200
Expected demand, MW		30 000
Expected net capacity		-7 800

Source: Svenska Kraftnät (2016/2017) and Energiföretagen (2040/2050). The table is also published in Bergman (2017).

It is difficult to predict the developments with respect to demand response and storage technology during the next couple of decades. A very conservative estimate, however, is that some 3000-4000 MW new capacity will be needed to safeguard capacity adequacy, and that a maximum of 1000 MW could be provided by new and upgraded hydro power plants. The question then is how investments in 2000-3000 MW of new thermal power could be induced. There are two options. One is to establish a capacity mechanism, while the other is to trust regular market forces to ensure this outcome. We will briefly discuss possible "market solutions", and then turn to a discussion about capacity mechanisms.

7.3 A MARKET SOLUTION

For a "market solution" to be realized it is probably necessary that the government declares that it is up to the market participants to safeguard capacity adequacy within the frame of the existing legislation. Given that kind of support, a "market solution" most likely would imply that a capacity market of some sort would be created by the market participants. Not because of a new regulation but because it would serve the needs of the market participants.

The market participants most interested in such a capacity market should be the wind power producers. As the wind power production is uncertain up to a couple of hours before delivery the fines associated with not being in balance constitute a significant financial risk for wind power producers. Thus, they would probably sign agreements with providers of firm capacity, i.e. hydro and thermal power producers, major consumers, groups of small consumers represented by aggregators, and operators of storages.

These agreements could be bilateral and tailor-made for the parties. However, one could also envisage a market for standardized contracts issued by providers of firm capacity and aimed at reducing the quantity risks associated with wind power production. The issuing firm capacity provider would commit to provide a given quantity of electricity during a specific hour (or some other period) once the wind speed in the relevant area is lower than a threshold level. The wind power producer would pay a fixed price for the contract instead of running the risk of paying unbalance fines. Thus, the contracts would give firm capacity providers a steady stream of revenues and thus incentives to build and maintain peak capacity. At the same time wind power producers would be protected against the quantity risks associated with wind power.

7.4 CAPACITY MECHANISMS

The alternative to a "market solution" is to introduce a capacity mechanism, i.e. a new regulation. Such a mechanism could be designed in several different ways. The common feature of all the alternatives is that there is a legally based regulation stipulating the minimum available peak capacity of the system.[31] Table 5 shows a common classification of the main types of capacity mechanism.

Table 5. Capacity Mechanisms

Volume Based				Price Based
Targeted	**Market-Wide**			
Strategic reserve	*Capacity obligation*	*Capacity auction*	*Reliability option*	*Capacity payment*

Source: Bergman (2017)

Note that a "Strategic reserve" is "targeted" in the sense that a certain amount of capacity is kept for the single purpose of being available for use at times of imminent capacity shortage. The Swedish "Effektreserv" thus is an example of a strategic reserve.

The "Market-Wide" alternatives, on the contrary, imply that all available capacity can be bid to the market at any time. In short, these alternatives imply the following:

- *Capacity obligation:* Retailers and major consumers are required to contract an amount of capacity linked to their self-assessed future supply or consumption plus a reserve margin. Their access to capacity may be based on bilateral agreements with producers. Alternatively, there may be a market for standardized capacity certificates issued by producers. Capacity obligations are currently in use in France.

- *Capacity auction:* The system operator procures a certain amount of capacity to be available at a certain future period. Several types of capacity providers, i.e. generators, major consumers and operators of storages, may participate. The auction typically starts with a high price per unit of capacity (MW), and then the price is reduced step by step until the target amount of capacity is committed. All winning bids are paid the price of the marginal winning bid. The design of UK capacity market included these capacity auctions. This market should have been running in January 2019 but was suspended for an EU State Aid investigation in November 2018.

- *Reliability option:* Retailers are obliged to buy "reliability options" allowing access to a certain amount of capacity at a predetermined "strike" price. The options, which are like so called call options, are issued by capacity providers and imply two types of commitments. One is to keep a certain amount of capacity available at a given future point in time. The other is to pay the holder of the option the excess of the market price over the strike price at that point in

[31] Here, we do not consider measure of import capacity as part of the available peak capacity.

time. Thus, the capacity provider gets a steady revenue, while the purchase price of the holder is capped at the level of the strike price. Reliability options are currently in use in Ireland.

