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A future capacity mechanism to ensure resource adequacy in the electricity market

Government assignment regarding proposals for design after 16 March 2025

SVENSKA KRAFTNÄT

Svenska kraftnät

Svenska kraftnät is a state-owned transmission system operator, with the task of managing, operating and developing a cost-effective, operationally safe and environmentally sound transmission system. The transmission system includes 400 kV and 220 kV power lines with substations and interconnectors. Svenska kraftnät develops the transmission grid and the electricity market to meet society's need for a reliable, sustainable and cost-effective supply of electricity. Svenska kraftnät therefore plays an important role in enabling climate policies.

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Summary

The assignment and its limitations

As part of its efforts to create a secure electricity supply, on 15 December 2022, the government commissioned Svenska kraftnät to propose capacity mechanisms with the prerequisites to replace the Swedish power reserve and ensure resource adequacy after 16 March 2025 in accordance with the reliability standard for Sweden. This task represents point two of a major government assignment to strengthen the security of supply in the energy sector (I2022/02319).

The issue of how a capacity mechanism should be designed after 2025 is a complex one with a potentially large impact on the functioning of the electricity market. The introduction of a capacity mechanism needs to be preceded by an application to the European Commission. The European Commission will examine the application and consider whether the design is consistent with the Electricity Regulation and State aid rules, and a successful design requires dialogue with many stakeholders, both nationally and internationally. Due to the short time frame for this task, Svenska kraftnät has not presented a full proposal for a capacity mechanism, but has focused on identifying and critically assessing key design elements to consider in connection with the continuing process of designing a capacity mechanism after 2025.

Conclusions and assessments

Sweden has an increasing resource adequacy problem on the electricity market, which means periods of high electricity prices and a greater risk of power shortages and subsequent disconnection of consumption. According to the latest national assessments from Svenska kraftnät and at European level, Sweden risks failing to meet the established Swedish reliability standard of one hour within a few years. There are a number of challenges associated with investment in new electricity generation, such as permit processes and various types of environmental requirements. Market participants also emphasise the importance of long-term policies. As part of this assignment, Svenska kraftnät has assessed whether there is a need for a capacity mechanism after 2025 and how such a mechanism should be designed. The expected electrification will lead to greater demand for electricity, but there is huge uncertainty about future electricity use. This creates major risks for investors, which has a negative impact on investment decisions regarding new production capacity. Svenska kraftnät believes the introduction of a well-designed capacity

mechanism can contribute to improving incentives for investment, but cannot handle all the challenges associated with investments in new capacity per se.

The assumptions underlying forecasts and long-term scenarios about future electricity use are subject to uncertainties. Svenska kraftnät has made a number of assessments based on its latest analyses that unanimously indicate a sharp deterioration in the power balance within a few years. Possible implications of the European energy crisis with its high electricity prices have not had time to be fully reflected in the analyses. The assessments may change if the schedules for one or more announced electricity-intensive industrial initiatives in Sweden are delayed or cancelled. Interest rates have also risen rapidly to curb high inflation, which may have a negative impact on such industrial initiatives. Svenska kraftnät will reconsider its assessments if electricity use is developing at a slower pace. However, given the long lead times for introducing a capacity mechanism, it is important to start the process in good time in order to meet the reliability standard in a likely future with sharply increasing electricity use.

If the proposals presented in this report are implemented, this will constitute a significant change in the Swedish electricity market. Svenska kraftnät has not yet had the opportunity to conduct a complete impact assessment of the proposals. A necessary next step is therefore to assess the consequences for the Swedish and Nordic electricity markets and the market participants in more detail.

Sweden will still need a capacity mechanism after 2025

The energy transition is expected to result in a sharp increase in electricity consumption over time and an altered production mix with an increasing proportion of renewable and weather-dependent electricity generation. For Sweden, forecasts and scenarios indicate strong growth in electricity consumption, which is not accompanied by a corresponding increase in production capacity that can meet demand during periods of system stress. As early as 2027, the additional capacity requirement to cope with the power balance may reach between 2,500 and 3,000 MW in southern Sweden in order to meet the reliability standard of a maximum of one hour of power shortage per year. By 2045, the additional capacity requirement may reach between 13,700 and 15,000 MW nationally in the most extreme scenario, which can potentially be solved through a combination of production capacity, demand response and energy storage. Svenska kraftnät believes that, under the current circumstances, an energy-only market cannot deliver all the flexibility that is needed in order to meet the reliability standard. To make the energy transition possible without compromising compliance with the reliability standard, Svenska kraftnät believes that a capacity mechanism will still be needed after 2025.

A market-wide capacity market should be introduced

A fundamental choice of direction with regard to capacity mechanisms is whether they should be targeted or market-wide. Targeted mechanisms are in practice limited to a strategic reserve similar to the current Swedish power reserve and are judged to have a small impact on an energy-only market. However, a strategic reserve is primarily designed to maintain existing capacity that would otherwise be shut down, and not to provide incentives for new investment. In view of the fact that the expected electrification will lead to a major need for new investment, Svenska kraftnät believes that a strategic reserve is not suitable in the long term for meeting Sweden's future needs. Svenska kraftnät therefore believes that a market-wide capacity market should be introduced in Sweden in the long term.

A Swedish capacity market should be divided geographically by bidding zone

Sweden is an elongated country with changing conditions for electricity generation and electricity use. At the time of producing this report, Northern Sweden (SE 1 and 2) has an electricity generation surplus that is exported to the consumption-dominated deficit area in southern Sweden (SE 3 and 4). A high expansion rate of renewable electricity generation, especially in northern Sweden, makes it difficult to remove transmission constraints in the transmission grid at the required rate. The capacity market should therefore be divided in a way that highlights the transmission constraints in the transmission grid so that capacity payments are higher in deficit areas.

Svenska kraftnät believes that the geographical boundaries of the capacity market need to at least follow the bidding zone configuration at any given time, as each bidding zone has unique challenges as well as the prerequisites for meeting the national reliability standard with the help of new production capacity, flexible electricity consumption or net imports. A change in bidding zone configuration will therefore mean a change in the geographical boundaries of the capacity market.

Foreign participation in a Swedish capacity market is likely to be a prerequisite for approval

Article 26 of the Electricity Regulation sets out several conditions for cross-border participation in capacity mechanisms that are not a strategic reserve. Svenska kraftnät believes that foreign participation in a market-wide capacity market is a prerequisite for the approval of such a mechanism. This has been the case in all decisions made by the EU Commission in recent years. However, Svenska kraftnät questions the effectiveness of cross-border participation from countries without capacity markets in terms of impact on resource adequacy in Sweden as it is not deemed to lead to investments in new capacity. Sweden's total import capacity is 10.3 GW, but foreign participation will be considerably lower as it depends on the expected availability of interconnectors and access to bids that have not been called off abroad. It should also be kept in mind that parts of the import capacity go to northern Sweden and consequently do not have a direct contribution in the event of a shortage in southern Sweden.

A Swedish capacity market should be designed with centralised procurement

The capacity market can either be designed so that a central operator, such as a TSO, procures capacity or that capacity is procured in a decentralised manner by grid owners or electricity suppliers/balancing responsible parties. Most of the European countries that have introduced capacity markets have chosen a centralised model. Svenska kraftnät believes that a centralised model is more appropriate for Sweden.

Centralised procurement means better prerequisites for central planners to meet their targets. Standardised products procured in a major procurement process involve reduced transaction costs through increased liquidity and price transparency, possibly at the expense of the conditions not being suitable for all potential capacity providers. A centralised capacity market also facilitates the management of transmission capacity between bidding zone borders in Sweden and abroad.

Availability should primarily be ensured by introducing reliability options

Svenska kraftnät believes that financial incentives in the form of reliability options should be the primary mechanism to ensure the availability of capacity resources. These could also be combined with availability obligation in declared shortage situations. In addition to providing strong incentives for availability, reliability options also have other benefits, such as limiting the market power of resource owners and contributing to price hedging/payment obligation to customers in the event of high energy prices.

One product is preferable from a Swedish perspective

Design of the product is important in order to achieve a technology-neutral procurement that is open to all. A comparison of a number of European countries that have recently introduced, or are planning to introduce, a market-wide capacity mechanism suggests that they have all (Belgium, Italy, Poland, Ireland and Northern Ireland) chosen to include just one product in the procurement process. Svenska kraftnät believes that one product is preferable from a Swedish perspective.

Consideration should be given to whether stricter requirements regarding CO_2 emissions than the EU's minimum requirements should be imposed

The EU sets out certain minimum requirements for CO_2 emissions for resources that take part in a capacity mechanism. New facilities may emit a maximum of 550 g of CO_2 per kWh, while older facilities may not emit more than 550 g of CO_2 per kWh or on average no more than 350 kg of CO_2 per installed kW. However, the requirement of a maximum of 550 g of CO_2 per kWh means that it is possible for modern gas power plants to be included in a capacity mechanism. This could potentially mean that new investments are made in facilities that have a considerable impact on climate and lead to longer-term lock-in effects. Unlike most national electricity systems in Europe, the Swedish electricity system is largely free from fossil-based production. Therefore, from a Swedish perspective, new investment in fossil-based production would move us towards a system with increased climate impact. In light of this, the government should consider whether it is justified to impose stricter requirements regarding CO_2 emissions than the EU's minimum requirements.

The capacity market ought to be designed based on a marginal pricing model

A fundamental design issue is whether pricing should be based on the marginal price (pay-as-clear) or whether each participant should be paid based on their own individual bid (pay-as-bid). In general, pay-as-clear is preferable, but pay-as-bid may be preferable under certain circumstances. Capacity markets have certain features that mean pay-as-bid could be preferable and further analysis may therefore be justified. Within the European regulatory framework, however, there is a strong preference for pay-as-clear, and Svenska kraftnät believes that it is likely to be difficult to obtain approval for a mechanism that is not based on marginal pricing.

The demand for capacity should be price elastic

The demand for capacity was fixed and price inelastic in the first capacity markets that were introduced in the USA. This proved to have significant disadvantages in terms of increased market power among resource owners and huge fluctuations in capacity prices. Consequently, these markets were reformed and in newer capacity markets the procured capacity is price elastic, i.e. at a high price, slightly lower volumes are procured than the target level, and at a low price, slightly higher volumes are procured. Svenska kraftnät believes that capacity that is procured should be price elastic. If there is a surplus of capacity, this should also result in a price for capacity that is zero or close to zero.

Procurement procedures should be carried out with a lead time of around four years

In order to increase competition in the capacity market and allow for the entry of new capacity, procurement procedures should be carried out with some lead time before the delivery period. The greater this lead time, the more competition can potentially increase, but it also makes it more difficult to forecast how much capacity should be procured. In most capacity markets, procurement procedures take place with a lead time of 3–5 years before the delivery period, with supplementary auctions closer to the delivery period. Svenska kraftnät believes that a lead time of around four years between the auction and the start of the delivery period is appropriate.

It should be possible to procure new capacity with high capital costs on long-term contracts

A fundamental purpose of capacity markets is to reduce the risk associated with investment. For new capacity with high capital costs, longer contracts are required in order to achieve this purpose. In most European capacity markets, contracts with a duration of between seven and 15 years are awarded for new capacity. Svenska kraftnät believes that contract lengths of this nature are appropriate in order to effectively reduce the risk involved in new investment.

Capacity mechanism will need to be financed through a charge to end customers

The net cost of a capacity mechanism will need to be financed through a charge that is ultimately passed on to end customers through their electricity supplier or network operator. Such a charge should be designed so that it is primarily levied on consumption during periods when the risk of a power shortage is high. The charge can be levied either by balancing responsible parties or by network operators. Svenska kraftnät currently has no firm understanding of which approach is most appropriate.

Comprehensive regulatory framework and long lead times for introduction

The introduction of a capacity mechanism requires approval by the European Commission. A strategic reserve is likely to mean a somewhat simpler approval process, as the design of such a reserve is described in relative detail in the European legislation. A market-wide mechanism needs to be justified in more detail and there are many more design choices to be made. This means that introducing a market-wide capacity mechanism involves a process that can be expected to take five to eight years from the beginning of the work to design such a mechanism to the first delivery period. This is also what experience from other countries has shown. Regardless of the choice of capacity mechanism, national legislation will also need to be put in place.

Given the long lead times for a market-wide capacity mechanism, it is very unlikely that such a mechanism may be in place when the current power reserve expires. Therefore, some form of transitional solution is necessary. Svenska kraftnät believes that the current power reserve, with some modifications, should be extended for around three years. This also requires the approval of the European Commission.

1 Introduction

The current power reserve is procured up to and including the winter of 2024/25. On 15 December 2022, Svenska kraftnät was commissioned by the government to propose a capacity mechanism design with the prerequisites to replace the Swedish power reserve after 16 March 2025 and ensure resource adequacy in accordance with the reliability standard for Sweden.

Svenska kraftnät shall pay particular attention to the following when carrying out the assignment:

- Chapter IV Resource Adequacy in Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity (Electricity Regulation), as well as other relevant European legislation.
- The ongoing work within the EU to review the current design of the electricity market and any regulatory changes it entails.
- As far as possible, draw up agreements and proposals for capacity mechanisms in such a way that they are compatible with the European regulatory framework for State aid.

1.1 Background

In November 2022, the government decided that the reliability standard for Sweden should be one (1) hour per year. Having a reliability standard in place and an implementation plan to improve the functioning of the electricity market are a prerequisite for introducing or retaining national capacity mechanisms (such as Sweden's power reserve), in accordance with the Electricity Regulation. The reliability standard, which indicates the necessary level of security of supply of the Member State, is compared with resource adequacy assessments. In simple terms, resource adequacy is a measure of the extent to which production resources and other supplies of electricity such as imports into a Member State are able to meet the expected demand.

Svenska kraftnät presents a national resource adequacy assessment each year in its power balance report. The trend over time is that margins are falling and that Sweden's dependence on imports of electricity during periods of system stress is increasing. The latest seasonal analysis from the European Network of Transmission System Operators for Electricity (ENTSO-E), Winter Outlook 2022–2023, highlights southern Sweden as one of the areas under most stress in Europe, with a loss of load expectation (LOLE) that is higher than in previous years and exceeds the reliability standard for Sweden (ENTSO-E, 2022:2). The long-term resource adequacy assessment also shows that in a few years' time Sweden has a significantly higher risk of power shortage than the reliability standard of one (1) hour per year allows.

The current power reserve, which Svenska kraftnät has at its disposal during the period from 16 November to 15 March each year, currently involves production of 562 MW. Contracts entered into are valid until the winter of 2024/25. The current Electricity Regulation, which came into force on 1 January 2020, limits the options for acquiring power in accordance with the previous procedure after 2025. Applying a capacity mechanism requires that resource adequacy is worse than the adopted reliability standard, which the assessments show is the case for southern Sweden.

1.2 Assignment

As part of creating a secure electricity supply, Svenska kraftnät will propose capacity mechanisms with the prerequisites to replace the power reserve and ensure resource adequacy after 16 March 2025 in accordance with the reliability standard for Sweden.

This report constitutes the second point of a major government assignment to strengthen security of supply in the energy sector (I2022/02319) and was submitted to the government on 31 March 2023.

1.3 Limitations

The issue of how a capacity mechanism should be designed after 2025 is a comprehensive and complex one with a potentially large impact on the functioning of the electricity market. A successful approval process at the European Commission requires dialogue with many stakeholders, both nationally and internationally. Due to the short time frame for this task, Svenska kraftnät has not presented a full proposal for a capacity mechanism, but has focused on identifying and critically assessing key design elements to consider in connection with the continuing process of designing a capacity mechanism after 2025.

1.4 Method and implementation

The work has been carried out through a bibliographical review of how national resource adequacy has developed over time, a review of the legal framework and an assessment of the theoretical and practical considerations that need to be made when designing any capacity mechanism. Several assessments are based on a series of workshops that Svenska kraftnät held in the autumn of 2022 together with consulting firms Compass Lexecon and DNV.

1.5 Report structure

Chapter 2 includes a description of the prerequisites for introducing capacity mechanisms based on EU law, resource adequacy assessments and economic arguments. Chapter 3 assesses the pros and cons of a targeted or market-wide capacity mechanism from a national perspective. Chapter 3 also includes a discussion on how a capacity mechanism can interact with other support schemes. Chapter 4 includes a review of the design choices that need to be made and justified in connection with any application to the European Commission for a market-wide capacity mechanism. Chapter 5 contains a timetable and dates for the introduction of a Swedish market-wide capacity mechanism. Appendix 1 contains an in-depth description of the resource adequacy assessments. Finally, Appendix 2 contains suggested questions to stakeholders in connection with any consultation.

2 Sweden will still need a capacity mechanism after 2025

The energy transition is expected to result in a sharp increase in electricity consumption over time and an altered production mix with an increasing proportion of renewable and weather-dependent electricity generation. Relying solely on voluntary contracts in an energy-only market risks higher costs for society in terms of delayed energy transition, resource adequacy problems in the electricity market, increased price volatility and associated price uncertainty that may hinder or delay investment in new capacity. A centralised procurement of capacity gives a TSO better control and management of the market so that the reliability standard is achieved.

