The Swedish electricity market – today and in the future

Pär Holmberg and Thomas P. Tangerås*
The authors are associate professors in economics and work at the Research Institute of Industrial Economics (IFN)

The energy crisis has driven electricity prices up to levels we have never experienced before, creating major price differences within the country. There is also a risk that users will be physically disconnected. This article examines today's electricity market, the energy crisis and the green energy transition.

During the energy crisis, bottlenecks in the electricity transmission system have created huge transfers of income from consumers to the transmission system operator, Svenska kraftnät. This congestion rent should be incorporated into the regulation of the transmission system operator.

To resolve the energy crisis, measures are needed to increase generation capacity in the short term, improve grid utilisation and reduce electricity consumption, especially when demand is high. We also present measures to increase the efficiency of the electricity system.

The electrification of the manufacturing and transport sectors will require a major expansion of electricity networks and production. In particular, new electricity will be needed to produce green hydrogen. This demand is price-sensitive and relies on a large-scale expansion of cheap electricity production. An effective energy transition will require long-term, technology-neutral rules, efficient authorisation processes and well-developed financial markets. In addition, political risks in the electricity market need to be reduced.

* This article was commissioned by Sveriges Riksbank and was completed at the end of 2022. The authors are grateful for comments received during the course of the work and for views expressed during seminars at the Riksbank and National Institute of Economic Research, as well as in a meeting with Urban Andersson at Energiforsk. The analysis and views expressed in this article are those of the authors and do not necessarily reflect the views of IFN or the Riksbank.

1 Introduction

The electricity system and the markets that maintain and develop the electricity system together constitute the country's *electricity supply*. In 2022, the electricity supply has received more attention in Sweden and Europe than ever before. The war in Ukraine and the ensuing energy crisis have pushed electricity prices up to levels never before experienced in Europe. Users are even at risk of being disconnected because enough electricity cannot be produced. This has never happened in Sweden in modern times.

While many have begun to reflect on the fundamental importance of the electricity supply to the economy, the electricity market is complex and can be difficult to understand. This article aims to describe how the electricity market works in Sweden. It then discusses the challenges for the electricity supply in the short and long term.

The article first describes the electricity system in section 2 and then the different parts of the electricity market in section 3. The ongoing energy crisis has increased the risk of electricity shortages and increased consumers' electricity costs. Section 4 examines electricity-market challenges and potential solutions from this short-term perspective. In the longer term, the key question is how to ensure a sustainable, reliable and resource-efficient energy transition. These issues are discussed in section 5. The article finishes with a summary discussion and conclusions in section 6.

2 The electricity system in Sweden

The backbone of the electricity system is the high-voltage transmission grid. This connects large-scale production of electricity, such as hydroelectric and nuclear power, with transmission substations for regional electricity grids through 157 connection points.[1] The regional grids connect other electricity producers and industrial facilities, such as steel mills and paper mills, to the electricity grid. They also transfer electricity via transmission substations to the low-voltage local grids, which, in turn, connect households and other smaller consumers to the system. The Swedish electricity system is part of the integrated European electricity system via high-voltage transmission connections with our Nordic neighbours as well as Lithuania, Poland and Germany.

The transmission grid is owned and operated by Svenska kraftnät (Svk), which is also a co-owner of most of the connections with foreign countries.[2] Six companies own and operate regional grids, the largest of which are Vattenfall and Ellevio.[3] A total of 149 private and public companies own and operate local grids.

Figure 1 shows a map of the transmission grid in Sweden with indicated connection points and international connections. The grid structure from north to south reflects the need to transport electricity produced by large-scale hydroelectric power in the

[1] Svenska kraftnät applies the threshold value that an industrial facility must have an input or output capacity of at least 100 megawatts (MW) to be connected to the transmission grid (Svenska kraftnät, 2023).

[2] The exception is the Baltic Cable between southern Sweden and Germany, which is owned by Statkraft.

[3] There are also individual transmission lines at regional grid level.

north to the population centres further south. The new transmission connections from Norway to the United Kingdom and Germany and new nuclear power in Finland are increasing flows in an east-west direction, straight across the current structure of the transmission grid. These flows are creating challenges for the Swedish electricity grid, to which we shall return.

Figure 1. Map of the Nordic and Baltic transmission grid, 2021

Source: Svenska kraftnät

2.1 Electricity production

Historically, most of Sweden's electricity production has been hydroelectric and nuclear, supplemented by fossil-fuel based thermal power. Figure 2 shows electricity production in Sweden by the main types of power used for each year in the period

2000-2020. It also shows net exports of electricity in the same period. Hydroelectric power shows large annual variations, partly because the inflow changes from year to year. Nuclear power also varies but has had a downward trend since the all-time-high in 2004 when the 11 reactors collectively produced 75 terawatt hours (TWh) of electricity.[4] Five reactors have been shut down since then. For example, following the closure of Ringhals 2 at the end of 2019, we see a substantial reduction in nuclear power production the following year. Ringhals 1 was closed on New Year's Eve 2020, but its consequences for electricity production are not captured in the figure below. Implemented and planned power increases in the remaining reactors are helping to limit the overall power reduction somewhat.[5]

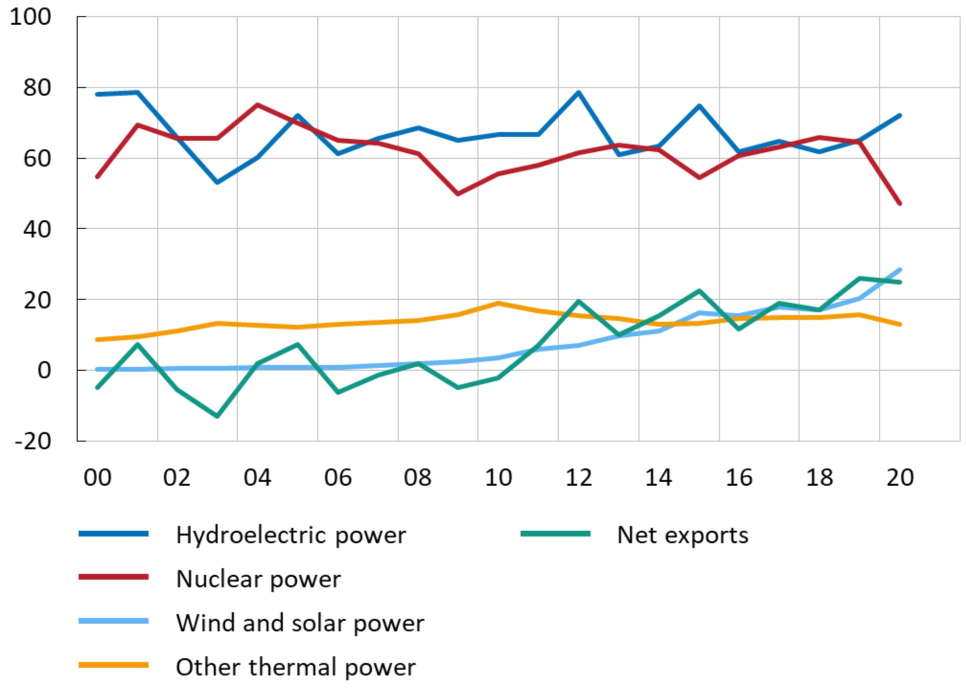
The different types of power affect the electricity supply in different ways because they differ in the extent to which they are dispatchable, flexible and have endurance. The output of a power plant is *dispatchable* if it is possible to predict with great certainty and well in advance, for example the day before, how much of the installed capacity will be available during its operating hours. Examples of dispatchable electricity production are hydroelectric, nuclear and thermal power. Electricity production is *flexible* if it can be increased or decreased at short notice, within 15 minutes or less, without incurring significant costs associated with the actual change in production. Nuclear power is an example of inflexible electricity production. Electricity production in a plant has *endurance* if the same level of production can be maintained over a long period of time. Examples are nuclear power and electricity production based on fossil fuels. Hydroelectric power has a special position in the Swedish electricity supply in that it is both dispatchable and very flexible, which means that it can act as a buffer to absorb other variations in production and consumption.

[4] Utilisation of nuclear power capacity has historically varied greatly from year to year. The record production that occurred after the closure of Barsebäck 1 in 1999 can be explained by the improved utilisation of the remaining capacity.

[5] Forsmark 1 has recently increased its capacity by 100 MW. In comparison, Ringhals 1 had a capacity of 881 MW.