- *Capacity payment:* Capacity providers are paid a predetermined price per unit of capacity that is kept available at a future point in time. The price is set at a level which is expected to induce the producers, major consumers and operators of storages facilities to keep the target aggregate capacity available. Capacity payments are currently in use in Italy, Portugal and Spain.

These alternatives all imply additional but different interventions in the electricity market, and it is not obvious which one is the best for Sweden.[32] However, if the "missing money problem" is the main reason for introducing a capacity mechanism then a system based on reliability options appears to be the natural choice. This is because capacity providers then are guaranteed a steady stream of revenues per unit of capacity, while consumers, via retailers, are protected from market prices exceeding the strike price. Thus, the problems associated with energy-only markets are solved and at the same time market prices are free to reflect the actual supply and demand conditions.

During the last few years several European countries have introduced capacity mechanisms. That is a strong indication that energy-only types of electricity markets commonly are conceived to need to be amended with a capacity mechanism. However, compared to the rest of Europe the Nordics are unique by having a very significant amount of hydro power. The flexibility of hydro power makes it ideal for balancing the short-term variations of wind and solar power production. This means that the cost-benefit analysis of capacity mechanisms looks different in the Nordics than in the rest of Europe. Alternatively, a "market solution" is more viable in the Nordics than in the rest of Europe. However, it is beyond the scope of this report to carry out such a cost-benefit analysis. Yet a few comments can be made.

On the benefit side it is most likely that a capacity mechanism would guarantee (generation) capacity adequacy. However, a capacity mechanisms may lead to more available capacity while more flexible capacity is what is really needed. That is, capacity that can start up, or change output, at very short notice. That is the case for hydro power plants, gas turbines, release from storages and some categories of demand response, but hardly for oil or coal fired condensing plants. Thus, there is a risk that a capacity mechanism will secure capacity adequacy in a sub-optimal way. On the cost side there is a risk that uncertainty about the availability of imports and demand response during peak period leads to excessive peak generation capacity requirements.

7.5 HEDGING OF PRICE RISKS

Above we concluded that electricity prices are likely to become more volatile as the shares of wind and solar power increase. How much more volatile depends on

[32] A decision to adopt one of them would include several specific decisions, for instance the level of required peak capacity and the treatment of import capacity, not further discussed in this report.

several factors. Meanwhile, ceteris paribus both increased demand response and access to storage capacity will reduce price volatility. It is also likely that an increase of the geographical extension of the electricity market would reduce price volatility. Yet future electricity prices are likely to be at least as volatile than they currently are, and market participants will continue to be interested in hedging price risks. Thus, liquid markets for electricity market related derivatives such as futures, options and EPADs (often called Contracts for Differences) will be needed.

However, as mentioned the volume of trade with electricity market derivatives, which is closely related to liquidity, has gradually decreased in recent years. While the volume of trade was around 2500 TWh in 2008 it was only around 1000 TWh in 2017. To our knowledge there is no published study analyzing the reasons for this development. However, unless this trend is reversed the future possibilities to hedge electricity price risks may not be as good as they have been in the past.

The appropriate design and functioning of the market for electricity derivatives depend on the design and functioning of the physical electricity market. One issue concerns the choice of reference price in the financial contracts. As mentioned, the currently used reference price is the Elspot System Price. From time to time there are significant deviations between the System Price and one or several Electricity Area prices. The market participants can hedge these price differences by means of EPADs. However, the volume of EPAD trade is small, which suggest that the System Price so far works acceptably well as reference price in the electricity derivatives. But with significantly higher shares of wind and solar power this may not be the case in the future.

The reason is that large amounts of wind and solar power will be concentrated in certain geographical areas. This will probably lead to more congestion in the transmission network in periods when wind and/or solar power production is high or low. As a result, there will be more frequent and larger differences between the System Price and various Electricity Area prices. One possible remedy is increased trade with EPADs. Another is to find a more suitable reference price. This is particularly the case if forward trading to a large extent moves from the day-ahead market to the intra-day market.