For Sweden, forecasts and scenarios indicate strong growth in electricity consumption, which is not accompanied by a corresponding increase in production capacity that can meet demand during periods of system stress. As early as 2027, the additional capacity requirement during scarcity hours may reach between 2,500–3,000 MW in SE 4 in order to reach the reliability standard of one hour. By 2045, the additional capacity requirement could reach between 13,700 and 15,000 MW nationally in the most extreme scenario. This capacity requirement can potentially be solved through a combination of production capacity, consumption flexibility and energy storage. Svenska kraftnät believes that an energy-only market cannot, under the current circumstances, deliver the flexibility needed to achieve the reliability standard, which is why a capacity mechanism will still be needed.

2.1 Legal prerequisites for introducing a capacity mechanism

Within EU law, the target model is an 'energy-only market'. In an energy-only market, a producer is compensated primarily[1] for the energy it produces, and not for the production capacity available. A capacity mechanism compensates an electricity producer for keeping capacity available and thus represents a departure from an energy-only market. Its introduction is therefore subject to approval by the European Commission. The EU will carry out a review to consider whether an application from Sweden is compatible with the Electricity Regulation and State aid rules.

[1] Except for balancing capacity or other capacity-based ancillary services or remedial actions.

The conditions and criteria that must be met are summarised in Table 1 and described in more detail in the following.

Table 1. Conditions and criteria that must be met prior to introducing a capacity mechanism.

EU regulations	Conditions and criteria prior to introducing a capacity mechanism
Electricity Regulation	Where the European resource adequacy assessment or national resource adequacy assessment has identified a resource adequacy concern, the Member State shall proceed as follows: a) Identify any regulatory distortions or market failures that caused or contributed to the emergence of the concern. b) Develop and publish an implementation plan for the European Commission to review. c) Conduct a comprehensive study of the possible effects on neighbouring Member States through consultation. d) Assess whether a strategic reserve is capable of addressing the resource adequacy concern. e) Propose a design, including a phase-out plan, for the European Commission to approve for a maximum of 10 years.
	If only the national assessment identifies a resource adequacy concern and not the European resource adequacy assessment: f) The Member State shall explain the assumptions and sensitivity analyses that account for the divergence to ACER which provides an opinion on whether the divergence is justified. The Member State shall take due account of ACER's opinion.
State aid	Notification and approval process at the European Commission according to the following compatibility criteria: • Necessity • Incentive effect • Suitability compared with other measures • Eligibility • Public consultation • Proportionality • Avoidance of undue negative effects on competition, trade and balancing

2.1.1 Electricity Regulation

Pursuant to Article 2(22) of the Electricity Regulation, a capacity mechanism means a temporary measure to ensure the achievement of the necessary level of resource adequacy by remunerating resources for their availability, excluding measures relating to ancillary services or congestion management. The overall method for assessing resource adequacy and the conditions under which capacity mechanisms may be used to increase resource adequacy in accordance with the national reliability standard is explained in Chapter IV of the Electricity Regulation.

Article 20 of the Electricity Regulation states that Member States shall monitor resource adequacy within their territory on the basis of the European resource adequacy assessment pursuant to Article 23 of the same Regulation. A Member State may also complement a European assessment by carrying out national assessments of resource adequacy in accordance with Article 24 of the Electricity Regulation.

A Member State may not introduce a capacity mechanism where both the European resource adequacy assessment and the national resource adequacy assessment have not identified a resource adequacy concern (Article 21(4)). Before introducing capacity mechanisms, the Member States concerned shall conduct a comprehensive study of the possible effects of such mechanisms on the neighbouring Member States by consulting at least its neighbouring Member States to which they have a direct network connection and the stakeholders of those Member States (Article 21(2)).

2.1.1.1 Implementation plans

Where the European resource adequacy assessment referred to in Article 23 or the national resource adequacy assessment referred to in Article 24 identifies a resource adequacy concern, the Member State concerned shall identify any regulatory distortions or market failures that caused or contributed to the emergence of the concern. Pursuant to Article 20(3) of the Electricity Regulation, Member States with identified resource adequacy concerns shall develop and publish an implementation plan with a timeline for adopting measures to eliminate any identified regulatory distortions or market failures as a part of the State aid process. The Member States concerned shall submit their implementation plans to the Commission for review (Article 20(4)).

Within four months of receipt of the implementation plan, the Commission shall issue an opinion on whether the measures are sufficient to eliminate the regulatory distortions or market failures that were identified, and may invite the Member States to amend their implementation plans accordingly (Article 20(5)). The Member States concerned shall monitor the application of their implementation plans and shall publish the results of the monitoring in an annual report and shall submit that report to the Commission (Article 20(6)). The Commission shall issue an opinion on whether the implementation plans have been sufficiently implemented and whether the resource adequacy concern has been resolved (Article 20(7)). Member States shall continue to adhere to the implementation plan after the identified resource adequacy concern has been resolved. (Article 20(8))

To eliminate residual resource adequacy concerns, Member States may, as a last resort while implementing the measures referred to in Article 20(3) of the Electricity Regulation in accordance with Article 107, 108 and 109 of the TFEU, introduce capacity mechanisms. (Article 21(1)). Capacity mechanisms shall be temporary in accordance with Article 21(8) of the Electricity Regulation. They shall be approved by the Commission for no longer than ten years. They shall be phased out or the amount of the committed capacities shall be reduced on the basis of the implementation plans referred to in Article 20. Member States shall continue to apply the implementation plan after the introduction of the capacity mechanism.

Pursuant to Article 21(5) of the Electricity Regulation, Member States may not introduce capacity mechanisms before the implementation plan as referred to in Article 20(3) has received an opinion by the Commission as referred to in Article 20(5).

Sweden submitted an implementation plan to the European Commission on 22 February 2023 (no. KN2023/01982). At the time of preparing this report, the European Commission has not issued an opinion.

2.1.1.2 Phase-out plan

Pursuant to Article 21(6) of the Electricity Regulation, where a Member State applies a capacity mechanism, it shall review that capacity mechanism and shall ensure that no new contracts are concluded under that mechanism if no resource adequacy assessment identifies a resource adequacy concern. When designing capacity mechanisms Member States shall include a provision allowing for an efficient administrative phase-out of the capacity mechanism where no new contracts are concluded pursuant to Article 21(6) during three consecutive years.

2.1.1.3 Reliability standard

From a socio-economic perspective, there is a balance between the benefit of increased reliability and the cost of investment in increased capacity, which must be taken into account when reliability targets are defined and quantified. Pursuant to Article 25 of the Electricity Regulation, countries applying a capacity mechanism shall have a reliability standard in place that indicates the necessary level of security of supply of the Member State in a transparent manner. Furthermore, the reliability standard shall be based on the methodology referred to in Article 23(6).

In accordance with the Electricity Regulation, the European Union Agency for the Cooperation of Energy Regulators (ACER) shall decide on a methodology for calculating the reliability standard[2]. The reliability standard shall be expressed as 'loss of load expectation' (LOLE) and 'expected energy not served' (EENS). The established methodology is based on calculating LOLE, and then calculating EENS indirectly. LOLE is calculated based on the 'value of lost load' (VoLL) and 'cost of new entry' (CONE).

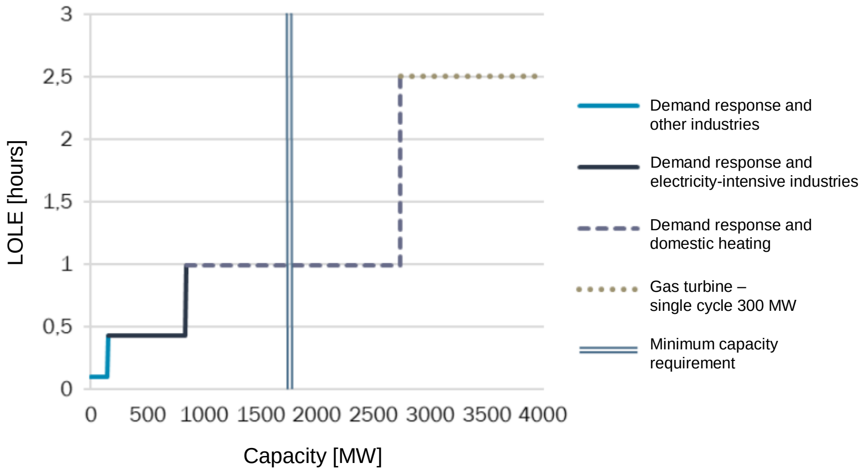
Based on the methodology established by ACER, the Swedish Energy Markets Inspectorate (Ei) calculated a proposal for a reliability standard with a LOLE level of 0.99 hours/year (Ei, R2021:05). The government then set the level at 1 hour/year. Ei set the VoLL as EUR 7,869/MWh, which is considered to be a weighted maximum price that customers are willing to pay on average to avoid supply disruptions. CONE must include fixed and variable costs for new facilities. The method for calculating CONE and results for different technologies can be found in Ei's reliability standard report.

In addition to VoLL and CONE, an estimate of the minimum capacity requirement for the reliability standard, which shall be less than or equal to the highest possible power shortage that emerged from the most recent European, regional or national resource adequacy assessment. Ei uses data from Svenska kraftnät regarding resource adequacy from 2021, which indicates a maximum power shortage of 1,750 MW (Svenska kraftnät, 2021:5).

Overall, Ei's assessment shows that the total available capacity, matching the level of 1,750 MW, consists of demand response from other industries, electricity-intensive industries and domestic heating. This results in a LOLE of 0.99 hours, see Figure 1.

[2] Methodology for calculating the value of lost load, the cost of new entry and the reliability standard, in accordance with Article 23(6) of Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity, 2 October 2020.

Figure 1. Available capacity and capacity requirement.



Source: Ei (R2021:05).

2.1.2 State aid rules

A capacity mechanism shall be established in accordance with Articles 107, 108 and 109 of the Treaty on the Functioning of the European Union (TFEU). Hancher, De Hauteclocque, Huhta, & Sadowska (2022) argue that it is very difficult to design a capacity mechanism that evades Article 107(1) TFEU as these are either directly or indirectly financed by state funds. In several announcements during the period 2014–2021, the European Commission has specifically addressed capacity mechanisms and their design to be compatible with the internal market. The most recently updated communication from the European Commission including guidelines on State aid for climate, environmental protection and energy 2022 concerns, among other things, aid for measures targeting resource adequacy.

In short, a capacity mechanism shall be assessed by the European Commission according to the following compatibility criteria:

- Necessity
- Incentive effect
- Suitability compared with other measures
- Eligibility
- Public consultation
- Proportionality
- Avoidance of undue negative effects on competition, trade and balancing

Several of the compatibility criteria are either based on, or refer directly to, the Electricity Regulation. For example, necessity is assessed based on the resource adequacy assessment and reliability standard provided for in the Electricity

Regulation. Other compliance criteria go further, or have a slightly different focus, than provided for in the Electricity Regulation, such as incentive effect and public consultation.

2.2 Reduced resource adequacy in Sweden over time

This section contains a literature review on resource adequacy and what assumptions about the future form the basis for why margins are expected to decrease over time. The overall picture from reviews at international and national level can be summarised according to the following points:

- Margins in the electricity market have decreased over time, with adverse effects in terms of adequacy and risk of power shortages.
- There is currently an increased risk of power shortages and the problem may worsen. There is an imminent risk that it will not be possible to achieve the established reliability standard for Sweden in the future, given the current regulatory framework.
- The expected electrification entails an increased need for electricity, but there are major uncertainties about future electricity consumption.

2.2.1 Summary of previous government assignments on adequacy

Svenska kraftnät has carried out a number of government assignments that to some extent have considered different aspects of adequacy. Below is a summary of these assignments on adequacy issues.

In November 2020, the government tasked Svenska kraftnät with identifying the ongoing work with ancillary services for maintaining normal state and for remedial actions and defence services for alert state and emergency state, which was reported in October 2021(Svenska kraftnät, 2021:3). The report focuses on the balancing and ancillary services markets and makes a number of proposals for changes to these markets. In addition to the above, the report also contains a general review of adequacy, especially with regard to the strategic power reserve and the development linked to it.

In January 2022, Svenska kraftnät was tasked by the government to report quarterly on measures to increase capacity available for trading between bidding zones[3]. Reports were submitted on 31 March, 30 June, 30 September

[3] https://www.regeringen.se/regeringsuppdrag/2022/01/uppdrag-att-kvartalsvis-informera-om-atgarder-for-att-oka-handelskapaciteten-mellan-elomraden/

and 31 December 2022[4]. The background to this assignment was the transmission capacity limits that have been introduced and which contributed to greater price differences between different bidding zones. Reporting focused on market solutions and technical solutions that affect capacity available for trading in the short term (next three years). Examples of market measures that have been implemented are sum allocation[5], procurement of resources for countertrading and adjustments of operational safety margins for transmission capacity. The last report also includes a section on the power reserve and an analysis of future requirements. Svenska kraftnät draws the conclusion here, based on adequacy assessments that have been carried out, that there will still be a need for a capacity mechanism after 2025 and that the need has increased. The conclusion is based on both national and European adequacy assessments.

In light of the recent period with very high electricity prices, Svenska kraftnät was tasked by the government to investigate the possibilities and prepare to procure demand response and electricity production with a clear impact on pricing in the electricity market, which was last reported in October 2022 (Svenska kraftnät, 2022:3). With regard to demand response, three different procurement models were presented, all of which are considered possible. Svenska kraftnät also presented two models for the procurement of plannable electricity production, but also notes that there are legal obstacles that make such procurement difficult to implement. However, the opportunities to procure larger production facilities for redispatch and countertrading were pointed out, which were also exploited in the winter of 2022/23. The potential for the power reserve to participate in the spot market and thereby potentially have a price-dampening effect was also discussed. However, changes in both national and European legislation are needed in order to achieve this.

In March 2022, Svenska kraftnät detailed in a report to the government how the implementation of the EU's clean energy package has progressed thus far (Svenska kraftnät, 2021:2). A section in this report deals with the Electricity Regulation and the area of resource adequacy. Member States are responsible for monitoring resource adequacy. Monitoring shall be based on the European resource adequacy assessment to be carried out by ENTSO-E once a year. The resource adequacy assessment must be carried out based on the method developed by ENTSO-E that must be approved by ACER. Each Member State also has the option to carry out a national resource adequacy assessment. The

[4] https://www.svk.se/siteassets/om-oss/rapporter/2022/sa-arbetar-vi-for-att-oka-overforingskapaciteten-kortsiktiga-atgarder-kvartal-4-2022.pdf
[5] https://www.svk.se/utveckling-av-kraftsystemet/systemansvar--elmarknad/ny-summaallokering-for-att-oka-tillganglig-handelskapacitet-for-se3-till-dk1-och-no1/

national assessment shall have a regional scope and shall be carried out using the same methodology as the European assessment. Svenska kraftnät has been tasked with monitoring resource adequacy in Sweden, through an amendment to the regulation (2007:1119) with instructions for Affärsverket svenska kraftnät. The report concludes that implementation is complete or ongoing for most of the requirements set out in the Electricity Regulation.

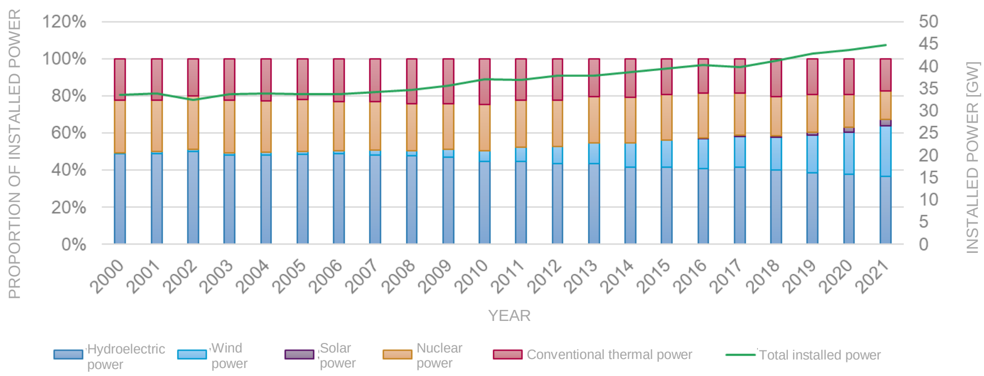
2.2.2 Development of the electricity system and resource adequacy

This section summarises resource adequacy assessments and the development in the resource adequacy situation over time. A more detailed description can be found in Appendix 1.

2.2.2.1 Development of the electricity system during the 2000s

The electricity system underwent development during the 2000s, which included an increase in the share of renewable and weather-dependent generation and a reduction in the share of plannable generation. Figure 2 shows the development of installed production capacity in Sweden during the period 2000-2021. As the figure shows, total installed capacity has increased, where the increase mainly involves new wind power. The share of hydroelectric power in capacity has decreased, but is largely constant in absolute terms at around 16 GW. Nuclear power has decreased both in relative and absolute terms from having a maximum installed capacity of 9,768 MW in 2016 to a level of 6,899 MW in 2021. Development is also reflected in volumes produced with a clear trend towards increasing amounts of wind power generation added in the past decade.