Figure 2. Annual production and net exports of electricity

TWh in Sweden, 2000-2020



Source: Statistics Sweden

The most remarkable development in Figure 2 is the increase in weather-dependent electricity production, particularly wind power, since 2006. Dispatchable electricity generation has fallen as a share of total electricity production from 100 per cent in 2000 to 82 per cent in 2020, to be replaced by non-dispatchable electricity production (wind and solar). Sweden has moved from being self-sufficient on an annual basis (with some variation) to becoming a net exporter of electricity. In particular, wind-power production and net exports have covaried since 2013, with Sweden currently exporting the equivalent of its entire wind-power production on an annual basis.[6]

Sweden appears to have a fairly stable electricity supply as all domestic electricity consumption is covered by dispatchable electricity generation. However, this picture needs to be modulated. Most of the high-voltage transmission capacity runs from north to south; see Figure 1. Large imbalances between local production and consumption of electricity sometimes create situations where the transmission grid does not have sufficient capacity to transfer all the demanded electricity. To take account of these *bottlenecks*, Sweden is divided into four bidding zones. When bottlenecks occur, each bidding zone is given its own electricity price to improve the local balance between supply and demand on the power exchange. We will return to an economic analysis of the bidding zones in Section 3.

[6] The increase in wind-power production can mainly be attributed to the special support for renewable electricity production introduced in 2003; see Holmberg and Tangerås (2020) for a description of the electricity certificate system. This support is now almost negligible and is being phased out. Wind power commissioned after 31 December 2021 is not eligible for electricity certificates.

Figure 3. Map of Nordic and Baltic bidding zones, 2022

Source: Svenska kraftnät

Figure 3 shows the geographical division of bidding zones. To reflect domestic bottlenecks, Denmark and Norway are divided into two and five bidding zones respectively. Every other EU country, except for Italy, currently consists of a single bidding zone. These countries therefore have national electricity prices.[7]

Table 1. Electricity production and consumption

TWh by electricity region in 2021

	SE1	SE2	SE3	SE4	Total
Production					
Hydroelectric power	22.1	38.8	11.4	1.3	73.6
Nuclear power	0.0	0.0	51.4	0.0	51.4
Solar and wind power	4.6	10.8	8.5	4.2	28.1
Other thermal power	0.2	1.1	5.4	1.6	8.3
Total	26.9	50.7	76.7	7.1	161.4
Usage (incl. grid losses)	10.7	15.4	85.9	23.9	135.9

Source: Svenska kraftnät

Table 1 shows production in 2021 of the main power types in each bidding zone and also gives the consumption breakdown by bidding zone.[8] The local imbalances between production and consumption are clearly visible. The two northern bidding zones together had a large electricity surplus of 51.5 TWh in 2021. The two southern bidding zones (SE3 and SE4) together had an electricity generation deficit of 26 TWh. There are large regional differences in terms of the production mix. SE1-SE3 has a large share of dispatchable electricity generation. All nuclear power is in SE3. SE4 stands out due to its shortage of production. In addition, more than half of the production in SE4 comes from weather-dependent power sources, while the rest is hydroelectric and thermal power.

2.2 Electricity consumption

Annual electricity consumption has remained fairly constant over the past 35 years, fluctuating between 136 TWh (2020) and 150 TWh (2004). In comparison, Sweden’s real GDP doubled between 1986 and 2020. There are important differences in consumption patterns between the different bidding zones. Table 2 shows electricity consumption in 2020 for different sectors.[9]

[7] Luxembourg is a special case. It has the same price as Germany. Another special case is Northern Ireland, which has the same price as Ireland.

[8] Production data from Svenska kraftnät do not include industrial cogeneration. For example, this generated 6.7 TWh of electricity in 2020 according to Statistics Sweden.

[9] Network losses occur when electricity is transferred over long distances and mean that more energy must always be fed into the grid than can be consumed. These losses represent the difference between the total measured electricity consumption of 135.9 TWh in Table 1 and 125.2 TWh in Table 2.

Table 2. Electricity consumption for different sectors
TWh by bidding zone in 2021

	SE1	SE2	SE3	SE4	Total
Homes (households)	1.7	3.6	25.0	7.6	37.9
Mineral extraction and manufacturing	6.3	6.9	26.3	6.8	46.3
Trade and other	1.1	1.0	9.2	2.4	13.7
Construction and property	0.5	0.9	9.8	2.6	13.8
Agriculture and forestry	0.1	0.3	1.6	1.0	3.0
Supply and transport	0.5	0.9	6.0	1.4	8.8
Public services	0.4	0.8	4.8	1.3	7.4
Total (excl. grid losses)	10.6	14.4	82.7	23.2	130.9

Source: Statistics Sweden

Around 35 per cent of electricity use in Sweden goes to the extraction of minerals or the manufacture of products. Heavy industry is of great importance in all bidding zones but is particularly dominant in northern Sweden. Residential electricity consumption accounts for just under 30 per cent of electricity consumption and is higher in southern Sweden than in northern Sweden, both in absolute terms and as a share of electricity consumption in each electricity region. This also applies to other sectors, such as supply/transport and public services. This is linked to the fact that more people live in the south than in the north.

2.3 Transmission grid

The main purpose of the transmission grid is to transport large amounts of electricity efficiently from production in the north to consumers in the south, and to facilitate the exchange of electricity with neighbouring Nordic countries and continental Europe. The transmission capacity from north to south is 3,300 MW between SE1 and SE2, 7,300 MW between SE2 and SE3 and 5,600 MW between SE3 and SE4.[10] This represents a potential import capacity to SE4 from SE2 of 49 TWh of electricity per year, assuming that the full capacity of the transmission grid is available throughout the year.[11] This is more than double the total electricity consumption of SE4; see Table 2.

The total export capacity from Sweden to neighbouring countries amounts to 10,850 MW. In terms of electricity production, this represents about 95 TWh on an annual basis, compared to the total domestic electricity production of about 160 TWh in 2021; see Table 1. The corresponding figure for import capacity is 10,630 MW, which represents about 93 TWh over the year as a whole. This compares to an annual consumption of about 130 TWh; see Table 2. The Swedish electricity system is thus

[10] The figures given are the maximum capacities that the network owners have offered on Nord Pool since January 2012.

[11] The most important bottleneck that limits trade between northern and southern Sweden is the capacity constraint between SE3 and SE4. The potential import capacity from SE2 to SE4 measured in megawatt hours (MWh) is calculated as 5 600 MW multiplied by the number of hours in a day (24) and the number of days in a year (365). 1 TWh equals 1 million MWh.

well integrated in the sense that export capacity represents 60 per cent of annual electricity production and import capacity 75 per cent of annual electricity consumption.

3 The Swedish electricity market

The economic electricity system consists of two main parts. One is the deregulated electricity market for electricity trade, the other is the regulated market for electricity distribution.[12]

3.1 The deregulated electricity trading market

Sweden is part of the regional Nordic-Baltic electricity market. In addition to Sweden, this market consists of Denmark, Finland and Norway and the Baltic countries of Estonia, Latvia and Lithuania. The electricity market consists of multiple sub-markets.

3.1.1 The day-ahead market

Most of the electricity produced in the Nordic countries is sold on the *Nord Pool Spot* power exchange. Since June 2020, there exists a competing power exchange, *EPEX Spot,* and Nasdaq plans to launch a third exchange.[13] The day-ahead market is a wholesale market in which electricity retailers and electricity-intensive industries buy electricity directly from producers. In 2020, 372 TWh of electricity was sold on this market, which represented 89 per cent of production in the Nord Pool area that year.[14] Due to its size, the day-ahead market is of fundamental importance to the entire electricity market. For example, the prices paid by households for their electricity consumption are set as the day-ahead price plus a mark-up. It also provides the reference price for the financial contracts that market participants use to price their production and consumption.

How are market prices determined?

Every day before noon, producers specify how much electricity they wish to sell at different prices every hour for the next 24 hours. Similarly, electricity retailers and large industrial consumers submit bids for how much electricity they are willing to buy at different prices every hour for the next 24 hours. The network owners announce the capacity of the transmission grid for each hour. A supply curve is then created for each hour of the next day by adding together all the bids received for that hour and a demand curve by summing up all bids for the same hour for all exchanges together. The *system price* for the hour in question is set at the level at which supply equals demand for the entire geographical market.

[12] Deregulation was implemented in 1996 as part of the wave of Nordic electricity market reforms. For those wishing to read more about the background, we refer to Holmberg and Tangerås (2020).

[13] The power exchanges send all bids and offers to the EU joint market-clearing algorithm, so they now have a distinct brokerage role.

[14] Trade and production data from Nord Pool.

Bidding zones

As a result of the regional imbalances between production and consumption, bottlenecks sometimes occur as the transmission grid does not have sufficient capacity to handle all the flows from north to south needed to balance supply and demand in Sweden at the system price. To reflect bottlenecks in the grid, the Nordic-Baltic electricity market is divided into fifteen different bidding zones. Norway has five bidding zones, Sweden has four and Denmark has two. Finland, Estonia, Latvia, and Lithuania each have one bidding zone.[15] Figure 3 illustrates this division.