While there will certainly be demand for electricity derivatives in the future there is an issue about the supply of these instruments. If increased volatility of electricity prices also implies larger amplitude in electricity price variations the risk associated with issuing electricity futures and call options will increase. This is because the difference between the maximum market price and the strike price that the issuer must cover will be higher. To hedge this risk the issuer needs to possess assets whose prices are negatively correlated with the value of the electricity derivative.

One such asset is power plants in operation during periods with high prices. Thus, if the market price is higher than the strike price in the electricity derivative the issuer loses money. But at the same time the revenues from power production will be high, which partly or totally covers the loss on the derivative. This means that owners of power plants can be expected to continue to issue electricity derivatives.

The question is to what extent this also applies to so called proprietary traders, i.e. market participants managing portfolios with financial assets but having no direct connection to electricity production, consumption or trade. What makes the electricity derivatives interesting for these traders is that the variations in electricity prices may be negatively correlated with the prices of assets in their portfolios. This means that increased electricity price volatility could in fact make electricity derivatives more attractive to proprietary traders and thus help to increase the liquidity of the financial electricity market and facilitates trading. However, this is an area where more research is needed, and definite conclusions are clearly premature.

7.6 DESIGN OF RENEWABLE ENERGY SUPPORT SYSTEMS

The cornerstone of the current renewable energy support system in Sweden is the market for tradable electricity certificates. It was introduced in 2003 with the purpose of stimulating investments in wind, solar and other kinds of power plants producing "green" electricity. In 2012 the market was extended to include Norway, and goals for the period up to 2020 were decided. The system has recently been extended to 2045, with a target to increase the yearly production of "green" electricity in Sweden by 18 TWh between 2020 and 2030. Thus, there will be substantial support to the production of "green" electricity at least during the next couple of decades.

At the time when the tradable electricity certificate system was introduced none of the renewable electricity producing technologies were competitive from a cost point of view. Thus, support was a necessary condition for realizing the target development of "green" electricity production. Since 2003 wind power production has grown from 0,6 TWh to 16,3 TWh in 2015 (see Table 2). In terms of installed capacity, the growth has been from close to zero in 2003 to around 7000 MW in 2015. Although the corresponding numbers for solar power are much smaller the development since 2003 suggests that the renewable energy support system in Sweden has worked very well in terms of adding production capacity. "Green" electricity by now accounts for a significant part of electricity supply in Sweden.

However, the fast growth of wind power production also depends on the considerable cost reduction that has been experienced during the last decades, reflecting both technological developments and learning-by-doing. There is reason to believe that the favorable development of the wind power technology has been at least partly made possible by the support. One can say that the subsidies have successfully internalized the positive externalities associated with early investments in wind power and thus helped to make the wind power technology competitive.[33]

Due to the reduction of costs, however, wind power no longer needs support to be competitive. Moreover, it is likely that the positive externalities which motivated support during the early phase of wind power investments have ceased to exist. This means that continued support for wind power may be unnecessary and may

[33] See Pollitt and Chyong (2018) for a modelling exercise regarding the impact of the intermittent renewables on the European electricity supply industry.

in fact distort competition on the electricity market. From an economic efficiency point of view, it therefore appears to be time to start phasing out the wind power subsidies. When it comes to solar power, which still is in an early stage of development in Sweden (but not in the rest of the world), the situation is different and continued support is probably warranted.

However, despite the economic efficiency concerns it is most likely that the political commitments to support wind and solar power production are firm and that the support will continue. But as the commitments to the tradable electricity certificate system may not be equally strong it is worthwhile to briefly discuss alternative designs of the support system. The question then is what the most efficient design of that support is. By "efficient" we mean a wind and solar power support design that distorts electricity market competition as little as possible. There are basically two support alternatives. One is to directly support production of "green" electricity, i.e. the MWh's. The other is to make that support indirect by supporting investments in wind power plants, i.e. the MW's.