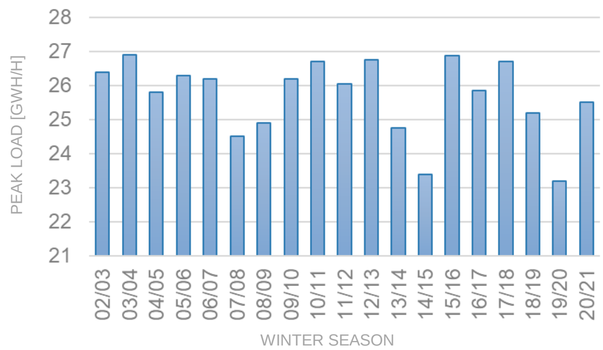
Figure 2. Installed production capacity and share per technology.



Source: Data from Statistics Sweden.

Annual consumption has remained largely constant over the past 20 years in Sweden. In the 2000s, the highest annual domestic electricity consumption to date was just over 150 TWh. This occurred in 2001. In 2020, electricity consumption fell to approx. 135 TWh, which can be attributed to the COVID-19 lockdowns. Maximum consumption during the year is of particular interest from an adequacy perspective. This can be studied through the so-called 'peak load hour', which historically occurred during the winter season, either during one hour in the morning or one hour in the afternoon/evening. The level of consumption during this hour depends on, among other things, temperature and wind, which has a major impact on heating demand and consequently on consumption. Figure 3 shows the consumption in Sweden during peak load hours for each winter season. It is not possible to discern any clear trend in peak loads based on the data from the last 20 years. However, it is possible that there will be higher levels in the future due to electrification and consequently a generally higher level of consumption.

Figure 3. Highest hourly electricity consumption per winter season.



With regard to demand in 2022 and 2023, and the energy crisis Europe is experiencing, the high market prices and increased awareness have led to a reduction in consumption. Svenska kraftnät has reported clear trends compared with previous years regarding reductions for Sweden to date of up to 8.2%, which occurred in December 2022 (Svenska kraftnät, 2023). The differences between domestic production and consumption are made up of exports or imports. Throughout the 2000s, Sweden both imported and exported electricity, but exports of electricity have increased over the past 10 years and viewed on an annual basis, Sweden has been a net exporter since 2011. In terms of energy over a longer period of time, Sweden has a surplus, but it should be noted that supply can vary greatly over shorter time horizons due to variations in wind power generation, among other things.

In summary, the trend in the past 20 years can be described as the consumption side having remained relatively unchanged over the period, but that there have been major changes in generation and imports/exports. The production mix has changed to include more weather-dependent electricity generation, primarily in the northern and central parts of the country, and with a reduced plannable production capacity in the southern parts of the country. Overall, generation has increased and so have annual export volumes.

2.2.2.2 European adequacy studies

At European level, adequacy studies are conducted within the European Resource Adequacy Assessment (ERAA), which is carried out annually by the European network of TSOs, ENTSO-E. The purpose of the ERAA is to provide stakeholders and decision makers with a basis for informed decisions on various investments and policy measures. The ERAA is also key in terms of the ability of Member States to establish or maintain capacity mechanisms using the results of the ERAA in terms of LOLE (and EENS) as justification for the introduction of capacity mechanisms if LOLE exceeds the nationally established reliability standard. The methods used to carry out the ERAA were approved by ACER in October 2020, including the application of a probabilistic method. Methods are being developed to make this possible both internationally at ENTSO-E and at Svenska kraftnät.

The first ERAA was carried out in 2021, and contains adequacy assessments for 2025 and 2030 (ENTSO-E, 2021). The study is based on four scenarios, where national forecasts collected from TSOs are the starting point. The final results from ERAA 2021 for Sweden can be summarised in that LOLE amounts to a maximum of 0.4 hours/year in the study for SE4. However, it should be noted that parts of the ERAA methodology under the Electricity Market Directive were not implemented in the execution of ERAA 2021, and the results should therefore be considered with this in mind.

The methodology for ERAA was further developed prior to the assessments carried out in connection with ERAA 2022 (ENTSO-E, 2022). The results for Sweden are presented in Table 2. In comparison with the results from ERAA 2021, adequacy has deteriorated significantly for southern Sweden. For example, there is an increase in LOLE in SE4 for 2030 from 0.4 hours/year in ERAA 2021 to 5.5 hours/year in ERAA 2022 for comparable scenarios. The differences between ERAA 2021 and 2022 can partly be explained by the fact that the methodology has developed during the time between the two assessments, and partly by differences in the national forecasts on which the scenarios are based.

Table 2. LOLE in hours/year from ERAA 2022 for SE3 and SE4. Other bidding zones in Sweden have LOLE=0 for all assessment years.

Bidding zone	2025	2027	2030
SE3	1.9	2.5	1.2
SE4	2.0	5.1	5.5

Cross-border transmission capacity between different countries and regions in Europe means that countries have the opportunity to contribute to adequacy in other countries through imports and exports via transmission interconnectors. Consequently, it is important to also consider the availability of transmission interconnectors in terms of their ability to export to Sweden and the power balance in neighbouring countries when adequacy is assessed and discussed. The greatest adequacy challenges for Sweden can be found in SE3 and SE4, and the LOLE for countries and areas directly linked to SE3 and SE4 can be found in Table 3. As the table shows, there are also challenges for adequacy in the neighbouring countries and regions, which indicates that the possibility of importing to Sweden may be limited during periods of system stress. This is also confirmed by the correlation analysis carried out as part of the ERAA.

Table 3. LOLE in hours/year for countries and regions adjacent to SE3 and SE4.

Bidding zone	2025	2027	2030
NO1	0	0	0
DK1	9.8	13.4	2.3
DK2	7.4	11.1	10.9
FI	3.5	1.6	2.1
DE	10.5	13.7	20.4
PL	≤ 0.1	0.2	2.0
LT	3.8	6.2	6.0

2.2.2.3 National adequacy assessments

Svenska kraftnät carries out various national adequacy assessments and follow-ups with different time perspectives. Such follow-up assessments are made through the power balance report that Svenska kraftnät presents to the government each spring regarding the power balance in Sweden for the most recent winter, as well as a forecast for the coming winter and over the longer term. The most recent report was delivered at the end of May 2022 (Svenska kraftnät, 2022:2). During the winter of 2021/22, the peak load was 25,600 MWh/h, which occurred between 5 pm and 6 pm on 7 December. Net imports to Sweden were 1,600 MWh/h at that time. Flows between the country's bidding zones were in a north-south direction, with full transmission between SE2 and SE3. Thus, SE3 and SE4 represented bidding zones with imports, and in order to study the adequacy of the system, it is therefore of extra interest to study SE3 and SE4 in more detail. With regard to the situation in southern Sweden during the peak load hour, the power balance report concludes that 710 MW upregulation bids and power reserves were available in southern Sweden, and theoretically another 1,300 MW in imports from other countries. This means that approx. 2,000 MW of additional net consumption could have been handled. However, the conditions were more favourable than under normal circumstances with lower temperatures and more wind. Reduced wind power generation that reflects the level applied in the static assessment of the power balance would have resulted in the generation of 1,600 MW less, which could not have been covered by the available balancing resources and power reserve without disconnecting consumption.

Svenska kraftnät publishes annual short-term market analyses (SMA) designed to assess the development of the electricity system for the next five years based on known plans and decisions. The latest version was published in December 2022 (Svenska kraftnät, 2022:1) and covers the period 2023-2027. Input data for SMA consist of forecasts for electricity production, consumption and transmission interconnectors, and are collected from Svenska kraftnät, the Swedish Energy Agency, Svensk Vindenergi and the Swedish Bioenergy Association. On the basis of estimates based on lead times for grid development and grid connection requests from consumers, Swedish electricity consumption may increase sharply during the period, where the main increase is expected to come from industrial establishments. Experience gained from major investment projects shows, however, that uncertainties can postpone schedules, which can then result in a delay in increased electricity consumption. With regard to uncertainties, the report also states that the energy situation in the EU is very uncertain and therefore difficult to forecast. The energy crisis that has arisen means that developments in the global situation and rapid changes have a major impact on the electricity system.

Overall, assessments from SMA 2022 show that the risk of a power shortage for Sweden is lower than the determined reliability standard of one hour/year at the beginning of the assessment period, and then increases sharply towards the end of the assessment period, assuming that the electricity consumption forecast is realised. In Table 4 this is shown in terms of LOLE and EENS. As can be seen, LOLE is 1 hour/year in 2026, which is the current reliability standard, and reaches 9.6 hours/year in 2027. The assessments therefore show a drastic deterioration in the resource adequacy of the electricity market by 2027. Preliminary assessments indicate that an additional 2,500 to 3,000 MW of available plannable generation capacity is required in order to reach the LOLE level of 1 hour/year for 2027. As the table shows, an assessment analysis was also carried out concerning the power reserve and reduced electricity consumption. Despite reduced electricity consumption, LOLE also exceeds the reliability standard in 2027 in that scenario.

Table 4. Results from SMA 2022.

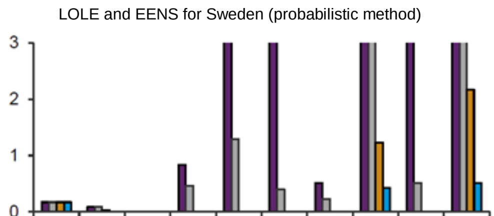
	2023	2024	2025	2026	2027
LOLE (hrs/year)	0.2	<0.1	0.4	1.0	9.6
EENS (GWh/year)	0.1	<0.1	0.1	0.4	6.6
LOLE (sensitivity analysis with power reserve being intact)			0.1	0.5	5.9
LOLE (sensitivity analysis with reduced electricity consumption)	<0.1	<0.1	<0.1	<0.1	1.9

The challenges for resource adequacy are also highlighted in Svenska kraftnät's long-term market analysis (LMA), which is published every two years, and in which different possible development paths for the system are presented and assessed. The latest LMA was published in 2021 (Svenska kraftnät, 2021:1) and a new one is planned for autumn 2023. The LMA has a longer time horizon and studies different scenarios up to 2050 with the aim of evaluating investment options and enabling a proactive way of working. The starting point for the analyses are four different scenarios intended to represent four different development paths for the electrical system: Small-scale renewables (SR); Roadmaps mixed (RM); Electrification plannable (EP); and Electrification renewables (ER). The scenarios differ in terms of electricity consumption, investments in generation capacity, etc. It should be noted here that, unlike an SMA, the LMA is based on *scenarios,* not on forecasts. The difference is that a forecast is an estimate of a reasonable, albeit uncertain, future (a best guess as to what will occur), while a scenario is a possible development from many possible developments. The starting point for forecasts and scenarios is therefore different, where scenarios are used to define development paths that differ significantly.

A key driving force in the development of the electricity system is the strong prevailing trend of electrification of the transport sector, industry and new operators such as data centres. The defined scenarios include different assumptions about the scope of this electrification, but all scenarios include an increase in electricity consumption. To represent different levels of this electrification, there is a range of the electricity usage between 173–286 TWh/year for 2045 for the different scenarios. In terms of generation, all scenarios include an increase in wind power, but the levels of investment in wind power vary between scenarios within a range of 22.6 GW to 55.3 GW in installed capacity for 2045.

Figure 4 shows the results from the simulations carried out in the LMA regarding LOLE and EENS for the years 2021, 2025, 2035 and 2045 for the respective scenarios defined. In addition, increased levels of flexibility have been assumed in the assessments, where the impact on LOLE and EENS is presented. As the figure shows, there are significant challenges for adequacy in most of the scenarios. The simulation results show that flexibility is needed for a well functioning system by 2045 in the majority of scenarios. However, in the case of the scenarios with the highest LOLE values, a considerable amount of flexibility is required in order to achieve LOLE values that meet the current reliability standard of 1 hour/year. The amount of flexibility that would be needed to keep LOLE at an acceptable level for the more extreme scenarios is so extensive that it can be considered unlikely to be realised in an energy-only market. For example, in the case of the ER scenario, flexibility would be required in the range of 13,700 to 15,000 MW in order to achieve LOLE of 1 hour/year in 2045.

Figure 4. Adequacy results from LMA 2021.



	2021	2025	2035 SR	2035 RM	2035 EP	2035 ER	2045 SR	2045 RM	2045 EP	2045 ER
LOLE, no flex, hrs/year	0,2	0,1	0,0	0,8	12	16	0,5	28	229	889
+flex hydrogen gas	0,2	0,1	0,0	0,5	1,3	0,4	0,2	12	0,5	40
+flex certain industries/electric cars	0,2	0,0	0,0	0,0	0,0	0,0	0,0	1,2	0,0	2,2
+flex data centres	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,4	0,0	0,5
EENS, no flex, GWh/year	0,02	0,01	0,00	0,34	10	16	0,25	33	119	1607
+flex hydrogen gas	0,02	0,01	0,00	0,14	0,81	0,17	0,12	11	0,23	46
+flex certain industries/electric cars	0,02	0,00	0,00	0,00	0,00	0,00	0,00	0,86	0,00	1,70
+flex data centres	0,02	0,00	0,00	0,00	0,00	0,00	0,00	0,22	0,00	0,36

Work on the next LMA version is under way with publication planned in the autumn of 2023. A key change in the updated version is a significant revision of the demand trend, where electricity consumption volumes have increased compared to the levels in the LMA 2021.

Overall, the national adequacy assessments show that there is currently a greater risk of power shortages and the problems may get worse. There is an imminent risk that it will not be possible to achieve the established reliability standard for Sweden in the future, given the current regulatory framework.

2.3 Resource adequacy in the electricity market

This section outlines the theories on how investments arise, especially in relation to electricity production. Investments in generation capacity are generally motivated by the fact that expected revenues exceed fixed and variable costs and thereby contribute to profitability. Revenue includes sales in the energy markets, but may also relate to any capacity payments and subsidies. This section begins by describing investments based on an energy-only market, and then goes on to include capacity mechanisms.

2.3.1 Investment and resource adequacy in an energy-only market

The European model is based on an energy-only market, where the purchased product involves energy over different time horizons. Given an ideal energy-only market, it makes sense for producers to invest in capacity as long as the market revenue generated by the investment exceeds fixed and variable costs. The basis of the European electricity market model is a free market with free pricing, which means that market prices follow marginal pricing principles (Schweppe, Caramanis, & Tabors, 1988).

One way of studying various investment options for production facilities, for example, is through the expected utilisation rate and the distribution between fixed and variable costs. Options involving high fixed costs but low variable costs are typically suitable for facilities with a high utilisation rate (i.e. many full load hours) as the total cost is minimised over time. Similarly, facilities with low fixed costs but high variable costs represent effective investment options at low expected utilisation rates.

From a resource adequacy perspective, peak load facilities, i.e. facilities that are used for a few hours, but which are crucial for maintaining the power balance, are of particular interest. According to the above, these types of facilities have relatively low fixed but high variable costs. As the number of hours in which peak load generation are used is relatively low, the prices on the energy market must be relatively high during these hours in order to generate sufficient revenue for the facility to be profitable. Firm generation needed to meet the increase in consumption over time also needs periods of high prices in the energy market in order for the facility to be profitable.

From a theoretical economic perspective, an energy-only market can create sufficient incentives for investment in peak load capacity, provided that market prices are allowed to be high enough to generate revenues during peak load hours that exceed the total costs of the facility. Assuming that investments are made if the prices are allowed to be high enough, the issue from a socio-economic perspective will then be which price levels are justifiable and effective. Given that a shortage situation arises, the benefit to society of an additional kWh of generation can be expressed as the difference between VOLL and the marginal cost of the additional generation. As the usage of additional generation is assumed to be reflected in the expected number of hours that there is a power shortage (i.e. LOLE), the overall benefit to society becomes the product of LOLE and the difference between VOLL and the marginal cost. The result of this calculation can then be compared to the investment cost. In cases where the investment cost is less than or equal to the overall benefit to society, the investment can be said to be socio-economically efficient as the benefit exceeds the cost (Holmberg & Tangerås, Kommande). It can be noted here that the benefit of investments in peak load generation to reduce the number of hours where there are power shortages is weighed against the costs of such investments. This assessment is the starting point for the methods used to calculate the reliability standard described in section 2.1.1.3.

In order for sufficient investments in peak load generation to be realised in an energy-only market, market prices must be allowed to reach the same level as VOLL, otherwise the operators will not be able to cover all their costs during the few hours that the facility is in use. Market prices that exceed VOLL, however, provide room for overinvestment, which deviates from the socio-economic optimum. It can be proven in theory that a price cap on the energy market equal to VOLL provides effective incentives under certain simplifying assumptions about the market (Joskow & Tirole, 2007).

The above principles serve as a starting point in the argument that an energy-only market provides sufficient and effective incentives for investments in new generation. Through peak-load pricing with a sufficiently high price cap, the market will, from a theoretical perspective, provide sufficient incentives to achieve a system with a socio-economically efficient adequacy level(Stoft, 2002).

2.3.1.1 Revenue in an energy-only market

An energy-only market model comprises several markets and trading in electricity takes place over different time perspectives based on long-term bilateral agreements such as PPAs, via financial markets, day-ahead and intraday markets to balancing markets which are managed in real time. Therefore, the incentives for investment arise on the basis of the total revenues from these markets.