To manage congestion, an individual zonal price is created for each bidding zone. As the zonal price goes down in bidding zones with surplus electricity production and up in bidding zones with a deficit in electricity production, the supply of electricity decreases in the former bidding zones while the supply increases in the latter bidding zones. The improved balance between supply and demand within each bidding zone reduces the need to trade electricity between the different bidding zones. The zonal prices are adjusted until the flows of electricity match the specified capacity of the transmission grid. The purpose of bidding zones is to increase the efficiency of the electricity supply in the short and long term by having prices signal where in the system there is a shortage or surplus of electricity.[16] In addition, price differentials signal the profitability of investing in new transfer capacity in the electricity grid. One other consequence of the design of the market is that all bidding zones between which there is *no* bottleneck have the same electricity price. Sweden often has a uniform electricity price at night and at weekends when demand in southern Sweden is relatively low. Southern Sweden (SE4) often has the same electricity price as the rest of Northern Europe due to the extensive network capacity to Germany and the Baltic states.

Table 3. Annual average prices
öre/kWh on the day-ahead market 2012-2022

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
SE1	28	34	29	20	28	30	45	40	15	43	63
SE2	28	34	29	20	28	30	45	40	15	43	66
SE3	28	34	29	21	28	30	46	41	22	67	138
SE4	30	35	29	21	28	31	48	42	27	82	162

Source: Nord Pool Group

Table 3 shows the average annual zonal prices in the day-ahead market between 2012 and 2022. The price in northern Sweden has fluctuated between 20 and 66 öre/kWh since the introduction of bidding zones. Electricity prices in northern and southern

[15] Sweden was divided into four bidding zones on 1 November 2011, before which it consisted of a single bidding zone. In order to manage the excess demand in southern Sweden at the uniform Swedish price, Svenska kraftnät regularly limited the export of electricity to Denmark. The EU considered that this practice could violate EU competition rules. Svenska kraftnät subsequently decided to introduce bidding zones in order to achieve a better local balance between electricity supply and demand.

[16] Lundin (2022) shows that bidding zones have increased investment in wind power in southern as compared to northern Sweden.

Sweden were approximately equal until 2020. Since then, zonal prices in SE3 and SE4 have been significantly higher than in the north, and the difference has increased. The average price in SE4 for 2022 was five times higher than the average up to 2020. One major explanation is the energy crisis that has driven up electricity prices in SE3 and SE4 as a result of integration with Europe. The war in Ukraine has not affected prices particularly much in SE1 and SE2 compared to the levels that can be considered normal. The bottlenecks in the electricity system have effectively insulated the northern bidding zones of Sweden from the crisis. The increasing differences in electricity prices have domestic explanations such as increasing local imbalances between electricity supply and demand.

Who benefits from bottlenecks?

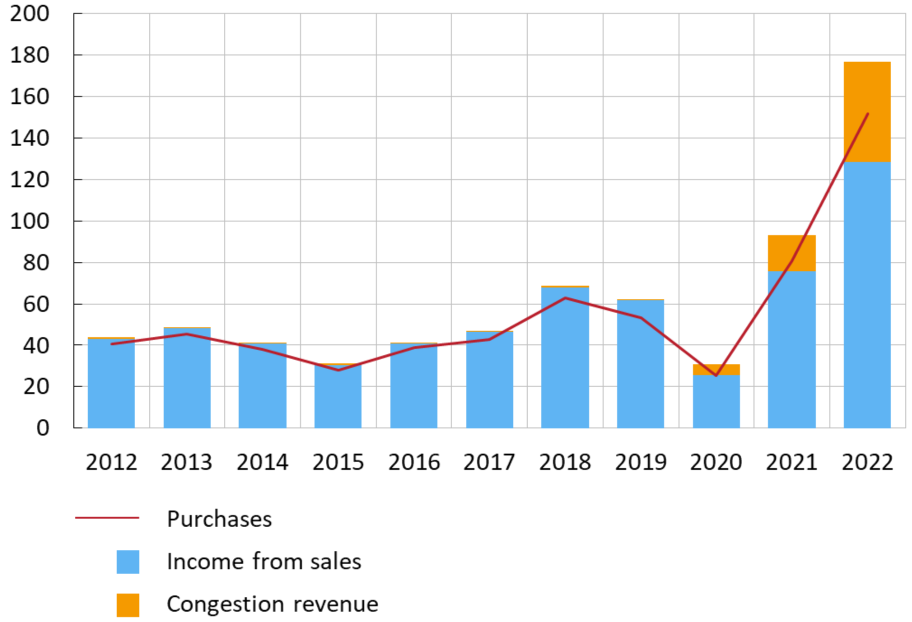
All electricity consumption [production] within a single bidding zone pays [receives] the local zonal price. Those benefiting from the price differences between bidding zones are the owners of the transmission network. The *congestion revenue* between two bidding zones is calculated as the zonal price difference multiplied by the trade between the two zones. Svenska kraftnät thus receives congestion revenue by exporting cheap electricity from producers in the north to consumers in the south.[17] The Nordic electricity market is, in turn, integrated with the continental electricity market. This means, for example, that the price of electricity in SE4 is the same as in Germany, as long as network capacity does not restrict trade flows between the countries. If network capacity to other countries is constrained, then congestion revenues is also generated on the international connection. International congestion revenue is shared between the owners of the congested connections.

The total value of sales by producers in all four bidding zones plus the domestic congestion revenue equals the total cost of purchases by consumers in all four bidding zones plus the value of net exports abroad. Figure 4 shows the different revenue and cost flows in nominal values on the Nord Pool day-ahead market for each year between 2012 and 2022. The blue bars show the annual income generated by domestic producers in Sweden from selling their electricity on the day-ahead market. The yellow bars show the size of the annual domestic congestion revenue. The red line shows how much the purchase of electricity on the day-ahead market has cost consumers for each year. The difference between the sum of the two bars and the line represents the annual net export value from Sweden.

[17] Svenska kraftnät refers to bottleneck incomes as *capacity charges*. In the EU regulatory framework, they are referred to as *congestion revenues*.

Figure 4. Value of trading

SEK bn on the day-ahead market SE1-SE4 by year 2012-2022



Source: Nord Pool Group

Electricity companies' incomes and customers' costs show large annual variations. Until 2020, the domestic congestion revenue was almost negligible. The value of net exports was also of minor importance. Since then, the level and composition of incomes and expenditures in the day-ahead market have changed significantly as a result of the increase in the price of electricity in southern Sweden as we showed in Table 3. The increase in the cost of purchases in the last two years is particularly noteworthy. In 2022, consumers spent six times as much on electricity as in 2020. One contributing factor to the unusually low electricity costs in 2020 was the low electricity consumption in that year. In 2020, total electricity consumption (excluding losses) amounted to 125 TWh. The average for the previous twelve years was about 130 TWh.

Congestion revenue has increased dramatically in recent years. In 2022, Svk earned almost SEK 49 billion from domestic bottlenecks alone. This is a third of what consumers in Sweden paid for their electricity on the power exchange in the same year. Trading on the power exchange over the last two years has meant a significant redistribution from consumers to the state, which owns the transmission network through Svenska kraftnät. In addition, the value of exports has increased significantly in 2021 and 2022 from previously low levels.

Resource scarcity

Sometimes there is insufficient local production and grid capacity to meet local demand in one or more bidding zones. In this case, there is no clearing of the day-ahead market. This happened most recently in the Baltic states on 17 August 2022. If there are no reserves available, electricity is rationed in the sense that customers have to share the capacity available on the market. The price is set at the maximum price on the power exchange, which, at the time of the Baltic case, was EUR 4,000/MWh. Situations of resource scarcity do not necessarily mean that the market is not functioning. Periods of extreme prices are needed for producers to recover their capital costs.

3.1.2 Markets for balancing power

The amount of electricity fed into the grid must always and everywhere be equal to electricity consumption, including the exchange with foreign countries, in order to maintain the balance of the electricity system. Large imbalances can lead to costly disturbances and power cuts. Electricity is traded on the day-ahead market up to 36 hours before the actual operating hour. Consequently, there is often a need to adjust production and consumption as new information reaches the market in the form of updated weather forecasts or unplanned changes in production or the transmission network. The various balancing markets are becoming increasingly important as the need to adjust planned production increases in line with the growth in weather-dependent electricity production.

One important market in which companies can adjust their positions is the *intraday market* of the power exchange. This opens two hours after the day-ahead market closes and closes 60 minutes before the operating hour. The intraday market follows the division into bidding zones and works almost like a stock market in that traders place bids on a continuous basis. Continuous trading means that the price can vary over the trading period, even for electricity contracted for a particular operating hour.

Svenska kraftnät organises a number of markets for balancing power. These differ in terms of the requirements for how quickly capacity can be activated. The largest of these, the *manual frequency restoration reserve (mFRR*) requires that production be activated within fifteen minutes of Svenska kraftnät's request for activation.[18] Bidding for this market closes 45 minutes before dispatch hour and works in a similar way to the day-ahead market.