The tradable electricity certificate system is a MWh support system, with the level of support depending on the market prices of the certificates. Thus, the profitability of wind and solar power production depends both on the market prices of electricity and the market prices of certificates. Consequently, there is some uncertainty whether the target "green" electricity capacity in, say, 2030 will be attained. Moreover, the design of the support implies that the market prices of electricity may be negative. This is because the sum of a negative electricity price and a positive certificate price may be positive and thus induce wind and solar power producers to produce even when the market price is below zero.

However, although support per MWh could distort the market, in the sense that the merit order between different types of power plants is changed, this has not been the case. The reason is that even without the support the variable cost of wind and solar power production would be lower than the variable cost in all other types of power production plants. Thus, whenever there is wind and solar radiation, respectively, wind and solar power are the least-cost power production alternatives.

An alternative design of the support system would be to arrange wind and solar power capacity auctions. Thus, based on the political goals regarding "green" electricity production target levels of new wind and solar power capacity could be decided. Power producers, current as well as potential, would then place bids stating how much investment support they would need to invest in a given amount of wind or solar power capacity (MW). The auction would start with a zero or close to zero support, and then step by step increase the level of support until the desired level of wind and solar power capacity is committed.

With this kind of support system in place, and given the capacity contracted for in the auction and certainty of delivery, there would be no uncertainty about the attainment of wind and solar capacity targets. Moreover, there would be no periods with negative market prices of electricity. At the same time, like in the current system, wind and solar power producers would be exposed to the volatility and uncertainty of the market prices of electricity. Indeed, the pros and cons of a change from the current tradable electricity certificate system to a support system based on capacity auctions should be seriously evaluated.

7.7 THE FUTURE ROLE OF DSOS

The core of the current electricity market design is vertical separation between generation, transmission, distribution and retailing, with competing firms in generation and retailing and "natural" monopolies in transmission and distribution. Thus, there should be a "Chinese wall" between distribution, i.e. operation of the local distribution network, and retailing.

The regulation of the network operators implies a requirement to maintain a high level of security of supply. Among several other things this includes enough capacity to serve demand at any time. Obviously, ceteris paribus the need for capacity to serve a given amount of demand, i.e. MWhs per year, is lower the less variable the demand is. So far retail electricity consumption has varied systematically between day and night, and between different hours during the day. Yet time-varying tariffs are not common, which may suggest that a more even consumption pattern might not have been very desirable (or feasible) from the network operators' point of view.

However, with major local electricity consumers as server farms and large number of electric vehicles the situation may change. That is, it may become desirable for the network operators to counteract demand peaks and thus reduce the need for investments in additional capacity. This means that measures to stimulate "flexibility", i.e. changes in the time pattern of local electricity consumption, become attractive.

One option is increased use of time-varying tariffs to reduce demand-peaks. Another option is to actively influence the retail customers to change their time-pattern of demand. The question then is whether markets for "flexibility" can be designed, and whether the DSOs could be suitable organizers of such markets without in effect becoming retailers. Alternatively, "aggregators", i.e. agents acting on behalf of several retail customers, and other agents may take on the role of organizing "flexibility" markets.

The questions related to the possibility of creating markets for "flexibility" and the future role of DSOs, as well as the link between TSO and DSOs, are complex. Research on these topics would also include the design of network regulation (including investment, at the local, national and regional (interconnector) level, which may have to change given the change in the energy mix). For the moment being, however, we are not able to make recommendations in relation to these issues.

8 Conclusions and directions for research

Within the next couple of decades, the Nordic electricity supply system will change. The shares of wind and solar power will be considerably higher than they are today, and new technology will probably open both for efficient storage and considerably more demand response. In parallel some countries will change their energy profiles as Sweden will close its nuclear power plants while Finland will invest in this technology.

Moreover, the Nordic electricity market is more and more integrated to the European market for electricity. At the same time the security of supply issues will largely remain national or regional issues.

Our focus in this report is to assess whether these developments may affect the current electricity market design. At the outset we posed two questions:

- Given the current market design, will the emerging electricity supply system have enough flexibility to maintain security of supply?
- If not, how can the security of supply issue be dealt with in the most efficient way?
- Given the current market design, will market participants be able to hedge emerging price and quantity risks at a reasonable cost?
- If not, how can the issue of price and quantity risk be dealt with in the most efficient way?