Depending on the type of resource to which the investment relates and the preferences of different operators, the different markets can have different significance for investment decisions. With regard to investments in new generation with low marginal costs, long-term agreements such as PPAs play a role by creating a long-term perspective in revenue streams for producers, thereby reducing uncertainties and capital costs. For certain investments, such as efficiency-enhancing measures, risk management over shorter time horizons may be sufficient. This can be managed through the financial markets that, depending on the product, have time horizons of up to six years. The day-ahead market covers shorter time horizons, but plays a central role in creating a reference price for the longer-term markets. Finally, the real-time balancing markets also provide some investment signals by demonstrating how the need for balancing resources is evolving.

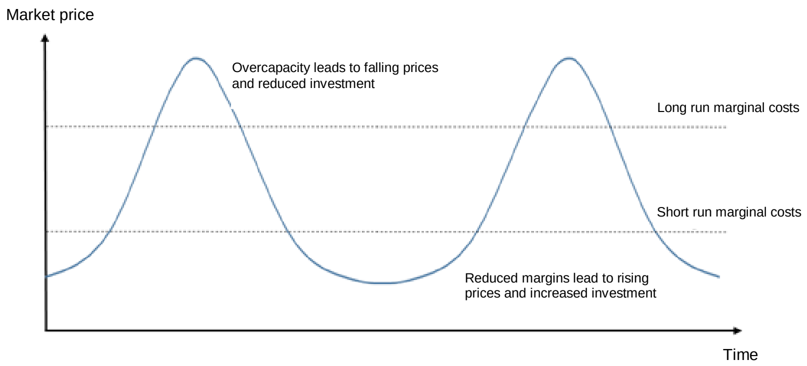
With regard to production resources with a low utilisation rate and which are used for few hours, revenue comes primarily from the short-term markets, such as the day-ahead market, the intraday market and the real-time markets.

2.3.1.2 Challenges for investment and resource adequacy in an energy-only market

All of the markets referred to in the previous section can contribute with revenue streams for operators thereby providing incentives for investment in production and flexibility. General price levels as well as volatility in these markets can give rise to investments in different types of facilities with varying features. However, there are a number of challenges concerning investment in an energy-only market.

In an energy-only market, investments in production capacity tend to be 'lumpy' and a cyclical pattern may occur with periods of overinvestment followed by periods of underinvestment (Arango & Larsen, 2011; Hary, Rious, & Saguan, 2016), as illustrated in Figure 5 . The logic behind this is that during times of surplus, the average price of electricity starts to fall in order to move closer to the short run marginal costs of generation. This in turn leads to underinvestment due to missing money on account of inadequate revenues to cover fixed costs. This phase can be explained by the fact that operators tend to be risk averse and therefore postpone investment due to uncertainties regarding future revenues. This means that the investments that would be needed are made late in relation to the need. When production facilities are closed down due to age and no new investments are made, there is increased scarcity and therefore higher energy prices. An increase in the average price gives a clear investment signal to market operators, which leads to capacity volumes being added to the system at an increasing rate. One explanation for overinvestment may be incomplete information about competitors' investments, which leads to 'herd behaviour'. Long lead times and irreversible investment decisions further accentuate this effect. This means that the market is back at the starting point with a surplus of capacity, and so the next cycle begins. From an adequacy perspective, this cyclical behaviour means that reliability suffers during periods of underinvestment, and that during periods of overinvestment the margins are too great in terms of what is justifiable from a socio-economic perspective.

Figure 5. Cyclical investment patterns in an energy-only market.



From an adequacy perspective, investment to cover the residual load[6] is a critical aspect. A key parameter for decisions to invest in production is the number of full load hours for which a facility may be used. Investment in intermittent production will typically reduce the full load hours for other production, but will only contribute to a limited extent to solving the issue of covering the highest residual load in the system. However, when the number of hours a facility may be used is reduced, the business case for investment in such facilities is undermined and makes revenues more volatile over time (Gross, Heptonstall, & Blyth, 2007).

As indicated previously, it is necessary for the market to allow for high prices at levels that far exceed marginal costs in situations where there is greater scarcity in order for investment in marginal production to be made. Although the market allows sufficiently high prices, a complicating factor is the relatively considerable uncertainty that such investments entail in terms of need. Demand for electricity and residual load can vary greatly from year to year, meaning that a facility that is used in one year may not be used for several years to come. Another complicating factor in energy-only markets is that market volatility gives rise to uncertainties thereby increasing capital costs. From this

[6] Residual load here means the net load, including intermittent generation such as wind power and solar power.

perspective, the risk is relatively high for such investments and there may be more attractive options for using capital. This applies to risk-averse operators in particular. Furthermore, there is a political risk as long investment cycles mean that the regulatory environment can change several times during a facility's lifetime. For investors, this means uncertainty as they need to be able to rely on maintaining high profits in certain periods to compensate for poor profitability in other periods. Long lead times and permit processes also increase investment uncertainty.

Historically, demand in the electricity market has been largely inelastic to market price, at least in the short term (Cialani & Mortazavi, 2018). This poses another challenge for the day-ahead market in terms of adequacy and the ability to clear the market. As demand is largely inelastic, situations may arise where supply cannot meet demand resulting in a shortage situation. Greater demand response to fluctuating prices would eliminate or mitigate this effect. Therefore it can be argued that adequacy challenges are more a question of a demand-side market failure than a question of insufficient investment in production capacity (Cramton, Ockenfels, & Stoft, 2013).

2.3.2 Investments with a capacity mechanism

2.3.2.1 Arguments for a capacity mechanism

Based on the previous section on investment in an energy-only market, potential weaknesses exist that prevent investment from happening to the extent, or at the times, required in order to maintain effective adequacy. An answer to these challenges could be the introduction of a capacity mechanism (Joskow, 2008).

One weakness is whether prices are allowed to rise to such an extent that a sufficient amount of production capacity is 'in-the-money' to produce electricity only a few hours per year on average. There may be several reasons why prices do not reach such levels because there are price ceilings lower than VOLL. Reasons for such price caps may be management of market power(Holmberg & Newbery, 2010) or to protect consumers from high electricity prices. An uncertainty in this context is the degree of utilisation of the investment, as the residual load varies from year to year and marginal production can remain unused for long periods. Another uncertainty in this context is future changes in market regulations which mean that the environment may change over time in terms of, inter alia, price caps. The introduction of a capacity mechanism is one way of overcoming 'the problem of missing money' thereby creating sufficient incentives for investments to materialise.

Another weakness from an adequacy perspective is the cyclical investment behaviour, which is common in capital-intensive industries. Here, a capacity mechanism can create the conditions for investment to take place at the right time by reducing the risk for risk-averse operators.

The arguments for various forms of capacity mechanisms therefore consist of mitigating the effects of the potential weaknesses that energy-only markets have by design. Furthermore, inelastic demand makes it difficult to create 'market-based disconnection' in periods of scarcity when the price would be close to VOLL, which, in theory, would lead to a socio-economically efficient balance between investment in production and disconnection of load. From that perspective, the overall purpose of a capacity mechanism is to provide the amount of capacity that optimises the number of hours of power shortage (Cramton, Ockenfels, & Stoft, 2013).

2.3.2.2 Criticism of capacity mechanisms

There are a variety of possible design choices for capacity mechanisms and design criteria (Battle & Pérez-Arriaga, 2008). Usually there is a central operator, such as a TSO, which defines requirements and directly or indirectly[7] procures a specified volume of capacity. Demand is therefore a given and competition takes place through the price of capacity. This requires the need for capacity to be quantified in advance for the period covered by the capacity mechanism. Given that the mechanism is motivated by insufficient investment, relatively long contract terms are required, which means that the need for capacity is associated with great uncertainty. One criticism of capacity mechanisms is that the need is very uncertain, and that the central operator responsible for procurement overinvests in capacity (Newbery, 2016). Reasons for overinvestment may be a perceived pressure to maintain a reliable system, allowing for a worst case scenario, combined with a lack of incentives for the central operator to keep the costs of the capacity mechanism in check.

In addition to generating unjustifiably high costs, overinvestment also gives rise to the problem of missing money in the energy market, despite the fact that the very purpose was to overcome this problem (Newbery, 2016). The reason is that the average price in the energy market is affected and falls in the event of overinvestment, giving rise to a number of effects. One such effect is that operators avoid investing if the investment is not covered by the capacity mechanism because of the comparative disadvantage of not receiving a capacity

[7] TSO usually procures capacity, but in some countries and systems this responsibility is decentralised to DSO or resellers (e.g. France and CAISO).

payment. Furthermore, capacity market costs increase as revenues from the energy market fall for operators, which has to be compensated for through increased claims within the capacity mechanism framework. This creates a negative spiral where the share of revenues from the capacity market increases at the expense of decreasing shares from the energy market. This in turn leads to increased central control of the system's and the market's development through the growing importance of the capacity mechanism and the increased decoupling of investment from energy market revenues (Hogan, 2013).

Capacity markets are motivated by ineffective adequacy. In order for the mechanism to be effective, it is of key importance that the capacity procured is available in periods of system stress (Holmberg & Tangerås, Coming). However, there are examples of the opposite, for example Texas, which lost almost 30 GW of thermal production during the winter storm of 2021, primarily due to problems with gas deliveries when it was needed most, in spite of good incentives to produce electricity (Crampton, 2022). In order to be effective, the capacity mechanism should therefore be designed so that availability in periods of system stress is rewarded through penalty fees in the event of non-delivery at such times, or through reliability options that create incentives for availability in situations with high market prices (Bidwell, 2005).

2.4 Socio-economic efficiency

The design of a capacity mechanism post 2025 needs to be justified on more grounds than its compliance with State aid rules and the Electricity Regulation or its ability to reduce risks for investors. It should be justifiable on the basis of socio-economic efficiency in a broader perspective.

A capacity mechanism correctly designed through a competitive procurement process, with the right capacity requirement in the right place in the electricity system, can result in reduced system costs in the medium term by ensuring that Sweden's reliability standard is achieved at the lowest cost. Reduced system costs to achieve a given outcome are a socio-economic benefit that can be evaluated. Without sufficient capacity during periods of system stress there are also more or less difficult to assess risks associated with reduced net benefit to society:

- Delayed energy transition and missed climate targets.
- Deterioration in resource adequacy and power shortages, resulting in higher costs in accordance with the value of lost load for industrial facilities, service industries and households.
- Price volatility and unpredictability of the availability of spare capacity for new connections delays and discourages investment in electricity-

intensive industries due to investment risks (higher risk premiums) and higher capital costs.

- In the long run, higher capital costs will lead to a reduced consumer surplus among end customers due to higher commodity prices.
- Greater risk of short-term and costly market interventions by policymakers and the TSO creating market uncertainty.

The disadvantages that are highlighted with such market interventions and that can lead to increased social costs are that the procurer rarely has complete information about the future and tends to dimension the capacity mechanism for a worst-case scenario, which leads to too much production capacity and stranded costs that may be passed on to customers. Another risk is that the requirements are designed so that in practice they favour electricity production at the expense of flexible electricity consumption and storage facilities with low marginal costs.

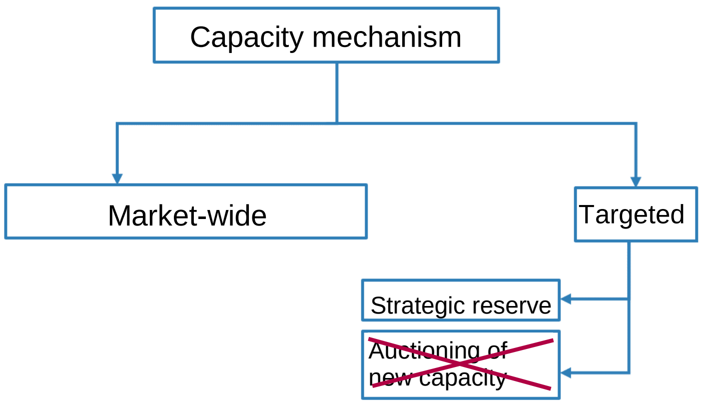
3 A targeted or market-wide capacity mechanism

There are many forms of capacity mechanisms. On a general level, these can be grouped into two categories: targeted or market-wide mechanisms as illustrated in Figure 6. This represents an important choice of direction in terms of introducing a capacity mechanism after 16 March 2025. In a targeted capacity mechanism, only the additional capacity needed to meet the reliability standard is procured. In a market-wide mechanism, all the capacity needed to meet the reliability standard can participate and be remunerated, regardless of whether it is new or existing capacity. This makes capacity a new product that complements the energy products available on the electricity market.

A procurement process in the context of a targeted capacity mechanism can in theory be designed to only include new capacity[8] or as a strategic reserve where the procurement process is open to all to submit tenders. In practice, EU law limits a targeted capacity mechanism to only being designed as a strategic reserve that is open for all resources to participate in.

A market-wide capacity mechanism involves a number of design choices which are described in more detail in Chapter 4. This chapter begins with the legal framework provided by the Electricity Regulation and concludes with an assessment of the pros and cons of targeted and market-wide capacity mechanisms.

Figure 6. General grouping of capacity mechanisms.



[8] This also includes capacity mechanisms designed as State investment aid.

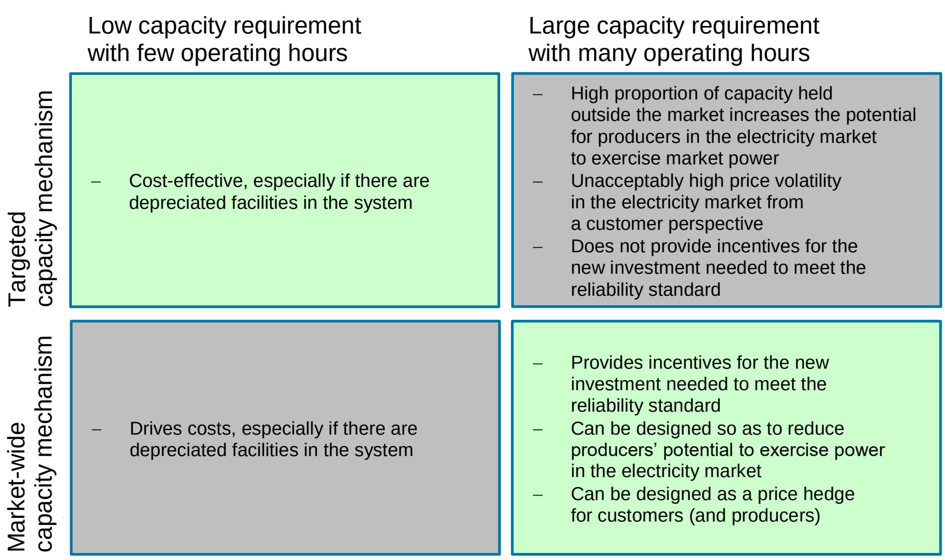
In summary, there are a number of pros and cons with each alternative, as shown in Table 5.

Table 5. Comparison of targeted and market-wide capacity mechanisms.

Features	Targeted capacity mechanism (strategic reserve)	Market-wide capacity mechanism
Impact on energy-only market	Minor: same or increased profitability (price volatility) of flexible resources	Major: reduced profitability (price volatility) of flexible resources
Link to energy market	Weak: ineffective use of available resources	Strong: efficient use of available resources
Reactive or proactive management of resource adequacy concerns	Reactive: short-term capacity auctions with short delivery periods	Proactive: forward-looking capacity auctions with long delivery periods
Approval process at the European Commission	Quick	Slow
Red tape for TSO and market operators	Minor	Major
Procurement process design	Low level of complexity	High level of complexity

There are also pros and cons that depend on the size of the capacity requirement as shown in Figure 7.

Figure 7. The pros and cons of targeted and market-wide capacity mechanisms depend on the size of the capacity requirement and how it is expected to evolve over time.



Svenska kraftnät believes that the additional capacity needed in a number of years may be so great that the current power reserve in the form of a strategic reserve will not be fit for purpose. Since it may be very difficult to meet the additional capacity needed with existing facilities, storage or demand response which, for various reasons, are not already participating in the energy market, Svenska kraftnät will recommend the introduction of a market-wide capacity mechanism in due course. However, a strategic reserve is deemed to be fit for purpose as a transitional solution for a few years after 2025 (approx. three years), but with certain modifications (for example, open to demand response and requirement for participating resources to be available all year round) in order to obtain approval from the EU Commission.

3.1 Legal overview

The Electricity Regulation contains a number of general principles for capacity mechanisms. Member States must assess whether a capacity mechanism in the form of a strategic reserve is capable of addressing resource adequacy concerns. Where this is not the case, Member States may implement a different type of capacity mechanism (Article 21(3)).

According to Article 22(1) of the Electricity Regulation, a capacity mechanism shall be temporary, not create undue market distortions and not limit cross-zonal trade and not go beyond what is necessary to address the adequacy concerns referred to in Article 20.