Even *within* bidding zones, bottlenecks can occur and need to be managed to maintain the balance of the system. This is particularly the case around Stockholm in SE3 and Malmö in SE4. Normally, Svenska kraftnät handles such internal bottlenecks by *redispatch*.[19] This means that Svenska kraftnät pays [charges] electricity companies to increase [decrease] their production where there is local excess [deficit] demand. This results in a deficit for Svenska kraftnät, as the cost of increasing production in one direction exceeds the value of reducing production in the other direction. The

[18] The other three short-term markets for reserves are FCR-Normal (1-3 minutes), FCR-Disturbance (5-30 seconds) and aFRR (2 minutes); see Svenska kraftnät (2021b) for details. There is also a disturbance reserve and a strategic reserve that can be used to balance the electricity system. Holmberg and Tangerås (2020) discuss some of these reserves in detail.

[19] In emergency situations, Svenska kraftnät has the legal right to physically disconnect some production or consumption in order to maintain the balance of the system. However, this extreme measure has never been necessary.

costs of re-regulation are spread across consumers and producers on a flat-rate basis.[20]

3.1.3 Retail market

Retailers compete for end users and buy their electricity on the power exchange to cover their customers' expected consumption. Their margins are limited due to intense competition in the retail market.

Customers can choose between two main types of contracts. Under variable-price contracts, the retail price is a mark-up on the power exchange price. Hourly-price contracts provide full exposure to the hourly day-ahead price for customers with hourly metering of electricity consumption. Variable-price contracts may also involve monthly metering where customers then pay a monthly price based on a flat rate consumption profile. The second variant is a fixed-price contract with a duration between one and three years. In this case, the retailer offers a predetermined price for each kWh used by the customer during the contract period.

Table 4. Electricity contracts by type of contract

Shares in per cent by bidding zone, July 2022

	SE1	SE2	SE3	SE4	Total
Variable price	46.1	47.3	53.9	66.6	55.6
Fixed price	40.3	25.7	25.7	16.4	24.4
Other[21]	13.6	27.0	20.4	17.0	20.0
Total	100	100	100	100	100

Source: Statistics Sweden

Table 4 shows that in July 2022 more than half of all customers in Sweden had variable-price contracts, with the proportion increasing the further south you go in the country. Almost a quarter of all customers have fixed-price contracts. The most common option is to sign a three-year contract. The proportion of customers with fixed-price contracts increases the further north you go in the country. The split between variable and fixed contracts has remained relatively constant in recent years.

3.1.4 The financial markets

Retailers may need to price hedge their planned purchases on the power exchange some time in advance to reduce their exposure to the spot market. This is particularly the case if the retailer has many customers with fixed-price contracts. At the same time, electricity producers may wish to hedge prices in order to guarantee their revenues. Consequently, there is a market for standardised financial contracts, such as those traded on Nasdaq Commodities, which usually have a relatively short

[20] Congestion revenues have typically covered the costs of redispatch for Svk.

[21] Other contracts include what are called designated electricity contracts. These contracts are allocated to customers who do not actively choose an electricity supplier. Such contracts are usually more expensive than the other contracts and can be terminated at short notice should the customer choose a different contract. Around 9 per cent of users in Sweden had such a contract in July 2022.

maturity, three to five years maximum. Producers and large consumers can also enter into bilateral financial contracts directly with each other, which can have a longer time horizon.

Power Purchase Agreements (PPAs) have been particularly important for the development of the electricity market. A PPA is typically signed between the owner of a planned wind power project and a buyer who wishes to secure the price of their electricity consumption by specifically financing renewable electricity production. PPAs guarantee a fixed price for a fixed share of the planned electricity production over a large part of the planned lifetime of the project. These financial contracts are often a prerequisite for obtaining bank loans for wind power projects.

3.2 The economic regulation of electricity networks

The electricity grid is divided into the transmission network, regional networks, and local networks. All network companies are price regulated because the cost of competing infrastructure limits the possibility of achieving effective competition in the electricity grid. The current regulation was introduced in 2012 and is based on a revenue allowance that each network company is allocated for each regulatory period. The allowance determines the maximum network tariffs a network company can charge its customers and is set for four years at a time by the Swedish Energy Markets Inspectorate (Ei). The revenue allowance must cover operating costs and provide a sufficient return on invested capital to obtain access to capital for investments in competition with alternative investments with equivalent risk (Chapter 5, Section 1 of the Electricity Act).

The operating costs of network companies consist firstly of their exogenous costs. Examples include network losses, subscriptions to overhead and neighbouring networks and charges to local authorities. For these costs, network companies receive full cost coverage. In addition, there are operating costs in the form of maintenance, customer specific metering, costs of calculating and reporting network losses and other costs. Network companies are subject to an efficiency requirement concerning such endogenous operating costs. The Ei determines the efficiency requirement individually for each network company in the light of its historical costs compared with the costs of other network companies operating under similar conditions. The operating costs may change from year to year, and therefore the revenue allowance is flexible with respect to these costs over the regulatory period.

The cost of capital is the second major cost item for network companies. If the cost compensation is too generous, then it leads to over-investment, and conversely if it is too strict. The first step is to calculate the company's capital base. This is the net present value of the current network assets, adjusted by investment and depreciation during the regulatory period. The capital base is based on the estimated cost of building the corresponding grid at current prices. The capital base of local and regional networks was estimated at around SEK 460 billion for 2018 (Ei, 2022b). The second step is to calculate a rate of return. For the 2012–2015 regulatory period, Ei set the pre-tax real rate of return at 5.2 per cent. The rate fell to 4.53 per cent in 2016–2019. For the period 2020–2023, Ei applies a rate of return of 2.16 per cent.

A specific characteristic of the transmission grid is that the network owner earns congestion revenue on price differences between bidding zones and from interconnections. These revenues are kept outside the revenue allowance and should, among other purposes, be used to reinforce the transmission grid. The large price differences in recent years have resulted in such large revenues for Svenska kraftnät that it has become necessary to refund congestion revenue to customers.

Table 5. Total revenue allowance

SEK bn for different regulatory periods

	Requested allowance	Ei allowance	Judicial review
2012-15 (2010 price level)	183	160	196
2016-19 (2014 price level)	176	164	173
2020-23 (2018 price level)	-	168	-

Source: Ei (2022c)

The first column of Table 5 shows the total allowance requested by the network companies to pay for their operations in the regional and local grids for the different regulatory periods.[22] The second column summarises the allowances determined by the regulatory authority. Ei has consistently reduced the allowances compared to the network companies' requests. The allowances have increased in real terms, despite the reduction in the cost of capital. In part, this increase is due to new investments in the electricity grid, which have increased the underlying capital base over time.

The network companies have successfully challenged the decided allowances in court, arguing that the awarded rates of return were too low. The courts adjusted the rate to 6.5 per cent for 2012–2015 and 5.85 per cent for 2016–2019. The consequences can be seen in the last column of Table 5. In fact, the network companies received a higher interest rate and therefore larger revenue allowances for 2012-2015 than they had requested. No legal decisions are available for the last regulatory period. With a capital base of SEK 460 billion, 1 per cent higher capital costs would increase the companies' allowances by SEK 18 billion over four years. This would imply an increase in network tariffs for 2020-23 of over 10 per cent.

The real rate of return is affected by the quality and efficiency of network operation. In particular, quality is assessed by the number of transmission interruptions, while the assessment of efficiency depends on the magnitude of network losses and strain on the local electricity grid. Depending on the measured quality and efficiency, the rate of return may increase or decrease by a maximum of one third per year.

The average annual network tariff has increased for all types of household customers since the introduction of the new regulations in 2012 (Ei, 2022c). For the whole period 2012–21, the network tariff for a typical customer in a detached house increased by almost 22 per cent, from 30 to 37 öre/kWh. Smaller customers pay higher tariffs on average than larger customers because the fixed network tariff is disproportionately

[22] As of 2020 the network companies no longer apply for allowances.

high for smaller customers. For example, the network tariff for customers in flats increased from 68 to 80 öre/kWh between 2012 and 2021. In comparison, the CPI increased by just over 8 per cent over the same period.[23] Compared to the average electricity price over the same period in Table 3, the network tariff has represented both the most important share and a rising share of household electricity bills. An exception is households with the highest electricity consumption.[24]

The individual network companies unilaterally determine the structure of their network tariffs. The requirements of the Electricity Act are that the total tariffs charged by the network companies must not exceed the revenue allowance during the regulatory period. Tariffs must be objective and non-discriminatory and, for local networks, they must not be structured according to where in the grid a connection is located. In practice, grid tariffs usually have a fixed component and a variable component that depends on the price and consumption of electricity.

Ei is currently working on updated regulations for the design of network tariffs. Once these are introduced, network companies will not have the same freedom as today to set their tariffs. In particular, dynamic network tariffs would help to increase flexibility in demand to reduce the risk of local electricity shortages; see Holmberg and Tangerås (2022).