Our first conclusion is that due to the ample supply of flexible hydro power, the issue of security of supply is less severe in the Nordics than elsewhere in Europe. Yet we believe that the current market institutions should be extended to include a market, or some other kind of mechanism, for capacity, i.e. MW's. However, it does not necessarily have to be a mechanism imposed by a new regulation. Bilateral trades between producers of intermittent and firm power, or possibly an organized market, may ensure the desired security of supply. But in case policy makers, and market participants, do not trust a "market solution" we believe that an Irish type of capacity mechanism, based on so called reliability options, would be the preferred model.

On the second issue one important question is related to the choice of reference price in the financial contracts. As mentioned, the higher share of wind and solar power are likely to increase the frequency and amplitude of differences between electricity area prices and the System Price, i.e. the price that currently serves as refence price for financial derivatives. Thus, hedging against System Price risks will not provide efficient insurance against electricity price risks in the same way as in the past. However, we are confident that the market participants will find an efficient solution to this problem.

An equally important but more complex issue is related to the liquidity of electricity market derivatives. During the last decade the volume of trade with electricity market derivatives has gradually decreased. If this development continues the liquidity of the derivatives might become too low, which would limit the possibilities to hedge electricity price risks. It might be that increased electricity price volatility makes electricity market derivatives more attractive to so called proprietary traders. But this is just one of several possibilities, and we are not able to make a reliable prediction about the future development of the financial side of the electricity trading.

The transformation of the electricity supply system will give rise to several issues, many of which are suitable for research by economists and electricity system specialists. Of these issues we want to especially point out two areas. One is the financial electricity trade. We have learned that very little has been done in terms of research on the design and functioning of these markets. At the same time efficient financial markets are extremely important when electricity price volatility, and the amplitude of price variations, increase. The other area is related to the future role of the DSOs in the light of "smart" networks and large local consumers such as server farms and numerous electric vehicles.

The future development of the electricity supply system, in the Nordics as well as in Europe as whole, is a complex process in which technological and institutional development coupled with legislation are driving forces. Within this process the economic incentives faced by investors, producers, retailers and consumers will play an important role and, in the end, largely determine the actual outcomes. Economics is essentially about understanding how economic incentives are formed and affect behavior under different technological, institutional and regulatory conditions. Thus, economic research with a focus on electricity market design and related topics has the potential to provide useful insights and guidance both to decision makers in government, industry and finance, and to individual households.

> *"Yes, 'n' how many times can a man turn his head*
>
> *And pretend that he just doesen't see?*
>
> *The answer, my friend is blowin' in the wind*
>
> *The answer is blowin' in the wind*
>
> *Bob Dylan, 1963*

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BLOWING IN THE WIND?

Thus the "Swedish" electricity market is now part of an integrated Nordic electricity market, more and more integrated with the continental European electricity markets. Parallel to this integration process the European electricity supply system is in a state of transition, with increasing shares of non-dispatchable wind and solar power as the key feature. The changes underway will have consequences for the technical operation of the system but also for the electricity trading arrangements.

During the last few years several European countries have introduced capacity mechanisms. However, compared to the rest of Europe the Nordics are unique by having a very significant amount of hydro power. The flexibility of hydro power makes it ideal for balancing the short-term variations of wind and solar power production. This means that the cost-benefit analysis of capacity mechanisms looks different in the Nordics than in the rest of Europe. Moreover, a "market solution", i.e. a market for capacity created by the market participants, may develop before a capacity mechanism based on further regulation of the electricity market is conceived to be warranted.

The future development of the electricity supply system, in the Nordics as well as in Europe as whole, is a complex process in which technological and institutional development coupled with legislation are driving forces. Economics is essentially about understanding how economic incentives are formed and affect behavior under different technological, institutional and regulatory conditions. Thus, economic research with a focus on electricity market design and related topics has the potential to provide useful insights and guidance both to decision makers in government, industry and finance, and to individual households.

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