Capacity providers must be selected by means of a transparent, non-discriminatory and competitive process and incentives provided for capacity providers to be available in times of expected system stress. More specifically, the capacity mechanism shall apply appropriate penalties to capacity providers that are not available in times of system stress. The capacity mechanism shall also set out the technical conditions for the participation of capacity providers in advance of the selection process and ensure that remuneration is determined through a competitive process. This excludes price-based capacity mechanisms where remuneration is determined in advance, but requires that the procurement process is volume-based, i.e. is carried out on the basis of a predetermined capacity volume and where remuneration is determined competitively.

A capacity mechanism shall be open to participation of all resources that are capable of providing the required technical performance, including energy storage and demand side management. This excludes a targeted capacity mechanism where only new capacity is allowed to participate since it is not open to the participation of all existing resources. Historically, there have been different types of aid for investment in Sweden, for example for small-scale hydropower, biomass CHP plants and wind power, which are examples of mechanisms designed as targeted support. However, they have in common that they are not designed as a capacity mechanism with the aim of ensuring available capacity in the event of scarcity in the electricity market. In 2014, Belgium attempted to conduct a targeted procurement of new gas turbines with a total of 700–900 MW. However, it had to cancel the procurement process as the capacity mechanism met with huge criticism from, among others, the Belgian Federal Commission for Electricity and Gas Regulation, CREG, based on its discrimination of other technologies and existing capacity. The European Commission also judged in an evaluation that the capacity mechanism posed a risk of being illegal State aid, as it was discriminatory and risked distorting competition and trade between Member States. Especially in light of the recently published communication from the European Commission including guidelines for State aid for environmental protection and energy 2014–2020 (Hancher, De Hauteclocque, Huhta, & Sadowska, 2022).

Consequently, a strategic reserve remains the only alternative to a targeted capacity mechanism, but with conditions for the resources that are included, as stated in section 3.1.1.

3.1.1 Strategic reserve

A strategic reserve is a targeted capacity mechanism in the sense that only a limited number of capacity providers are awarded contracts and are remunerated for being available. A strategic reserve should be the first choice under Article 21(3) of the Electricity Regulation. Article 22(2) of the Electricity Regulation sets out a number of principles and requirements for the design of a strategic reserve so that it does not have undue negative effects on competition, trading and balancing:

(a) where a capacity mechanism has been designed as a strategic reserve, the resources thereof are to be dispatched only if the transmission system operators are likely to exhaust their balancing resources to establish an equilibrium between demand and supply;

(b) during imbalance settlement periods where resources in the strategic reserve are dispatched, imbalances in the market are to be settled at least at the value of lost load or at a higher value than the intraday technical price limit as referred in Article 10(1), whichever is higher;

(c) the output of the strategic reserve following dispatch is to be attributed to balancing responsible parties through the imbalance settlement mechanism;

(d) the resources taking part in the strategic reserve are not to receive remuneration from the wholesale electricity markets or from the balancing markets;

(e) the resources in the strategic reserve are to be held outside the market for at least the duration of the contractual period.

The requirement referred to in point (a) of the first subparagraph shall be without prejudice to the activation of resources before actual dispatch in order to respect the ramping constraints and operating requirements of the resources. The output of the strategic reserve during activation shall not be attributed to balance groups through wholesale markets and shall not change their imbalances.

3.1.2 Other capacity mechanisms

Article 22(3) of the Electricity Regulation provides that capacity mechanisms other than strategic reserves shall:

(a) be constructed so as to ensure that the price paid for availability automatically tends to zero when the level of capacity supplied is expected to be adequate to meet the level of capacity demanded;

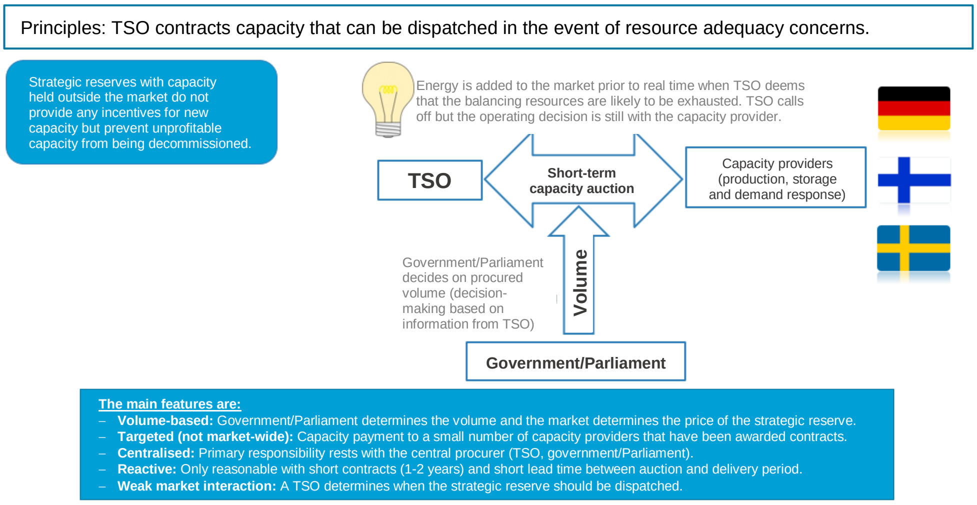
(b) remunerate the participating resources only for their availability and ensure that the remuneration does not affect decisions of the capacity provider on whether or not to generate;

(c) ensure that capacity obligations are transferable between eligible capacity providers.

3.2 Targeted capacity mechanism

The legal framework described in section 3.1 means that a targeted capacity mechanism can only be designed as a strategic reserve similar to the mechanism that Sweden currently operates. Figure 8 shows a schematic diagram of a strategic reserve and countries in Europe operating such a reserve.

Figure 8. Schematic diagram of a strategic reserve.



3.2.1 Pros and cons of a strategic reserve

A strategic reserve should be the first choice in accordance with the Electricity Regulation. Its design is also more detailed in the Electricity Regulation compared to other capacity mechanisms. One advantage of the high level of detail in EU law and the explicit preference for a strategic reserve is that it should simplify and shorten the process of getting an application approved by the EU Commission. The options need to be justified on a general level and have more design choices that need to be discussed, made and justified.

A strategic reserve also does not have the same requirements for cross-border participation, which should be associated with a less complex procurement process design and lower procurement costs. In a decentralised electricity market like the Nordic market, a strategic reserve is associated with less red tape for TSOs and market operators as it only requires a TSO to define the equivalent of de-rating factors and verify the availability of the resources included in the reserve.

In theory, a strategic reserve can lead to minor distortions in an energy-only market compared to alternatives that include a market-wide capacity mechanism. This is due, among other things, to the fact that a strategic reserve must be designed as a last resort for a TSO to activate prior to manual disconnection in order to manage incidents involving expected power shortages in the electricity market. To avoid affecting the profitability (price volatility) of existing and potential new flexibility resources, the activation of resources in the strategic reserve will not affect the pricing of operators' imbalance settlements, but shall be settled at least at the value of lost load or at a value higher than the technical price limit on the intraday market, which is currently EUR 9,999 per MWh.

There are also requirements for participating resources to be held outside the electricity market, which eliminates the risk of distortion of competition due to a small number of resource owners receiving a capacity payment within the framework of the capacity mechanism, which can make their bids more competitive.

If the need for additional capacity in order to meet the national reliability standard is minimal with a small number of expected operating hours, a strategic reserve can be a cost-effective solution. Especially if there is existing capacity in the system that would otherwise be decommissioned for profitability reasons. Traditionally, strategic reserves have been justified from precisely this aspect, as they involve thermal fossil-fuel power plants that have become unprofitable in the electricity market due to the expansion of renewable electricity generation with low marginal costs.

The drawbacks of a strategic reserve become increasingly salient as the capacity requirement and expected operating hours increase. A large capacity requirement means that a large proportion of contracted capacity is held outside the market, which increases the potential for producers who are still part of the energy market to exercise market power. This risk is very real given the rather price inelastic demand curve that has been observed historically in the electricity market.

The major drawback of a strategic reserve is the reactive management of resource adequacy concerns and the inability to provide incentives for new investment. Short lead times between the auction and the delivery period combined with short contract durations (in Sweden 1–5 years) is good for older, existing plants with an uncertain operating status, but does not provide incentives for new investment. Its focus on existing plants tends to result in bids from capacity providers reflecting short- or medium-term opportunity costs to withhold capacity from the energy market, plus fixed maintenance costs, minus anticipated gains from actually being activated in order to provide energy (Cramton, Ockenfels, & Stoft, 2013). The combination of short-term contracts, short lead times and low prices makes it unlikely that a strategic reserve can provide incentives for investment in new capacity. The European Commission put forward a similar argument in a 2016 report in which it concludes that a strategic reserve may be useful in overcoming shorter periods where there are challenges in terms of adequacy, provided that adequate capacity is available that would otherwise risk leaving the system. A strategic reserve is therefore less suitable for promoting new investment, which usually requires more long-term capacity mechanisms (EU Commission, 2016). Svenska kraftnät confirms that in the unlikely event of new investment, it is not cost-effective to finance the entire investment cost through a strategic reserve, in view of its low resource utilisation.

From a market perspective, a large proportion of capacity held outside the market will mean that price volatility will be very high. Although increased price volatility provides greater incentives for new investment in firm and flexible production through revenue from the energy market, fluctuating energy prices may be perceived as unacceptable from a customer perspective, especially as customers are already financing a costly strategic reserve. Holding back a large proportion of capacity from the energy market can also lead to increased resource use and higher electricity prices through inefficient dispatch of available resources and, over time, bias the long-term production mix (Cramton, Ockenfels, & Stoft, 2013).

Table 6. Pros and cons of a strategic reserve. The disadvantages become increasingly salient the greater the capacity requirement.

Pros	Cons
Low impact on the energy-only market with same or increased profitability (price volatility) of flexible resources	Weak energy market interaction can lead to inefficient use of available resources
Quick and smooth approval process at the European Commission	Reactive management of resource adequacy concerns
Less red tape for TSO and market participants	
Less complex procurement design	
Given a low capacity requirement and few operating hours: • Cost-effective, especially if there are existing plants in the system	Given a high capacity requirement and numerous operating hours: • High proportion of capacity held outside the market increases the potential for producers in the energy market to exercise market power • Unacceptably high price volatility in the energy market from a customer perspective • Does not provide incentives for the new investment needed to meet the reliability standard

In summary, a strategic reserve can be a cost-efficient and appropriate transitional solution for addressing a minor resource adequacy concern of a temporary nature by contracting existing plants that are at risk of closure. The reactive management of resource adequacy concerns and the inability to provide incentives for new investment in capacity mean that a strategic reserve is not fit for the purpose of addressing major resource adequacy concerns.

3.2.2 Examples of strategic reserves

In Europe, a small number of Member States operate a strategic reserve in order to ensure resource adequacy in the electricity market. Below is a review of Member States that have, or have had, a strategic reserve.

3.2.2.1 Sweden

The current Swedish power reserve is regulated in accordance with the Lag (2003:436) om effektreserv (Act on Power Reserves), which is time-limited to 16 March 2025, and Förordning (2016:423) om effektreserv (Regulation on Power Reserves). The recast Electricity Regulation came into force on 1 January 2020, which means, inter alia, that no new power reserve contracts can be entered into after this date. In the run-up to the entry into force of the recast Electricity Regulation, Svenska kraftnät chose, as a transitional solution, to use the applicable options in autumn 2019 and renew its agreement with Karlshamnsverket to make 562 MW of electricity production capacity available to the power reserve until 16 March 2025.

Demand response was not deemed to be part of the transitional solution for legal and practical reasons. The legal basis for excluding demand response was provided in the wording of Article 22(2) of the Electricity Regulation, i.e. that operators participating in the power reserve are to be held outside the market. However, there may be reason to reconsider that assessment in light of Article 22(1) of the Electricity Regulation, which stipulates that a capacity mechanism should be open to the participation of all resources that are capable of providing the required technical performance, including energy storage and demand side management. Finland is an example in the EU where demand response can participate in the strategic reserve. The practical reason for excluding demand response in Sweden was that consumers were said to be reluctant to enter into five-year contracts due to uncertainties regarding the development of underlying consumption over time.

The power reserve may only be activated if Svenska kraftnät is likely to exhaust its balancing resources. Such an assessment can only take place close to the operational phase. This is why the option to activate the power reserve on the day-ahead market was removed prior to winter 2022/23. Activation of the power reserve will now only take place if Svenska kraftnät believes that the balancing resources will be exhausted. If the power reserve is activated for balancing power, the imbalance price is set at the highest of:

- value of lost load (VoLL) or,
- a value of one euro higher than the technical price limit on the intraday market.

If Sweden were to extend the existing power reserve after 2025, this would probably require State aid approval. In addition, modifications will be needed in order to fully adapt the power reserve in line with European requirements.

At present, the agreement with Karlshamn only covers availability during the winter period (16 November –15 March). At other times, the resource owner can make its resources available on the wholesale markets for electricity or on the balancing markets. This means it can receive remuneration from the wholesale electricity markets or from balancing markets, which can be called into question based on the wording in the Electricity Regulation that the resources are to be held outside the market for the duration of the contractual period.

In addition to changes relating to compliance with European requirements, the Lag om effektreserv (2003:436) needs to be amended as it is time-limited until 16 March 2025. The Förordning (2016:423) om effektreserv also needs to be reviewed, as it, inter alia, limits the volume to 750 MW unless there are special reasons to the contrary.

3.2.2.2 Finland

Finland had its application to the European Commission for a Finnish capacity mechanism of EUR 150 million in the form of a strategic reserve approved on 11 October 2022.[9] This makes it possible for Finland to procure reserve power on an ongoing basis until 2032.

Ahead of the 2022/23 winter period, on 23 August 2022, Fingrid published an initial assessment of the capacity needed to address resource adequacy concerns. In this assessment, the requirement was estimated at 600 MW. However, the Finnish Energy Authority decided to cancel the procurement of reserve power for the period 1 November 2022 until 31 October 2023, as it had not received a single approved tender. Svenska kraftnät and Fingrid have a long tradition of harmonised rules on pricing principles, among other things, and the market places in which the power reserve should be activated. If Finland had procured reserve power, it would have followed the same principles for activation and pricing as Sweden.

[9] State Aid SA.55604 – Finnish strategic reserve.

3.2.2.3 Belgium

Belgium had a strategic reserve until winter 2021/22. The strategic reserve was approved by the European Commission, and its design was based on the Communication from the Commission – Guidelines on State aid for climate, environmental protection and energy 2014-2021. Belgium gave as reasons in its application to the European Commission that it expects to have a structural capacity deficit from 2025 once its planned nuclear shutdown has been completed. It also argued that an energy-only market only provided incentives for a very small proportion of the additional capacity needed by 2025. The Belgian Electricity Act was amended so that a market-wide mechanism for capacity payment could be introduced. The first auction took place in October 2021 with delivery in November 2025.

3.2.2.4 Germany

In Germany, several capacity reserves are procured for specific purposes such as grid adequacy, resource adequacy and to maintain operational reliability in the event of outages.

The capacity reserve for resource adequacy is considered a strategic reserve and was approved by the European Commission in February 2018. The first auction was held in December 2019 with a delivery period of October 2020-September 2022. Resources that receive a capacity payment are held outside the electricity market and are activated by German TSOs in cases where resource adequacy concerns arise after the day-ahead market has closed. The delivery period is two years with the option to extend. If the contracts are not extended, these resources may not return to participating in the market and must be phased out. However, the resources can still be used as a grid reserve.

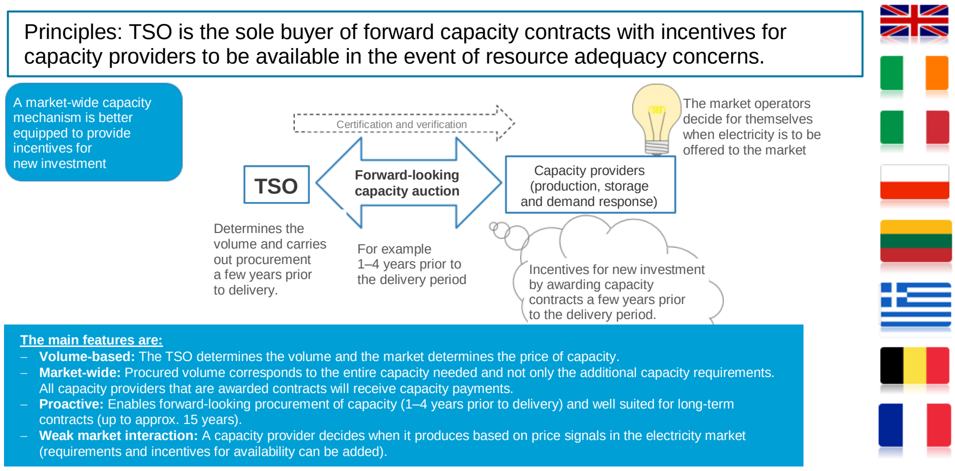
3.3 Market-wide capacity mechanism

Market-wide capacity mechanisms are not dealt with in as much detail in EU law as a strategic reserve, and consequently there are more design choices to consider in order to select an appropriate design based on national requirements. Therefore, in this section, the pros and cons of a market-wide capacity mechanism are addressed on a more general level. Figure 9 shows a schematic diagram of a centralised[10] market-wide capacity mechanism and countries in Europe that have one or plan to operate one. As the design varies

[10] A centralised capacity mechanism is by far the most common design in Europe. France is the only country that operates a decentralised capacity market but has announced plans to move to a centralised model.

from country to country, a more thorough review of the different applications will be presented in chapter 4.