4 Short-term challenges in the electricity market

The electricity market in Sweden is facing multiple short-term challenges. One particularly acute challenge is the ongoing electricity crisis, which has led to unmanageably high electricity prices for some consumers and increased the risk of electricity shortages. The energy crisis actually consists of three independent crises that have hit the EU at the same time. Russia's invasion of Ukraine has choked off exports of electricity, gas and coal from Russia, making fossil-based electricity generation in the EU more expensive. Europe's nuclear reactors have reduced output by 19 per cent (E3G and Ember, 2022). Some nuclear power has been phased out, but a bigger problem has been the technical problems that have affected French nuclear reactors in particular over the past year. The third crisis is that hydroelectric power production in the EU has fallen by 21 per cent due to droughts in southern Norway and elsewhere (E3G and Ember, 2022).

Sweden has also experienced nuclear power shutdowns and technical problems at its remaining plants. Despite this, Sweden export a lot of electricity. In 2022 Sweden was Europe's largest net exporter of electricity. Usually, the risk of electricity shortages is low in the country as a whole and, usually, we can import electricity from our neighbours when we need it. During the energy crisis the risk of electricity shortages has been heightened, at least for the hours that Sweden is import-dependent.

---

[23] Network tariffs increased significantly more in Sweden than in neighbouring countries over the period (Lundin and Söderberg, 2022).

[24] Note that the high-cost protection scheme for households introduced in winter 2022 was calculated as a deduction from the grid tariff.

In addition, throughout the 2020s, there will be a risk of electricity shortages in Sweden's major cities, mainly Stockholm and Uppsala. This problem is independent of the energy crisis and is mostly due to a lack of transmission capacity into the cities and a lack of generation capacity within the cities. Electricity shortages in large cities are not further addressed in this paper, as they are analysed in detail by Holmberg and Tangerås (2022).

A further challenge is the deteriorating reliability of the electricity supply, particularly in southern Sweden. One problem is the shutdown of dispatchable production in southern Sweden. Norway's exports of electricity to the United Kingdom and Germany have created additional problems due to the increasing power flows in an east-west direction through Sweden. Figure 1 suggests that the power system is not dimensioned for such flows and has therefore become more sensitive to disturbances. As a result, the safety margins in the grid have had to be increased.

To address these challenges, politicians and authorities have decided on a series of measures, and further measures are under discussion. These include reducing electricity consumption, increasing electricity production, making the electricity market more efficient and redistributing resources from those who have benefited from the crisis to those who have been harmed by it.

4.1 Reduced electricity consumption

4.1.1 Energy efficiency

Electricity consumption in Sweden has remained fairly constant, and even declined slightly, over the past 35 years, despite annual GDP growth. The efficiency of electricity consumption has increased about 2-3 per cent per year (WSP, 2020). According to some analysts, increased focus on energy conservation, climate change and the environment could increase the efficiency of electricity consumption to 3-4 percent per year in the future (NEPP, 2015; WSP, 2020). The government is contributing with various measures to accelerate the process. For households, subsidies of up to 50 per cent are available for insulation and installation of heat pumps in residential facilities. Companies and tenant-owned apartments can receive support for up to 30 per cent of the cost of various energy efficiency measures.

One advantage of increasing energy efficiency is that it is a measure that has a rapid effect compared to the expansion of electricity production. Reduced electricity demand also contributes to lower electricity prices. Consequently, temporary subsidies to stimulate energy efficiency during energy crises may be justifiable. In the long run, however, such subsidies are ineffective as they distort the market.

4.1.2 Saving electricity

Energy efficiency leads to a lasting reduction in electricity consumption. One temporary measure to restrain electricity prices during the current electricity crisis would be to reduce electricity consumption temporarily. Demand for electricity is very insensitive to short-term price changes and the supply price increases rapidly at very high production levels (Holmberg and Tangerås, 2022). Overall, this means that the price of electricity risks becoming very high during hours of electricity shortage when demand is close to the available production capacity. At these times, a small shift in demand can have a large effect on the price. Wråke et al. (2022) estimate that electricity prices in southern Sweden would decrease by 85 öre/kWh if the whole of Europe reduced electricity consumption by 5 per cent. If only southern Sweden were to save 5 per cent, the price there would fall by 40 öre/kWh. In the EU, it has been agreed that each country should reduce electricity consumption by 5 per cent during hours of particularly high electricity consumption. The ambition is for each country to save 10 per cent of its electricity consumption, but this is a voluntary commitment. Two examples of industrialised countries that have been forced to make rapid electricity savings in the 2000s are New Zealand and Japan, where electricity consumption was reduced by 10 and 18 per cent respectively over a short period of time (Pollitt, 2022).

High electricity prices in themselves contribute to a reduction in electricity consumption, but the government can also take measures to further increase electricity savings. First, the government can decide to reduce electricity consumption in the public sector, for example through injunctions of various types. The government can also pay compensation for electricity savings, for example a fixed amount for each kWh saved by a consumer compared to the previous year. Over the period from 1 December 2022 to 31 March 2023, Svenska kraftnät will pay compensation to companies that reduce their consumption during hours of high consumption. The aim is for the measure to reduce consumption during these hours by 5 per cent.

For users with fixed-price contracts, there may be a socio-economic justification for subsidising saving electricity, as these users have no financial incentive to reduce electricity consumption even if the variable price is high. For other groups, such a subsidy leads to under-consumption of electricity, which is inefficient. On the other hand, lower electricity prices and increased consumer surpluses help other consumers that are badly affected by the energy crisis, so it may be justifiable to subsidise electricity saving temporarily for all consumers for compensatory purposes.

4.2 Increased supply of thermal power

There is about 1,000 MW of thermal power mothballed in Sweden, which is roughly equivalent to one nuclear power reactor. Potentially, this capacity could be producing even in the short term if preconditions could be improved. Svenska kraftnät (2022b) forecasted that this could reduce the price of electricity in southern Sweden by 10 per cent during the winter of 22/23. Thermal power could also help to improve the reliability of the electricity supply in southern Sweden, which could, in turn, increase the transmission of electricity from northern to southern Sweden.

Temporary exemptions from environmental legislation may be required to make such capacity available to the market. In addition, owners may need compensation to make it viable to bring these units into operation. The new EU revenue cap (see section 4.4.1 below) may make it harder to bring this production to market, but the

Government has some scope to raise the revenue cap for thermal power. Another problem is that the regulatory framework makes it difficult to target a specific type of production with specific subsidies. However, it should be possible to take temporary measures that generally improve the preconditions for electricity generation, such as reduced taxes, reduced grid tariffs and increased procurement of back-up power.

4.3 Improving the electricity market

4.3.1 A more appropriate partition into bidding zones

Together with authorities and system operators, the EU has carried out an evaluation of the partition into bidding zones in member states based on simulations of the bottlenecks in the electricity system (ACER, 2022). In Sweden, four different alternatives will be evaluated in greater depth. All of these proposals include a new bidding zone in eastern Svealand with the aim of managing the east-west flows and bottlenecks in the Stockholm region in a better and more efficient way. The new bidding zones could be implemented in 2025. The consequences would likely include price increases in and around Stockholm due to excess demand in the region. In 2024, Svenska kraftnät plans to introduce more efficient management of the bottlenecks on the power exchange for existing bidding zones, which is known as flow-based pricing.

4.3.2 Increased oversight of the electricity market

The price-insensitive demand for electricity and the concentrated ownership of production capacity (Moghimi et al., 2022) enable generation owners to increase prices by withholding capacity from the electricity market. Lundin and Tangerås (2020) estimate that the use of market power has increased prices by an average of 4 percent; see also Tangerås and Mauritzen (2018). The profitability of exploiting market power may increase in an energy crisis like the one we are currently facing, as companies can generate very high prices by withholding only a little capacity. Consequently, relevant authorities should tighten oversight of the electricity market. Lundin (2021) argues that the joint ownership of nuclear power by electricity companies has contributed to the exercise of market power. It may also have contributed to the premature closure of nuclear power and should be broken up if possible.

4.3.3 Maintaining liquidity in financial trading

Effective hedging is particularly important as risks are elevated because of the energy crisis. High liquidity in financial trading implies that market participants can use hedging at low transaction costs at reasonably stable prices.

One aspect that has become increasingly important during the crisis is the collateral that Nasdaq Commodities and other trading platforms require from parties entering into financial contracts. The amount of collateral increases as the difference between the contract price and the electricity price increases. As a producer may have the value of several years' production or consumption pooled in forward contracts on the power exchange, the sums involved can be very high. For large electricity producers, meeting commitments to sell electricity at a predetermined price is normally not a problem. However, they may still face liquidity problems if financial collateral requirements increase too much. To avoid liquidity shortages in financial trading, the Government has decided to introduce credit guarantees for electricity producers of up to 80 per cent of the loan. The guarantee framework amounts to SEK 250 billion. Guarantees can be granted until 31 March 2023, and the total maturity must not exceed three years. The fee for the guarantee must be market-based and is set individually for each company.