Figure 9. Schematic diagram of a centralised market-wide capacity mechanism.



3.3.1 Pros and cons of a market-wide capacity mechanism

In a market-wide capacity mechanism, the capacity providers themselves determine when they produce based on price signals in the electricity market. Requirements and incentives for availability can also be added within the framework of the mechanism, which is also a requirement under the Electricity Regulation. The strong link to the electricity market enables the efficient use of available resources, provided that any requirements or incentives in the mechanism do not bias the bidding strategy of the operators in the sense that bids deviate from variable costs.

The major advantage of a market-wide capacity mechanism is that it enables proactive management of resource adequacy concerns that are expected to arise a few years into the future, especially if the expected requirement for additional capacity exceeds the supply of existing facilities that for various reasons are not already participating in the energy market. Additional capacity needed can be procured through a series of forward auctions with long delivery periods. This enables operators to finance and connect new facilities to the electricity system prior to the delivery period (see section 4.6).

Other benefits of a market-wide capacity mechanism are that it can be designed to reduce the potential of producers to exercise market power in the energy market, while at the same time be designed to offer price hedging for customers and producers (see section 4.3).

Some drawbacks of a market-wide capacity mechanism relate to a time-consuming approval process at the European Commission and complex design of procurement processes with requirements for cross-border participation in accordance with the argument presented in section 4.1.3. Participation in a capacity market is based on plant-specific bids and may need to be preceded by some form of prequalification and ultimately verification of the resource's availability during periods of system stress. This means more red tape for TSOs and market operators, which in particular risks affecting micro-producers and demand response. The greater red tape is in stark contrast with the Nordic electricity market, where the balancing responsible party can make portfolio bids based on its net position in the electricity market. The de-rating factors used to make bids from different types of technology comparable are complex to calculate in a fair manner and can give rise to bias in the market. This applies in particular to non-thermal technologies such as solar power, wind power, demand response, hydropower and energy storage that can be constructed in a number of different configurations (Holmberg & Tangerås, Coming). This should reasonably also apply to cogeneration which has different seasonal profiles depending on varying demand for heat, the option of cooling, flue gas condensation, etc.

A market-wide capacity mechanism can lead to reduced profitability (price volatility) of flexible resources in an energy-only market. This applies in particular if the central buyer (a TSO) procures too much capacity in relation to what is ideal, which leads to oversupply and low prices on the energy market. As the expected revenues from the energy market decline, remuneration requests and auction prices increase on the capacity markets. An over-dimensioned capacity mechanism can thus lead to the volume of new investment being determined entirely by a TSO, which effectively puts the basic function of the deregulated energy-only market out of play (Newbery, 2016).

A market-wide capacity mechanism is not cost-effective if the need for additional capacity in order to meet the national reliability standard is minimal and temporary with a low number of expected operating hours. Especially if the capacity requirement can be met with existing capacity that would otherwise be shut down for profitability reasons.

Table 7. Pros and cons of a market-wide capacity mechanism. The pros become more salient the greater the capacity requirement.

Pros	Cons
Strong link to the energy market leads to efficient use of available resources	Reduced profitability (price volatility) of flexible resources on the energy market
Enables proactive management of future resource adequacy concerns	Time-consuming approval process by the European Commission
	Extensive red tape for TSO and operators
	Complex procurement design
Given a high capacity requirement and numerous operating hours: • Provides incentives for the new investment needed to meet the reliability standard • Can be designed to reduce producers' potential to exercise market power in the energy market • Can be designed as a price hedge for customers (and producers)	Given a low capacity requirement and few operating hours: • Drives costs, especially if there are already depreciated facilities in the system

In summary, market-wide capacity mechanisms may be appropriate for addressing major resource adequacy concerns that are expected to occur a few years into the future as they provide incentives for new investment. They are less suited to addressing minor and temporary resource adequacy concerns that are expected to arise in the near future. The proactivity of market-wide capacity mechanisms makes them suitable for a Member State that believes clearer regulation and centralised management of the market is necessary to ensure incentives for all the investment in new capacity that is required in order to meet the reliability standard within a reasonable time, in spite of the greater red tape that this involves for the TSO and market operators.

3.4 Interaction with other aid schemes and review of European market design

On 15 March 2023, the European Commission proposed a reform of the EU's electricity market design. It is primarily the proposal to boost investment incentives that is of interest in terms of this report.

3.4.1 Contracts for difference

To promote the development of new fossil-free electricity production, the European Commission proposes two-way contracts for difference as a subsidy model for investment.

A contract for difference is basically a financial contract for remuneration based on whether the energy price differs from an agreed reference price. However, in the energy markets they have been used as a subsidy model where differences from an agreed reference price are paid to the producer for the volume of energy delivered. In principle, this can be a model where payment is made if the price is below the reference price and there is therefore a guarantee regarding the lowest price. A two-way contract for difference is a more symmetrical model in which the difference is paid back if the price exceeds an agreed reference price. The contract can either be designed so that the same reference price is used for payment (from the government) if prices are low and payment back (to the government) if prices are high. An alternative is that different reference prices are used and that the market price is obtained between these reference prices. The design therefore has a price-equalising effect and is intended to provide investors with the security of income from the energy market that is required for investments to be made, at the same time as the public party receives payments when the market price for electricity exceeds the upper reference price.

Discussions on contracts for difference at European level should be viewed from the perspective that they constitute a subsidy model for renewable or fossil-free production that is not flexible to any great extent. Technologies covered by the European Commission’s proposal are wind, solar, geothermal, hydropower without reservoir and nuclear power. Given the design of a contract for difference, this type of subsidy model is less suitable for providing incentives for investment in flexible production.

The technologies for which contracts for difference are proposed as a suitable instrument contribute to increasing adequacy in the market to varying degrees. However, there are no proposals that contracts for difference should include requirements for availability in periods of system stress in order to contribute to resource adequacy in the market. Furthermore, there are limited incentives for capacity covered by a contract for difference to be available in periods of system stress as it is likely that the market prices will then exceed the defined reference price. Therefore, market prices do not reach operators and incentives do not exist. If this type of arrangement is introduced, coordination will be required between contracts for difference and capacity contracts. Since both can be considered to constitute some form of State aid, a reasonable starting point is that facilities covered by a contract for difference are not eligible for remuneration from the capacity market. However, consideration should be given to the capacity that facilities with contracts for difference contribute in periods of system stress so that this is implicitly included in the supply curve for the capacity market.

3.4.2 Targeted support schemes for non-fossil flexibility through demand response and storage

The Commission proposes that Member States with capacity mechanisms consider promoting the participation of non-fossil flexibility as demand response and storage by introducing additional criteria or features to the design of capacity markets. Furthermore, it is proposed that if these measures are not sufficient to meet an identified need for flexibility, Member States may introduce flexibility support schemes involving payments for available capacity. According to the proposal, Member States that have not introduced capacity mechanisms should also be able to introduce targeted flexibility support schemes.

According to Svenska kraftnät interpretation, this is in practice a targeted capacity mechanism. It is not entirely clear in the European Commission's proposal whether this mechanism is strictly limited to demand response and storage, or whether non-fossil production could also be covered by such a mechanism. However, the starting point for the proposal appears to be to specifically support demand response and storage.

3.4.3 Peak shaving product as a non-frequency related ancillary service

The Commission also proposes the option of introducing a peak shaving product as a non-frequency related ancillary service. A TSO must then be able to procure such products in order to reduce demand for electricity during peak hours.

The dimensioning of such a product should be based on an assessment of the need for additional services to ensure security of supply. This assessment should consider the reliability standard, as well as grid stability criteria for maintaining operational security.

The proposal is that contracts for such a product should not be entered into earlier than two days prior to activation and that the contract period must not be longer than one day. Activation should also take place after the day-ahead market has closed and before the balancing market opens. The latter appears to pose an obvious risk that the regular day-ahead market and the intraday market will be drained of demand response.

This type of product can therefore be regarded as a targeted capacity market (against peak shaving) with very short lead times and short-term contracts.

3.4.4 Long-term power purchase agreements

According to the European Commission, long-term power purchase agreements (PPAs) can help reduce the effects of sudden and temporary movements on the electricity market and it may therefore be desirable to promote the transition to a more long-term electricity market. In order to open the PPA market to smaller operators, it is proposed, inter alia, to introduce certain state guarantees and other measures to promote the use of PPAs. PPAs can potentially help facilitate investment, but there is no direct link to a capacity mechanism.

4 Design choices

A market-wide capacity mechanism can be designed in several different ways. This chapter contains a review of the design choices that need to be made and justified in connection with any application to the European Commission.

4.1 Geographical boundaries and management of transmission capacity

The geographical boundaries of the capacity market and the management of transmission capacity between capacity markets are important aspects in the dimensioning and procurement of a capacity mechanism. Geographical boundaries are also crucial for providing locational signals for new capacity at the right place in the electricity system.

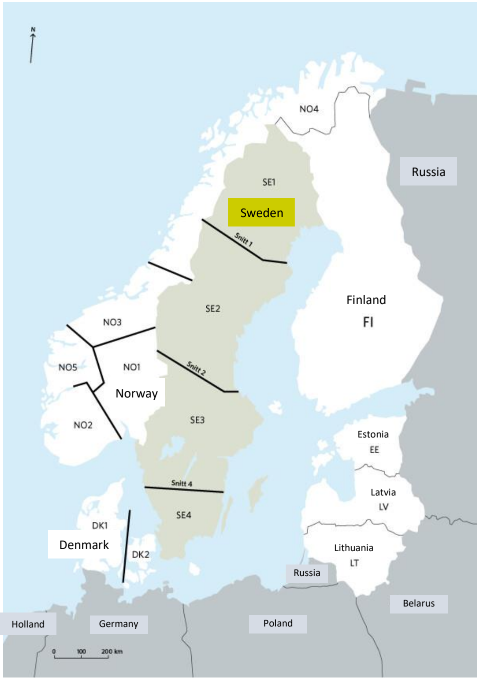
There are reasons to manage transmission capacity across internal bidding zone borders within Sweden differently from foreign participation via interconnectors, as the latter is strictly regulated under the Electricity Regulation and requires agreements with other TSOs. There is more scope when it comes to the management of transmission capacity across internal bidding zone borders, which is why it constitutes a key design choice when designing a capacity mechanism.

This section contains an assessment of the legal and theoretical framework for how the relevant market can be determined and proposals for tentative solutions, including how transmission capacity between domestic and foreign bidding zones should be managed.

4.1.1 The geographical boundaries of the market should follow those of the bidding zones

Svenska kraftnät believes that the geographical boundaries of the capacity market need to at least follow the bidding zone configuration at any given time, as each bidding zone has unique challenges as well as the prerequisites for meeting the national reliability standard with the help of new production capacity, flexible electricity consumption or net imports. A high expansion rate of renewable electricity generation, especially in northern Sweden, makes it difficult to remove transmission constraints in the transmission grid at the required rate. The capacity market should therefore be divided in a manner that highlights the transmission constraints in the transmission grid so that capacity payments are relatively higher in areas with a high LOLE and a great need for additional capacity.

Sweden is an elongated country with changing requirements for electricity generation and electricity use. At the time of producing this report, Northern Sweden (SE 1 and 2) has an electricity generation surplus that is exported to the consumption-dominated deficit area in southern Sweden (SE 3 and 4). National and European resource adequacy assessments show an increasing need for capacity in southern Sweden in order to meet the reliability standard.



The future may see a more dynamic trading flow and forecasts of increases in demand in northern Sweden indicate that, as early as 2026, long periods of northbound trading flows between SE 2 and 1 may occur during the summer period (Svenska kraftnät, 2022:1). If the planned hydrogen investments in northern Sweden become reality, the deficit in SE 1 will be drastically increased during the 2040s, which may change trading flow dynamics significantly(Svenska kraftnät, 2021:4).

According to Article 23(1) of the Electricity Regulation, a resource adequacy assessment is to be carried out for individual bidding zones where relevant. This requirement should be relevant for Sweden, as we have four bidding zones. There is little prospect of procuring capacity with higher geographical granularity than bidding zones as capacity mechanisms under the Electricity Regulation need to address an identified resource adequacy concern at bidding zone level, where relevant.

Transmission constraints within a bidding zone are to be managed primarily through market-based redispatching of flexible resources or grid reinforcement. There are also examples of countries in Europe that have resolved internal transmission constraints in bidding zones using grid capacity reserves (e.g. Germany and Austria). Grid capacity reserves are not defined in the Electricity Regulation, but are likely to require an application approved by the EU Commission in accordance with the regulations on State aid. In Austria's case, approval is conditional on the mechanism being a temporary transitional solution and participating resources being held outside the electricity market. Germany has a similar approach although it lacks formal approval from the European Commission. The purpose of a grid capacity reserve cannot be to maintain an incorrect bidding zone configuration in the long term, but the main rule is that bidding zones must be designed to reflect structural transmission constraints in the transmission grid. The prerequisites for procuring capacity with higher geographical granularity can, however, be changed as part of the bidding zone review which is to be carried out at regular intervals.

4.1.1.1 The configuration of bidding zones can be changed over time

Electricity systems are constantly changing and structural transmission constraints can, over time, both cease and arise in new locations. In accordance with Article 14 of the Electricity Regulation, each Member State is obliged to take part in the European bidding zone review which will take place on a regular basis.[11] The bidding zone review may have consequences for the current bidding zone configuration in Sweden. Such a change should not affect the commitment to existing capacity resources in the capacity mechanism. However, the reference price used for the financial settlement in the event of a reliability option can be changed so that it is based on the price in the new bidding zone where the capacity resource is located, which may involve a priori an increased risk for a resource owner who participates in the mechanism if the price differs significantly from the previous reference price, and the resource owner has problems being available during periods of high prices.

4.1.2 Transmission capacity management in Sweden

Svenska kraftnät believes that capacity should be priced according to the same conceptual approach as the auction algorithm on the day-ahead market. This means that transmission capacity between internal electricity areas is priced implicitly in the procurement based on the expected trade flows that arise in the energy market.

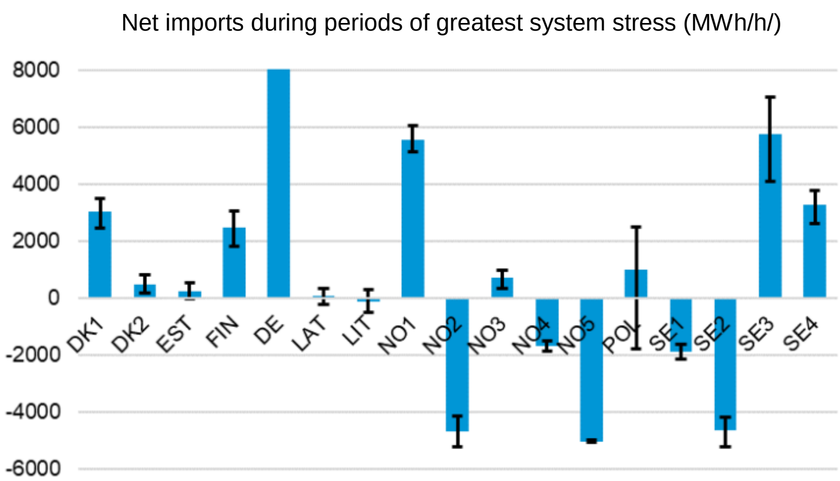
The management of transmission capacity in Sweden is an important design choice. The Italian capacity market is designed based on similar conditions to Sweden with several domestic bidding zones. The Italian TSO define a capacity demand curve based on the respective bidding zone and bidders submit bids for the zone where their capacity is located. The auction algorithm then accepts bids accordingly with the objective function to minimise costs in order to achieve the desired capacity level whilst not exceeding cross-zonal transmission limits. Conceptually, this is the same approach that applies to the day-ahead market. This means that if there are no binding transmission constraints, the agreed market price for capacity will be the same in all bidding zones, but if

[11] The ongoing bidding zone review is described on Svk's website https://www.svk.se/utveckling-av-kraftsystemet/systemansvar--elmarknad/elomradesoversyn/.

there are binding constraints, the algorithm splits the market into two or more zones with different capacity prices.

A difference from the auction algorithm in the day-ahead market is how transmission capacity is calculated. According to State aid regulations, a capacity mechanism must avoid undue negative effects on trading and balancing, among other things. Details on how to do so are provided for in Article 26(4) of the Electricity Regulation. In practice, this means that a capacity mechanism must honour the trading outcome on the day-ahead market and the balancing market and the transmission capacity calculations that form the basis for this. This means that the dimensioning of the capacity needed and the definition of the demand curve must take trading flows into account, and more specifically the expected net imports into the bidding zone during hours of power shortages in the electricity market. Figure 10 shows the results of a simulation of net imports to Swedish and foreign bidding zones during periods of greatest system stress for each bidding zone in the model year 2025, which Svenska kraftnät presented in the KMA 2022 report (Svenska kraftnät, 2022:1).

Figure 10. Simulated net imports during periods of greatest system stress for each bidding zone in the model year 2025. Negative value means that the bidding zone has net exports during periods of greatest system stress. The square brackets show the imports corresponding to the 10th and 90th percentiles for the 245 simulations. The bar for Germany is broken, the value is 14,400 MW.



Source: Svenska kraftnät (2022:1).

When determining the capacity needed for each bidding zone, the expected net imports during hours of power shortages in the electricity market need to be calculated based on what the future flow-based method for calculating transmission capacity is likely to look like and in consideration of how scarcity affects the allocated transmission capacity.

From an operator's perspective, capacity located in a bidding zone with a production surplus can contribute to resource adequacy in a bidding zone with a production deficit in accordance with the net exports between bidding zones expected during the determined hours. This increases the demand, and thereby the value, of the capacity in the exporting bidding zone compared with if the expected trade had not been considered in the dimensioning of the need. For capacity located in a bidding zone with a production deficit, the greater supply resulting from the expected net imports during the determined hours will mean that the value of the capacity is reduced compared with if the expected trade had not been considered in the dimensioning of the need. However, the market price of capacity will always be relatively higher in the deficit zone if the expected trade is binding in the sense that more expensive resources have to be contracted in the bidding zone with a capacity deficit in order to meet the reliability standard.

Any price differences that arise between bidding zones reflect the value of increased transmission capacity and should be recorded as congestion income for Svenska kraftnät to provide correct incentives for grid reinforcements or other measures that benefit customers.

4.1.3 Foreign participation via interconnectors

Sweden is connected to bidding zones in other countries and the total import capacity is 10.3 GW, which corresponds to approximately 25% of installed production capacity at national level, or 40% of the maximum consumption in Sweden of approximately 27 GW. The possibility to import capacity from other countries during hours with expected power shortages in the electricity market is significantly less than 10.3 GW, as this depends on the availability of interconnectors and the availability of bids that have not been called off abroad. It should also be kept in mind that parts of the import capacity go to northern Sweden and consequently do not have a direct contribution in the event of a shortage in southern Sweden.

The management of interconnectors and foreign resource owners in capacity mechanisms is relatively strictly regulated under EU law and regulations have developed over time. Originally, expected net imports from interconnectors were managed during periods of expected power shortages in the electricity market indirectly in the capacity mechanism. This was done by calculating the expected contribution from interconnectors during periods of expected power shortages in the electricity market. The capacity needed in the national capacity mechanism was subsequently adjusted in accordance with the expected contribution so that only the remaining requirement was procured. Examples of this are the first capacity auctions in the UK and France. Potential drawbacks of this approach are that neither transmission capacity nor foreign resource owners receive any capacity payment. This is similar to how foreign capacity is managed in the dimensioning and procurement of the strategic reserve that Sweden currently has.

A development of this approach was to modify the capacity mechanism with the aim of pricing transmission capacity by allowing interconnectors to participate directly in the procurement process. They were allowed to participate in accordance with the de-rating factor calculated on the basis of the expected net imports during periods of expected power shortages in the electricity market. They then had to compete with domestic resource owners and were included in the capacity mechanism if the bids were competitive. Examples of this design are the UK, which introduced it as a permanent solution. The approach involving the direct participation of interconnectors was also previously adopted in Poland and Ireland as a transitional solution. A consequence of this approach is that individual foreign resource owners do not receive any payment, but the approach recognises that it is the underlying electricity system that collectively contributes to enabling net exports to bidding zones where there is inadequacy.

The current target model in EU law is that capacity mechanisms that are not strategic reserves are open to direct cross-border participation of capacity providers in another Member State. Examples of countries that operate the target model are France, Ireland, Poland and Belgium. A common condition is that capacity providers in another Member State may only submit tenders for short-term contracts of a year or similar and are motivated by uncertainties about how much an interconnector is expected to contribute to resource adequacy during periods of expected power shortages in the electricity market.

A disadvantage of cross-border participation is that a capacity payment to individual resource owners in other Member States will at best have a negligible impact on national resource adequacy. Svenska kraftnät specifically questions the effectiveness of cross-border participation from countries without capacity markets in terms of impact on resource adequacy in Sweden as it is not deemed to lead to investment in new capacity. However, the European Commission has become increasingly strict in its approval process over time and now requires capacity mechanisms to be open to foreign resource owners from the outset (Ireland, Italy, Poland and Belgium). The legal prerequisites for foreign participation are described below.

4.1.3.1 Legal prerequisites

Article 26 of the Electricity Regulation sets out several conditions for cross-border participation in capacity mechanisms other than strategic reserves:

- open to resources in at least neighbouring countries (Article 26(2))
- capacity providers shall be able to participate in more than one capacity mechanism (Article 26(3) and 26(5))
- the electricity market outcome must not be affected (Article 26(4))
- capacity providers shall be required to make non-availability payments where their capacity is not available (Article 26(6))
- regional coordination centres shall calculate on an annual basis the maximum transmission capacity at each bidding zone border that is available for foreign participation in order to make recommendations to the TSOs that apply capacity mechanisms (Article 26(7);
- Where capacity mechanisms allow for cross-border participation in two neighbouring Member States, all congestion income arising in the capacity market shall accrue to the TSOs concerned (Article 26(9)).

TSOs where the foreign capacity is located are also obliged to set up a registry of eligible capacity providers who can provide the right technical performance and perform availability checks.

In 2020, Acer approved the detailed methodology[12] developed by ENTSO-E pursuant to Article 26.11 of the Electricity Regulation to calculate the maximum transmission capacity available for foreign participation, for sharing congestion income, common rules for carrying out availability checks, determining non-availability payments, terms of operation of the registry and identifying capacity eligible to participate in the capacity mechanism.

4.1.3.2 Proposal for cross-border participation according to EU target model

Svenska kraftnät believes that cross-border participation should be designed in accordance with the EU's target model developed by ENTSO-E and subsequently adopted by Acer (No 36/2020).

The current target model in the EU for cross-border participation of capacity providers in another Member State is based on a number of principles such as TSO-TSO cooperation on pre-auction design, prequalification of potential foreign capacity providers and monitoring of availability of contracted capacity

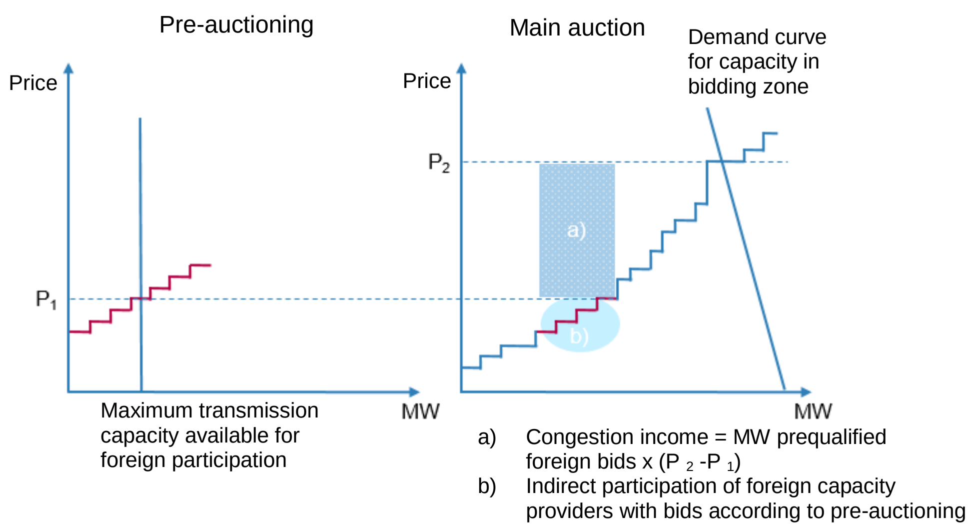
[12] See Acer's decision (No 36/2020) and associated Annex 1 (Technical specifications for cross-border participation in capacity mechanisms, 2020).

providers. In the following, we will focus in particular on the following key principles:

- **Calculation of maximum transmission capacity available for foreign participation** based on how much an interconnector is expected to contribute to resource adequacy in the connecting bidding zone during periods of expected power shortage in the electricity market. The calculation of maximum transmission capacity is updated annually. The purpose of the calculation is to ensure that the number of contracted MW from foreign capacity providers does not exceed imports from interconnectors during periods of expected power shortages in the electricity market.
- **Market-based** allocation of capacity contracts among all potential capacity providers, for example through an auction.
- **Congestion income** due to foreign participation to be divided between the TSOs that are directly connected.

Figure 11 contains a description of the principles that apply to foreign participation and the calculation of congestion income. In order to simplify the description, capacity payments are assumed to be determined according to pay-as-clear. In the pre-auction, foreign capacity providers are invited to compete for the maximum transmission capacity expected to be available for foreign participation. A TSO evaluates the tenders and selects the capacity providers that meet the transmission capacity at the lowest cost. These are prequalified for the main auction that follows. Pre-auctioning generates a clearing price (p1), which is later used to calculate the congestion income to be distributed between TSOs that are directly connected.

Figure 11. Principles for indirect participation by foreign capacity providers and calculation of congestion income.



Source: Compass Lexecon, in-house collation.

The main auction involves domestic and prequalified foreign capacity providers. Foreign capacity providers participate indirectly with the same bid as in the pre-auction. The capacity payment for domestic providers who are awarded contracts is determined by the clearing price in the main auction (p2) while the payment for foreign capacity providers is determined by the clearing price in the pre-auction (p1). A TSO calculates the congestion income in accordance with the number of MW in prequalified foreign bids multiplied by the price difference (P2-P1).

Consideration may be given to developing mutual rules allowing explicit participation of foreign capacity providers in interconnectors with Member States applying market-wide capacity mechanisms, such as Poland or other Member States in the future.

4.2 Centralised or decentralised capacity market

The question of a centralised or decentralised capacity market is basically about who is responsible for making a consumption forecast and procuring the capacity needed that is imposed by the central planner in relation to this.

In a centralised capacity market, a centralised purchaser has sole responsibility for making a consumption forecast and acquiring the capacity that is deemed necessary in order to ensure that resource adequacy meets the national reliability standard. In practice, it is usually a TSO who is responsible for making consumption forecasts and carrying out the procurement process.

In a decentralised capacity market, responsibility for making consumption forecasts and procuring the capacity needed is placed on electricity suppliers or local grid owners.

Svenska kraftnät believes that centralised procurement of capacity is preferable in a Swedish context, as it enables better utilisation of transmission capacity between bidding zones, less red tape and transaction costs, as well as better conditions for central planners to reach their targets compared to the alternative decentralised approach.

4.2.1 Theory and practice of a centralised or decentralised capacity market

The two alternatives have in common that it is a central planner who is responsible for determining how much capacity is needed is in relation to forecast consumption – the difference being who is responsible for making the consumption forecast and carrying out the procurement process.

Decentralised capacity markets are common in countries with vertically integrated and less competitive electricity markets, such as Chile, Brazil and Peru. More developed electricity markets using a decentralised capacity market include the Californian system operator CAISO, where electricity suppliers are required to contract a certain amount of capacity in relation to their expected consumption. In Europe, it is currently only France that uses a decentralised capacity market, although it is planning to move over to a centralised capacity market due to the reduced amount of red tape and increased guarantees of meeting targets that it entails.

Centralised capacity markets are the dominant design in Europe and are applied by Ireland, the UK, Belgium, Italy, Poland and PJM in the USA.

4.2.1.1 Decentralised capacity market

One advantage of a decentralised capacity market is that the decision-making on auctioned volumes is done by an operator closer to the customer, which *may* result in better consumption forecasts. Here the responsibility to procure the necessary capacity in relation to the consumption forecast usually lies with the local grid owner, which is logical as it is typically also the balancing responsible party for the grid customers it has. Consumption forecasts are facilitated by the fact that the grid customers represent a stable customer base, as the withdrawal points are difficult to move. Consumption forecasting is part of the grid owner's core business when planning reinvestment and grid expansion, giving rise to synergies in business operations.

This advantage is less obvious in view of the current model within the EU, where electricity trading and balancing responsibility are competitive businesses requiring separation from grid operations. A logical consequence of the European electricity market design and its unbundling rules is that the requirement to acquire the necessary capacity in relation to the consumption forecast should be placed on a competitive operator, for example electricity suppliers. This means greater complexity and uncertainty about the future commitment as they have a less stable customer base compared to a grid owner. In Sweden, around 20% of household customers renegotiate or switch electricity suppliers every year, which can mean that the customer base changes every five years. This complexity needs to be taken into account in the design, for example, by having capacity certificates or capacity contracts follow customers if they switch electricity suppliers, which can also give rise to greater risks for electricity suppliers when taking on new customers.

Another advantage identified in decentralised procurement is that it creates opportunities for tailored and innovative solutions that may suit certain operators. This option also has disadvantages due to greater red tape as a result of multiple operators being involved and increased transaction costs owing to diluted liquidity due to multiple small procurements of potentially non-standard products.

Another disadvantage identified in decentralised procurement is that it cannot guarantee that central planners will meet their targets in terms of resource adequacy in relation to the reliability standard. Furthermore, it is difficult to manage transmission capacity in decentralised capacity mechanisms, which is particularly relevant from a Swedish perspective with three internal bidding zone borders and numerous interconnectors.

4.2.1.2 Centralised capacity market

Centralised procurement means better prerequisites for central planners to meet their targets. Standardised products procured in a major procurement process involve reduced transaction costs through increased liquidity and price transparency, possibly at the expense of the conditions not being suitable for all potential capacity providers. A centralised capacity market also facilitates the management of transmission capacity across bidding zone borders in Sweden and with other countries.

4.3 Incentive to be available

With a market-wide capacity mechanism, capacity suppliers are expected to participate in the energy markets and receive a significant part of their revenue from the energy markets. The capacity payment must therefore be independent of dispatch in the energy market so as not to disrupt the functioning of the energy markets. However, there is a need to ensure that capacity is made available to the energy markets.

There are two basic models for incentivising capacity resources to be available when needed. The first model is to have a requirement to offer the contracted capacity to the market in periods of system stress combined with a penalty charge in the event of unavailability. The second model is to provide financial incentives via reliability options. These two models can also be combined.

Svenska kraftnät believes that the primary requirement should come from financial incentives in the form of reliability options, but that these should possibly be combined with requirements for availability in declared shortage situations. However, the latter requires more comprehensive complex administrative procedures and may be difficult to implement in the Nordic electricity market, as the option of making portfolio bids based on the operator's net position in the electricity market complicates the verification of the availability of individual facilities significantly.

4.3.1 Requirement to offer the contracted capacity to the market and penalties in the event of unavailability

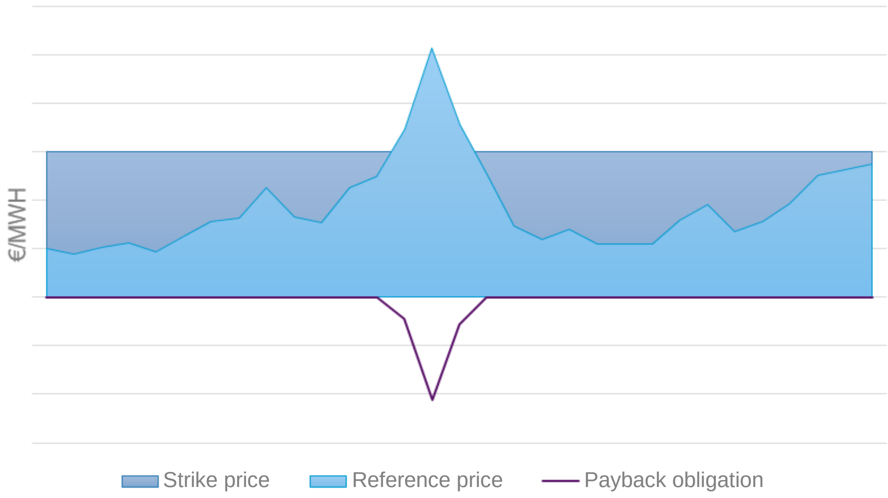
The model with the requirement to offer the contracted capacity to the market and penalties in the event of unavailability is based on the fact that, at times when the system operator declares a situation of system stress, there is a requirement to offer capacity on the day-ahead, intraday or ancillary services markets.

If the contracted capacity is not offered to the markets during periods of system stress, there is a penalty for unavailability.

4.3.2 Financial incentives through reliability options

The second model for incentivising availability takes advantage of the positive relationship between scarcity and high prices in the energy market. Introducing a payback requirement in the event of high prices, known as reliability options, clearly incentivises contracted capacity to plan operations and maintenance to be available at times or during periods of system stress. In simple terms, a reliability option means that a strike price is defined in relation to the appropriate market reference price. The reference price may be the price on the day before-market in the relevant bidding zone, but it is also possible, for example, to consider the price of balancing power in the balancing market. In cases where the reference price exceeds the defined strike price, a payback obligation arises from the difference between the market price and the strike price, as illustrated in Figure 12. The fact that the payback obligation arises regardless of whether the capacity provider has produced or not creates a strong financial incentive to be available during high price hours. Reliability options are basically valid for all hours. The payback obligation is linked to the price level and not whether the system operator has declared a situation of system stress.

Figure 12. Illustration of a reliability option.