Financial trading on Nasdaq mainly involves contracts settled against the system price of the day-ahead market; see section 3.1.1. However, in recent years and especially during the energy crisis, price differences within the Nordic region have grown; see, for example, Table 3. It is also possible to trade in contracts that hedge prices at bidding zone level, but this trade has significantly lower liquidity. One reason is that the bidding zones in Sweden are asymmetric in the sense that it may be difficult for a consumer in southern Sweden or a producer in northern Sweden to find a financial counterparty in their bidding zone. The problem of finding a counterparty would be reduced if Svenska kraftnät were to hedge its congestion revenue, for example by buying electricity in northern Sweden and selling it in southern Sweden on the financial market. Holmberg and Tangerås (2022) and Holtz et al. (2022) describe in more detail how Svenska kraftnät can trade in financial contracts.

4.4 Redistribution

4.4.1 Revenue cap for electricity production with low variable cost

During the crisis, electricity prices in Europe have risen as fuel prices have pushed up the variable cost of fossil-fuel based electricity production. The variable cost of fossil-free electricity production has not increased correspondingly, and these types of power have made large profits. The EU decided in 2022 to tax such windfall gains through a revenue cap of EUR 180/MWh (≈ SEK 1.8/kWh) for low variable cost electricity generation (EU regulation 2022/1854). For Sweden, this applies to nuclear, wind, solar and non-reservoir based hydroelectric power. The revenue cap will be temporary and applied between December 2022 and June 2023. The idea is for the revenue to be used to compensate electricity consumers.

The EU revenue cap is problematic because it reduces the incentive to invest in low variable cost production if operators expect similar regulation to be reintroduced in the future. The energy transition will slow down, electrification will be made more difficult, and the risk of electricity shortages will increase. The revenue cap also creates problems in the short term. Like the capacity tax on nuclear power, it risks contributing to the premature closure of nuclear reactors. In addition, it makes capacity expansion of existing generation units less profitable and prevents thermal power plants from being restarted (see section 4.2). The revenue cap also puts a strain on existing forward contracts.

There are proposals from various EU countries to change pricing on the power exchange so that redistribution from producers to consumers takes place in the market. This type of proposal has also been discussed in Sweden. The so-called BEKEN model, advocated in particular by the Left Party, has similar drawbacks to the punitive taxation of low variable cost power. It is not enough to change pricing on the power exchange to implement BEKEN, additional price regulation must be introduced to make it possible to maintain artificial price differentials on the power exchange. In addition, pricing of contracts written outside the power exchange would need to be regulated to avoid arbitrage.

To some extent, capacity markets can compensate producers for lost revenue. This means that producers receive an additional capacity payment, for all the production made available to the market. Capacity markets are used abroad and also have supporters in Sweden. However, the disadvantages of such a solution outweigh the advantages (Aagaard and Kleit, 2022; Holmberg and Tangerås, 2023).

4.4.2 Compensation to consumers

The electricity crisis has contributed to an increase in government revenues. In particular, the large domestic price differences have created huge congestion revenues in recent years; see Figure 4. These should primarily go to investments in the electricity grid, but (during the crisis) it is also within the EU regulatory framework to use these revenues to compensate electricity consumers. Svenska kraftnät has planned the distribution of approximately SEK 55 billion in retroactive support to households and businesses in SE3 and SE4. In bidding zone SE3, the support was 50 öre and in bidding zone SE4 79 öre per kWh of electricity consumed between October 2021 and September 2022. Ei has set a cap on this support which means that consumers who have used more than 3 GWh during this time period must make a separate application for consumption above that level.[25]

One advantage of retroactive support is that it does not interfere with price signals, as long as it does not create expectations of future support. The VAT reductions and the high-cost protection discussed during the election campaign would increase electricity consumption and prices on the power exchange. Compensation is also a better approach than changing pricing or punitive taxation of certain production as discussed in the last section.

4.5 Electricity prices in the short term

EU member states have agreed to reduce electricity consumption by 5-10 per cent. Svenska kraftnät plans to increase transmission capacity from northern to southern Sweden by 300-700 MW and to increase import capacity from Finland by 200-300 MW during the winter of 22/23.[26] Taken together, these measures should have a major impact on prices. Based on the results in Wråke et al. (2022), a reasonable expectation is that the spot price will decrease by a krona or more in southern Sweden compared to a situation where no measures are taken. However, increased transmission of electricity from the north to the south will increase the spot price in the north. The start-up of Finland's new nuclear reactor, Olkiluoto 3, will reduce

[25] The details are described in the press release in Ei (2022a).

[26] The measures are described in Svenska kraftnät (2022a).

import demand in Finland. Ringhals 4 is scheduled to restart during the spring of 2023. If all these measures go according to plan and Russia's war with Ukraine and Russia's sanctions against the EU do not escalate further, the worst of the price spikes should be over by March 2023, at least in Sweden. Forward prices on the financial markets confirm this prognosis. On the other hand, forward prices also show that things could get really tough before then. Electricity prices risk reaching record highs the winter of 22/23.[27]

The Swedish Energy Agency (2022) and the Swedish Wind Energy Association (2022) estimate that electricity production in Sweden will increase by about 5 TWh per year between 2020 and 2025, mainly through new wind power. This is equivalent to about half a new nuclear reactor per year. The Swedish Wind Energy Association's forecast indicates that about one third of this production will be located in southern Sweden. Sweco (2022) estimates that an addition of 15 TWh of wind power in 2023-2025 would reduce the average price in Sweden by about 15 öre/kWh. The Swedish Energy Agency forecasts that annual electricity consumption will remain fairly constant until 2025 and that Sweden's net electricity exports will be 41 TWh in 2024. Such an electricity surplus would help to reduce the impact of Europe's electricity prices on Sweden.

At the same time, there is a risk that the situation in the electricity market will worsen. A cold, prolonged winter would lead to extreme prices and possibly manual disconnection of consumers. Gas and water storage facilities would be drained, with consequences for electricity prices throughout 2023. There is also a risk that Russia could choke off energy exports to the EU somewhat further. In addition, Russia could target Europe's nuclear power industry, especially the 18 nuclear power stations in Eastern Europe and Finland that are partly dependent on Russian nuclear fuel and maintenance (Bowen and Dabbar, 2022). Furthermore, Russia has a market share of over 40 per cent in uranium processing. However, this should not lead to an acute energy crisis, as nuclear reactors in the EU normally have fuel stocks for production for a couple of years. However, the price of refined uranium from non-Russian suppliers rose sharply in 2022 (Combs, 2022). In the long run, there is a risk that this will reduce nuclear production or increase electricity prices.

5 Transition towards a sustainable electricity supply

Society is facing a major green transformation of the energy system. This will include the replacement of fossil-based energy with fossil-free electricity, so electricity consumption is expected to increase. Bergman et al. (2022) compile various forecasts of electricity consumption until 2050. According to the most conservative scenarios, electricity consumption will be 150 TWh in 2050, which is less than the current electricity production in Sweden. The most extreme scenarios indicate an electricity consumption of almost 300 TWh, which is more than double of the current annual electicity consumption. Energiforsk and Profu (2021) estimate that about three-

[27] The measures are described in Svenska kraftnät (2022a).

quarters of the increase in electricity consumption will take place in Norrland (SE1 and SE2).

One major reason for the growing demand for electricity is the need for hydrogen in the manufacturing and transport sectors. Green hydrogen is produced by electrolysis of water, which consumes a lot of electricity. Hydrogen is essential for the production of fossil-free steel, for example. LKAB estimates that it will need an additional 55 TWh per year for its future production (Svenska kraftnät, 2021a). This represents about 40 per cent of Sweden’s current electricity consumption. Electrification of transport, industrial processes and electricity consumption in new industries such as server halls and battery factories can be added.

5.1 Efficient investments in electricity production

Sweden is facing a major expansion of electricity production so that the planned energy transition can be realised. The question is how to do this efficiently. In an economically efficient electricity market, electricity is produced at the lowest possible total production and investment cost. In addition, an efficient market should have the right amount of production capacity to achieve the desired reliability of supply.

Demand for electricity fluctuates over both the day and the year. The degree of utilisation will thus vary for different facilities. In general, it is efficient to invest in a mix of technologies, with the choice of technology for specific facilities depending on how often they will be used. Typically, technologies with a low variable cost have a high investment cost, and vice versa. As the degree of utilisation decreases, it becomes more important that the facility does not cost money when it is not in use. This would make it more economically profitable for society to use technologies with higher variable costs and lower fixed costs. Gas turbines are a typical example of such *peak power*. It would not be economically profitable to expand electricity production to such an extent that the risk of electricity shortages would be completely eliminated. In an efficient electricity system, the risk of curtailment is therefore positive.

In order for investment to be efficient, it is also important to streamline permitting processes and to design adequate compensation for municipalities and landowners affected by the expansion of electricity generation and power grids.

5.2 Credit guarantees for green investment

The previous government mandated the Swedish National Debt Office to issue credit guarantees (Regulation 2021:524) on the grounds that it is difficult to obtain long-term loans for green investments in Sweden. The guarantee framework amounted to SEK 10 billion in 2021. After this, the framework is calculated at SEK 50 billion in 2022, SEK 65 billion in 2023 and SEK 80 billion in 2024.[28]

The European Parliament has decided to include nuclear power in the EU taxonomy for a limited period and under certain conditions. This could possibly mean that the

[28] The credit guarantees are described in more detail in Riksgälden (2021).

Swedish National Debt Office will conclude that credit guarantees for green investments can also be used for nuclear power investments. Under the Tidö Agreement, the new government wants to allocate an additional SEK 400 billion to credit guarantees earmarked for new dispatchable electricity, especially nuclear power. The idea is that the Swedish National Debt Office will issue these guarantees at a subsidised price.

In practice, it has been difficult to obtain bank loans for nuclear reactors. This could be a market failure justifying public provision of credit guarantees specifically for nuclear power. But subsidised credit guarantees are problematic if they distort investment towards specific power generation. It would be unfortunate if credit guarantees were to out compete well-functioning financial markets. Consequently, there is reason to question politically motivated credit guarantees, from a market perspective.

5.3 Reduced political risk

The variable energy policy is creating significant political risk for producers and consumers. For example, there are concerns that politicians will take measures that disadvantage certain types of electricity generation. The EU revenue cap for low variable cost production is one example, the capacity tax on nuclear power another. Political risk makes investment more expensive and slows down the energy transition. Some of the policy interventions made during the current energy crisis have been justified. But to make the rules of the electricity market more predictable, the conditions under which the state can intervene and the measures that can be taken should be regulated.

The Energy Charter Treaty provides foreign investors some protection against political risk (Horn, 2021). For example, Vattenfall received compensation when it was forced to prematurely shut down its nuclear reactors in Germany. One way to reduce political risk would be to introduce similar protection for Swedish investors as well (Holmberg and Tangerås, 2020). During the election campaign, the Moderate Party advocated investment protection for nuclear power against political risk. Such protection would be appropriate, but should also cover other electricity production. Statutory investment protection would also make it easier to maintain cross-party agreements on energy policy.

Volatile electricity prices increase political pressure to intervene during energy crises. Consumers with variable-price contracts have a particularly strong incentive to push for high-cost protection. From such a perspective, it would be better if fewer customers had variable-price contracts.[29] However, fixed-price contracts have the disadvantage that they do not provide an economic incentive to reduce consumption when there is a risk of electricity shortages. Mixed contracts represent a good compromise between variable and fixed price, as they offer consumers the opportunity to hedge part of their planned electricity consumption (Holmberg and Tangerås, 2022). One way to achieve higher liquidity and more stable prices in the

[29] After the energy crisis in 2021, Texas simply decided to ban variable-price electricity contracts.

forward market would be for Svenska kraftnät to hedge its congestion revenue; see section 4.3.3. Organised trade of long-term forward contracts would also be beneficial for liquidity in the financial market (Holmberg and Tangerås, 2020).

5.4 Costs of new electricity production

In terms of new electricity generation, it is mainly fossil-free that is of interest. Cost estimates below are based on the levelised cost of energy (LCOE). LCOE includes operation, maintenance and investment costs allocated to the estimated capacity utilisation. Onshore wind power has the lowest LCOE, about 30-35 öre/kWh according to Elmqvist (2021). Offshore wind power is significantly more expensive, with an estimated LCOE in Europe of SEK 1-1.6/kWh including grid cost of 40-60 per cent (IEA, 2019). The cost of offshore wind is expected to fall by about half by 2040 (IEA, 2019). Elmqvist (2021) is significantly more optimistic and estimates the cost of offshore wind in Sweden to 50-55 öre/kWh.

The cost of large-scale solar power in Sweden is around 40 öre/kWh (Elmqvist, 2021). The costs of wind and solar power have fallen sharply since 2009, by 70 and 90 per cent respectively (Lazard, 2020). These costs are likely to continue to fall, but not as rapidly. Solar power may become the most important generation technology in the world by 2050 according to some analysts, but such electricity production is not as efficient in Sweden.

The cost of new nuclear power is difficult to estimate. The reactors built in Western Europe and the United States in the 2000s have been subject to long delays with substantial cost overruns. Based on actual projects, Lazard (2020) estimates the LCOE of new nuclear power at SEK 1.6/kWh. The International Energy Agency (IEA, 2022) makes a similar estimate for the EU, but is more optimistic for the United States, where the cost is estimated at about SEK 1/kWh.[30] IEA (2022) estimates the cost of new nuclear power in Asia at 60-75 öre/kWh. One reason for the lower costs is the cheaper labour in Asia.

Elmqvist (2021) is more optimistic, estimating the cost of new Swedish nuclear power at 49-64 öre/kWh. Poland has recently contracted three new nuclear reactors that could fall within this range, provided they are completed on schedule and on budget. However, labour and construction costs are significantly lower in Poland than in Sweden. The unit price will also be lower if several units are contracted at the same time.

Many hope that costs can be substantially reduced for small modular reactors (SMRs), which have the potential to be mass-produced. IEA (2022) further argues that it is profitable to make investments to extend the lifetime of existing nuclear reactors. Such investments have an overall cost of around 40 öre/kWh.

Fossil-free thermal power, which burns biofuels or fossil fuels with carbon capture, has an estimated cost of about SEK 1/kWh (IEA, 2022). The reason why biofuels are

[30] This is very much in line with the U.S. Energy Information Administration (2022), which estimates the cost at approximately SEK 0.9/kWh in the United States.

relatively expensive is the IEA's assessment that there will be a shortage of biofuels in Europe. Thermal power using biofuels (including green hydrogen) would then be appropriate as peak power.

A significant share of Sweden's electricity production comes from thermal power plants that produce both electricity and heat. If heat is reused in the new nuclear reactors being built, they would be more efficient and profitable. This would be easier to implement for SMRs, which are safer than large-scale nuclear power and can therefore be located closer to consumers. Heat requirements may increase in the manufacturing sector, for example in hydrogen production. On the other hand, heat management is expected to become much more efficient, so it is likely that heat production may decrease.

5.5 Energy storage

The need to store energy will increase as weather-dependent renewable generation is expanded. Energy storage helps to keep the electricity system in balance and to make more efficient use of generation and the grid. Sweden's largest energy store is hydropower. However, environmental constraints make it difficult to increase hydropower in Sweden on a large scale. Nevertheless, some possibilities exist for restructuring hydropower. One interesting alternative is pumped storage, in which water is pumped into an upper reservoir when prices are low and released into a lower reservoir when prices are high. Such plants can achieve energy recovery of 75-80 per cent. Another large storage resource is provided by batteries in electric cars.

Intertemporal substitution of consumption can also be seen as a kind of energy storage. For example, energy consumption in freezers, refrigerators, electric heaters, heat pumps and water heaters could be changed without this needing to have a significant impact on the efficiency of these devices. Hydrogen storage fulfils a similar function by contributing to demand flexibility. Hybrit in Luleå is planning a storage facility for up to two weeks' production of hydrogen. Converting hydrogen into electricity is normally inefficient but may be relevant for power plants that run infrequently.

5.6 Extension of the transmission grid

The two major challenges for Svenska kraftnät are the expansion of the transmission grid and the renewal of parts of the network built in the 1950s and 1960s. The pace of investment has therefore been stepped up considerably. The plan is to increase grid investment fivefold in six years, from just over SEK 2 billion in 2018 to over SEK 10 billion in 2024 (Government Offices of Sweden, 2022). Svenska kraftnät will subsequently maintain a high investment rate for just over 15 years, until 2040.

Smart solutions could increase transmission in the grid even before investments are made. Svenska kraftnät estimates that such measures could increase transmission from northern to southern Sweden by about 800 MW before 2028, which corresponds to a capacity increase of 10 per cent. [31]

It is not economically viable to remove all bottlenecks in the grid and each new production plant must pay for the necessary grid reinforcements associated with the plant. The earlier exemption for offshore wind power is to be abolished under the Tidö Agreement, which will make off shore wind power significantly more costly

5.7 Electricity prices in the long term

Three things will most likely shape the electricity system in the future: 1) continued growth in wind and solar power, 2) increased amount of peak power, 3) increased energy storage capacity and increased flexibility in electricity consumption. Three types of price level can be envisaged in the market: A price close to zero when wind and solar power are producing at full capacity and there is a large surplus of cheap electricity production; a very high price when weather dependent electricity production is at a standstill and energy storage is insufficient; and an intermediate situation where nuclear, hydropower, hydrogen and other energy storage determine the price.

The above scenario is not dissimilar to pricing in today’s market, but more extreme prices in both directions will become more common. We are already seeing signs of increased volatility in electricity prices.

Technological developments are helping to reduce the costs of electricity generation. At the same time, the transition to fossil-free energy is making thermal power more expensive. In addition, consumers will contribute to paying for all the necessary and extensive grid reinforcements. The future price of electricity will also depend on the price sensitivity of demand. Hydrogen can be imported or produced by means other than electrolysis. In addition, fossil-free steel will compete in a global market. Low electricity prices will therefore be required for green hydrogen to become viable. This means it may be the acceptance of further expansion of onshore wind power that determines how much electricity consumption and production of green hydrogen can increase on a market basis.

6 Discussion and conclusions

Prices on the power exchange have exploded in recent years and bottlenecks in the transmission grid have created large differences between southern and northern Sweden in the cost of electricity. This situation has resulted in a substantial income transfer from consumers to the state in 2021 and 2022 through the congestion revenue that Svenska kraftnät earns from buying cheap power in the north and selling it at a high price in the south. At the same time, network tariffs paid by consumers to maintain and increase the capacity of the electricity grid are rising. These

[31] The measures are described in Svenska kraftnät (2022a).

developments highlight the need to treat congestion revenue as an integral part of the price regulation of transmission network owners.

Electricity prices reflect the energy crisis that has primarily affected continental Europe but that has also raised prices, mainly in southern Sweden, through electricity exports to neighbouring countries. Domestic factors, such as the shutdown of dispatchable electricity generation in southern Sweden, have exacerbated the situation. A battery of short-term measures is needed to solve the current energy crisis. Electricity consumption needs to be reduced, especially in situations where there is a risk of electricity shortages. Dispatchable electricity production needs to be increased, for example by reactivating electricity production that has been mothballed. In addition, better use can be made of the electricity grid and some redistribution from winners to losers will be necessary to compensate for high electricity costs. Low-income households are particularly at risk from high electricity prices, for example if they cannot afford to heat their homes.

Some forecasts predict a doubling of electricity consumption by 2050, based, in particular, on a dramatic increase in industrial hydrogen production through electrolysis. However, this consumption is price-sensitive and dependent on cheap electricity. How much consumption increases will probably depend on the scale of the expansion of onshore wind power. Whether offshore wind and new nuclear power will become economically viable depends on technological developments and how much the costs of these technologies can be pushed down. For example, nuclear power becomes more attractive if the heat it generates is also harnessed.

Either way, we can expect a major expansion of both networks and production. How much of the cost is passed on to consumers depends on the resource efficiency of the energy transition. An efficient transition will require long-term and technology-neutral regulations and efficient permit processes. In addition, the political risks need to be reduced and the financial markets developed.

References

Aagaard, Todd and Andrew Kleit (2022), *Electricity Capacity Markets*, Cambridge University Press.

ACER (2022), Decision No 11/2022 of the European Union Agency for the Cooperation of Energy Regulators of 8 August 2022 on the alternative bidding zone configurations to be considered in the bidding zone review process. Link.

Bergman, Lars, Niclas Damsgaard, Nils Henrik M. von der Fehr, Pär Holmberg, Lars Joelsson, Per Lundström, Anders Moritz, Mats Nilsson, Rickard Nilsson, Andreas Regnell, Jan Rönnback, Jan Strömbergsson, Magnus Thorstensson and Stefan Montin (2022), 'Långsiktiga investeringar och handel på framtidens elmarknad', Report 2022:859, Energiforsk April 2022.

Bowen, Matt and Paul Dabbar (2022), 'Reducing Russian involvement in western nuclear power markets', Center on Global Energy Policy at Columbia University SIPA.

Combs, Jeff (2022), 'Impact of Russia's invasion of Ukraine on Nuclear Energy', IAEE Energy Forum, Fourth quarter 2022, p. 11–14.

E3G and Ember (2022), 'More renewables, less inflation: Restoring EU economic stability through investment in renewables', Briefing Paper, October 2022.

Ei (2022a), 'Ei godkänner Svenska kraftnäts ansökan gällande elstöd med ett tillägg om hur mycket man kan få utan att visa kostnader', press release 17 November. Link.

Ei (2022b), 'Reglering av el- och gasnätsverksamhet - Utveckling sedan införandet av förhandsregleringen', Energimarknadsinspektionen R2022:01.

Ei (2022c), 'Sweden's electricity and natural gas market, 2021', The Swedish Energy Markets Inspectorate (Ei) R2022:07.

Elmqvist, Åsa (2021), 'El från nya anläggningar', Rapport 2021:714, Energiforsk December 2021.

Energiforsk and Profu (2021), 'Efterfrågan på fossilfri el - Analys av högnivåscenario', Study commissioned by Swedenergy.

Government Offices of Sweden (2022), 'Nationell strategi för elektrifiering – en trygg, konkurrenskraftig och hållbar elförsörjning för en historisk klimatomställning', Ministry of Infrastructure, I2022/00299.

Holmberg, Pär and Thomas Tangerås (2020), 'Incitamenten att investera i produktion på elmarknaden', *IFN Policy Paper 92*.

Holmberg, Pär and Thomas Tangerås (2022), 'Electricity Shortages in Major Swedish Cities – A Market Perspective'. Research report SNS.

Holmberg, Pär and Thomas Tangerås (2023), 'A survey of capacity mechanisms: lessons for the Swedish electricity market', *The Energy Journal* 44(6).

Holtz, Christian, Saara Hollmén, Petr Spodniak and Dmitri Perekhodtsev (2022), 'Measures to improve risk hedging opportunities on the electricity market in Sweden', Report prepared by Merlin & Metris AB and Compass Lexicon on behalf of Ei.

Horn, Henrik (2021), 'Energistadgefördragets nytta för EU – ekonomiska konsekvenser mot bakgrund av EU:s ambitioner i klimatpolitiken', Stockholm: Swedish Institute for European Policy Studies (SIEPS).

IEA (2019), 'Offshore Wind Outlook 2019', World Energy Outlook Special Report.

IEA (2022), Nuclear Power and Secure Energy Transitions: From today's challenges to tomorrow's clean energy systems.

Lazard (2020), Lazard's levelized cost of energy analysis – version 14.0.

Lundin, Erik (2021), 'Market power and joint ownership: Evidence from nuclear plants in Sweden', *Journal of Industrial Economics* 69(3), 485-536.

Lundin, Erik (2022), 'Geographic price granularity and investments in wind power: Evidence from a Swedish electricity market splitting reform', *Energy Economics*, forthcoming.

Lundin, Erik and Magnus Söderberg (2022), 'Analyzing Prices and Regulations in the Swedish Electricity Network Market: What Can We Learn from Our Neighboring countries?', Research report SNS.

Lundin, Erik and Thomas Tangerås (2020), 'Cournot competition in wholesale electricity markets: The Nordic power exchange, Nord Pool', *International Journal of Industrial Organization* 68, 1-20.

Moghimi, Farzad H., Hanna Ek Fälth, Lina Reichenberg and Afzal S. Siddiqui (2022), 'Climate policy and strategic operations in a hydro-thermal power system', manuscript, Stockholm University.

NEPP (2015), 'Elanvändningen i Sverige 2030 och 2050', Report commissioned by Royal Swedish Academy of Engineering Sciences, Electricity Crossroads.

Pollitt, Michael (2022), 'The Energy Market in Time of War', Center on Regulation in Europe (CERRE).

Riksgälden (2021), 'Credit guarantees for green investments'. Link.

Svenska kraftnät (2021a), 'Långsiktig marknadsanalys 2021: Scenarier för elsystemets utveckling fram till 2050'.

Svenska kraftnät (2021b), 'Stödtjänster och avhjälpande åtgärder i ett energisystem under förändring', Svk 2020/4162. Link.

Svenska kraftnät (2022a), 'Så arbetar vi för att öka överföringskapaciteten'. Link.

Svenska kraftnät (2022b), 'Uppdrag att förbereda ytterligare upphandling av förbrukningsflexibilitet och planerbar elproduktion i södra Sverige'.

Svenska kraftnät (2023), 'Anslut till transmissionsnätet'. Link.

Sweco (2022), 'Vindkraftens elpriseffekt', November.

Swedish Energy Agency (2022), 'Kontrollstation för elcertifikatsystemet 2023: Marknadens funktion och administrativa kostnader', ER 2022:09, Statens energimyndighet, June 2022.

Swedish Wind Energy Association (2022), Statistics and forecast – Q3 2022.

Tangerås, Thomas and Johannes Mauritzen (2018), 'Real-time versus day-ahead market power in a hydro-based electricity market', *Journal of Industrial Economics* 66(4), 904-941.

U.S. Energy Information Administration (2022), Levelized Costs of New Generation Resources in the Annual Energy Outlook 2022.

Wråke, Markus, Alberto Dalla Riva, Ida Græstad Jensen, Johan Holm, Kenneth Karlsson, Anders Kofoed-Wiuff, Phil Swisher, Thomas Unger (2022), 'Lowering prices in a hurry – Electricity Prices in the Wake of Russia's Invasion of Ukraine'. Energiforsk, Report 2022-886.

WSP (2020), 'Energieffektivisering och dess påverkan på elanvändningen', Report commissioned by the Confederation of Swedish Enterprise.