In addition to the strong financial incentives to be available at high energy prices provided by reliability options, there are a number of other benefits. In the event of any problems with market power, reliability options limit the incentives for participating resources to exercise market power, by triggering the payback obligation in the event of high prices. This means that the profits from, for example, holding capacity back in order to push up the price will be lower than they would otherwise have been. In addition, a price hedge is built into the system. Paybacks from reliability options are channelled back to end customers, either by partially covering the costs of the capacity mechanism or through a more direct repayment. In addition, the risk of capacity suppliers receiving 'double' remuneration is limited in the event of periods of unexpectedly high energy prices.

There are a number of difficulties in the design of reliability options. Some of these design choices are discussed below.

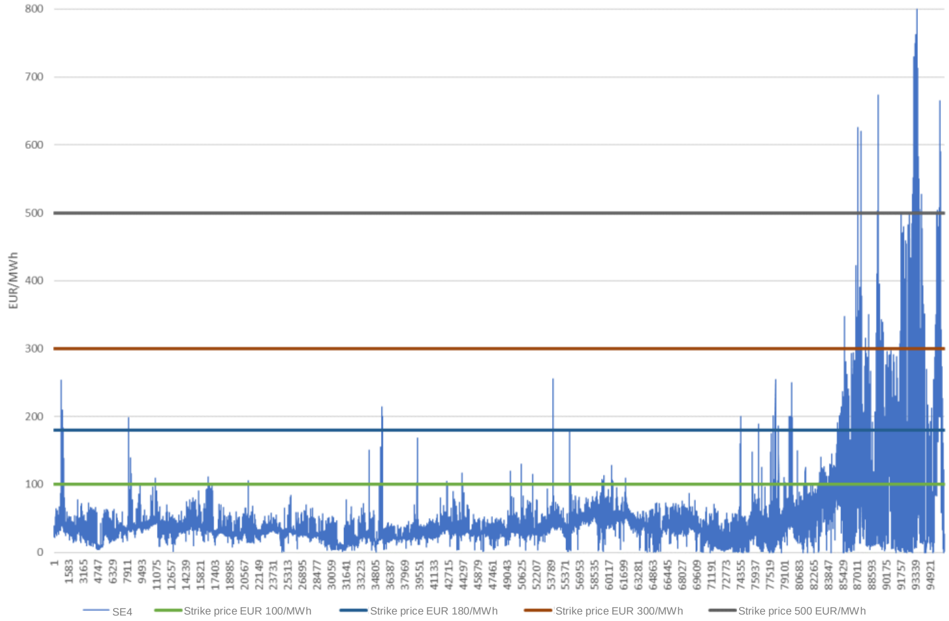
4.3.2.1 Definition of strike price

Firstly, the relevant reference price and strike price need to be defined. The latter in particular can be difficult. There is often some form of link to the variable costs of peak load capacity which, in many markets, has traditionally been represented by gas-fired power plants. Here it is common for the strike price to be indexed to the gas or other fuel price, as the strike price needs to exceed the variable costs. In Sweden's case, it is probably more appropriate to define strike prices independently of fuel prices. If the strike price is set relatively low, this means that the incentives to be available apply for more hours and that periods of high prices mean a bigger payback to customers. However, this leads to lower expected revenues from the energy markets and thus likely higher capacity bids. Furthermore, in the event of a low strike price, certain technologies may have variable costs that exceed the fixed strike price.

Determining the strike price will involve balancing these factors. Firstly, the strike price should be well above normal price levels. Figure *13* shows the historical hourly prices in SE4 over the past decade in relation to hypothetical strike prices in the range of EUR 100-500/MWh. The highest price during the period was around EUR 800/MWh. The figure shows that the vast majority of hours with prices above any of these levels was in 2022. For the period prior to 2022, there were only a few hours where the price exceeded EUR 100/MWh. The price hardly ever exceeded the level of EUR 300/MWh.

A possible model for determining the strike price could be to index to a (historical) price on the day-ahead market, for example the average value during a fixed previous period plus an appropriate additional charge.

Figure 13. Historical hourly prices in SE4 in 2012–2022 in relation to the hypothetical strike price.



Source: Electricity prices from NordPool.

It is also possible that certain technologies may need a higher strike price because their variable cost exceeds the generally defined strike price. In principle, this should be avoided as far as possible, but it may be necessary for individually set strike prices for facilities that can demonstrate higher verifiable variable costs. Such a facility could be a hydrogen-fired gas turbine, for example.

4.3.2.2 Managing demand response

Demand response has a different type of revenue stream and may need to be managed especially in relation to reliability options. In the case of demand response, no income is generated at high energy prices, except if the operator has financial or other long-term contracts and can 'sell back' previously purchased electricity. The starting point is that demand resources only avoid the cost of purchasing electricity.

In light of this, it is common for demand response to be managed differently from production in relation to reliability options and payback requirements.

In Italy, the Italian authorities showed in their application to the European Commission that the various flows of funds between the TSO and demand resources cancelled each other out. In addition, demand resources should receive remuneration for their capacity, but should also be involved in financing the capacity mechanism. These aspects were said to cancel each other out. Furthermore, reliability options imply that demand resources should pay back at high prices, but also be compensated for high prices. However, in the event of unavailability in declared shortage situations, a penalty is also imposed on demand resources. Here, however, significant difficulties can be expected with regard to verification.

There is also a similar arrangement in Ireland. The payback obligation does not apply to demand resources as long as they supply in accordance with their commitments, but it does take effect if demand response is not delivered in a scarcity situation. In this context, however, it is relevant to mention that in the Irish design, there is no penalty for unavailability beyond the payback for reliability options.

Both for demand resources and for energy storage, it may also be relevant to limit the duration expected from these resources. This should also be reflected in the de-rating factor and remuneration for the capacity that these resources receive.

4.3.3 Stop-loss

Several markets with reliability options apply a 'stop-loss' for paybacks. Belgium, for example, has a stop-loss mechanism for both payback obligations and penalties for unavailability. This mechanism means that the capacity provider never has to pay back a sum exceeding the annual capacity payment, i.e. if the contract value is reduced to zero, the payback obligation will also cease. This may be an appropriate risk mitigation for the capacity provider. In particular, it can enable zero bids if the problem of missing money from the energy market has ended. In Belgium’s case, it was argued that without such a stop-loss mechanism, a capacity provider will never submit a zero bid, even if there is no missing-money problem for providers.

This argument appears more reasonable in the event of a certain, but rather minor problem regarding missing money from the energy market. Where there is no such problem at all, the situation can be dealt with by the relevant capacity provider not participating in the auction, but this capacity being implicitly included in the supply curve as a zero bid.

4.4 Product definition and environmental requirements in procurement

The product procured in a capacity mechanism must be designed so that it contributes to meeting the reliability standard. According to the Electricity Regulation, a market-wide capacity mechanism must be designed so that all resource owners can participate on the same terms, regardless of technology.

The design of the product is important in order to achieve a technology-neutral procurement process that is open to all, taking into account the environmental requirements in accordance with European and national law and any additional environmental conditions in the procurement process. Regardless of whether the procurement involves one or two products, the determination of technology-specific de-rating factors is crucial in order to ensure effective competition so that the reliability standard is met at the lowest cost.

4.4.1 Theory and practice regarding number of products

Ideally, the number of products in the procurement process is governed by the number of target functions of the central planner, in line with the principle, one target, one product. Existing capacity mechanisms typically include either one or two products. A comparison of a number of European countries that have recently introduced, or are planning to introduce, a market-wide capacity mechanism suggests that they have all (Belgium, Italy, Poland, Ireland and Northern Ireland) chosen to include just one product in the procurement process. Svenska kraftnät believes that one product is preferable from a Swedish perspective.

4.4.1.1 Single product

There are several benefits to acquiring a single product. Firstly, it means a significantly simplified and more robust auction design with high price transparency among potential providers. Secondly, technology-specific de-rating factors indicate the relationship between how an additional MW installed capacity of a capacity resource with a given technology contributes to increasing resource adequacy, whether through firm or flexible capacity or both. The calculated technology-specific de-rating factor is used to make tenders from operators with different technologies comparable so that 'effective' MW is the subject of tender evaluation.

Technology-specific de-rating factors that are continuously updated to reflect the technology-specific marginal contribution to resource adequacy reduce the problem for planners to adjust the dimensioning of the capacity mechanism over time (in effective MW) in order to meet the reliability standard. If the proportion of weather-dependent production continues to increase in the capacity mix, a de-rating factor reflecting the marginal contribution to resource adequacy will reward flexible capacity. If resource adequacy problems change from occurring during peak hours to also occurring during longer periods of low wind and solar radiation, the method will reward storage and other flexible resources with long sustainability (hours or days). The method used to calculate the marginal contribution will then automatically assign higher de-rating factors to highly flexible technologies compared to technologies that provide firm generation. Table 8 shows examples of de-rating factors based on Belgium's auction in 2021 as well as Ei's report proposing a reliability standard for Sweden (Ei, R2021:05).

Table 8. Examples of de-rating factors based on Belgium's auction 2021 and Ei (R2021:05).

Technology	De-rating factor (Belgium, auction 2021)	De-rating factor (Ei, R2021:05)
Cogeneration	90–93%	90–95%
Nuclear power	96%	N/A
Demand response and storage	11–100%	50–95%
Offshore wind	15%	N/A
Onshore wind	6%	9%
Solar power	4%	N/A
Hydropower (run-of-river)	34%	N/A

One disadvantage of acquiring just one product is that it is difficult to calculate a de-rating factor for each technology. The calculation is also associated with uncertainty that increases the further into the future the calculation is made, which is particularly relevant for longer contracts with a delivery period that starts several years in the future. Uncertainty consists, for example, of the volume of consumption and its distribution over time, as well as the capacity mix that exists in Sweden and abroad at the given time. The idea is that the de-rating factors will be calculated before each new procurement round (e.g. annually) and, from an operator perspective, this can lead to increased uncertainty regarding how the market value of capacity may develop in the future, which is particularly relevant for short-term contracts (e.g. one-year contracts). It may undermine the function of the capacity mechanism as a measure to mitigate the economic impact of cyclical periods of high and low prices on the electricity market due to lumpy investments in long-lived facilities.

4.4.1.2 Two products

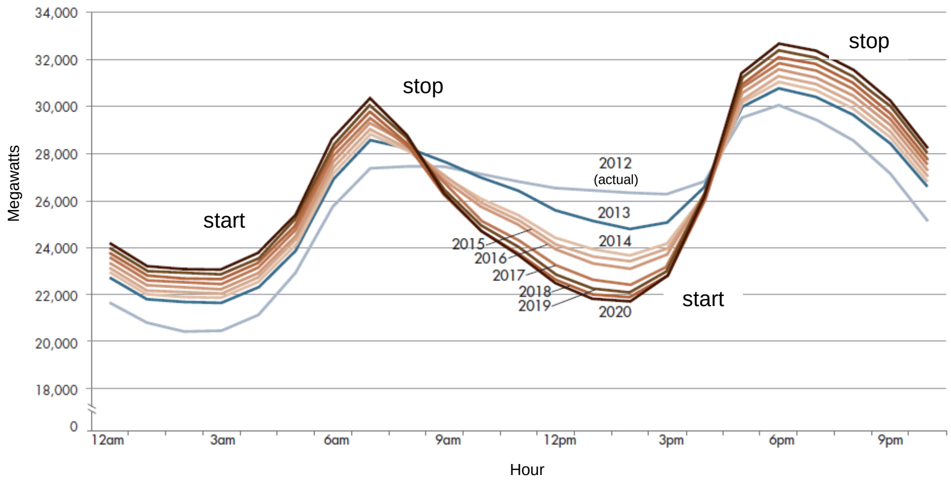
Two products are preferable if the planner has a clear understanding of the composition of abilities required from capacity resources in order to meet the reliability standard. Although the definition may vary, the requirement is usually formulated in terms of installed firm generation capacity and installed flexibility resource capacity. A disadvantage of two products is that the relationship between how an additional MW of installed capacity at a capacity resource with a given technology contributes to increasing resource adequacy is not as clear, making it difficult to evaluate objective effectiveness and make the necessary adjustments to procured firm generation capacity and flexibility.

The capacity needed for installed firm generation can, for example, be derived from analyses of how the residual load[13] is affected when the amount of installed firm generation capacity varies. Firm generation can also be assumed to be associated with ancillary services such as inertia, reactive power and voltage regulation, or can be judged to result in increased operational safety margins in the electricity system, which can increase resource adequacy by enabling increased import capacities to a bidding zone while maintaining operational reliability.

The capacity needed for installed flexibility resources can also be derived from an analysis of the residual load on different time scales (from one hour to several hours). Here, the focus should be on flexibility that can balance supply and demand in the day-ahead market, and these resources can therefore be relatively slow. Flexibility with a requirement for faster response times and ramping speed is procured in the ancillary services markets for balancing, where several products in Sweden also include capacity payments for availability. One example is CAISO, which introduced a capacity market in 2006. In 2015, CAISO expanded it with a second flexibility product due to the increasing proportion of renewable energy sources from sun and wind, which over time led to the daily residual load placing ever-increasing demands on ramping capacity during the early morning and evening, see Figure 14.

[13] The residual load is usually defined as the difference between electricity consumption and electricity generation from weather-dependent energy sources such as wind and solar power. Sometimes run-of-river hydropower is also defined as weather-dependent. The residual load provides a picture of the deficit or surplus that needs to be managed by dispatchable production, import or export in order to maintain the power balance in the electricity system.

Figure 14. The evolution of residual load in California from 2012 to 2020 due to an increasing proportion of weather-dependent energy sources in the electricity system.



Source: CAISO (2016).

Also in the case of two products, bids from capacity resources are made comparable by applying technology-specific de-rating factors in terms of their contribution to installed firm generation capacity and flexibility. Since the features associated with firm generation and flexibility resources partly complement each other, it is not possible to calculate de-rating factors analytically in a credible manner, but it is common for these to be determined on the basis of a simpler normative approach. De-rating factors determined using a normative approach are usually not updated as often, which makes it difficult to meet the targeted level of reliability. However, long-term, stable de-rating factors can lead to increased predictability for operators as to how the market value of capacity in short-term contracts may develop in the future. A capacity mechanism with two products thus has a greater potential to mitigate the economic effects of cyclical periods with high and low prices in the energy market.

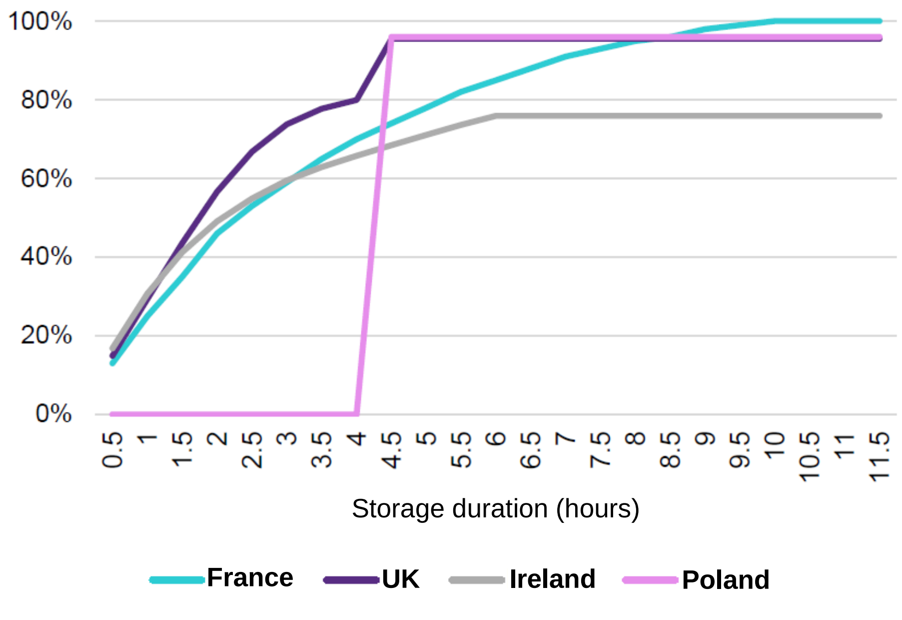
A second disadvantage of two products, which also leads to reduced objective effectiveness, is that resource owners with a given technology assess that the de-rating factor is unfair, by giving certain technologies a competitive advantage that does not reflect its contribution to installed firm generation capacity or flexibility. A third disadvantage of two products is that the auction becomes much more complex compared to the procurement of one product because the procurer has to take into account that firm generation and flexible resources complement each other and can be supplied from the same resource owner (e.g. a nuclear power plant or cogeneration plant).

The design of the procurement process needs to be evaluated carefully in the case of two products with regard to its substitutability and complementarity, and in theory sequential or co-optimised auctions can lead to lower procurement costs compared to simultaneous auctions. However, if the procurement process is to be open to foreign participation or carried out per bidding zone, the complexity will be enhanced even further.

4.4.1.3 De-rating factors for demand response

Flexibility resources consisting of demand response and storage (including pumped hydropower) are a heterogeneous technology in terms of technical and economic conditions to be available and the sustained duration for which it can be activated. The calculation of technology-specific de-rating factors based on the marginal contribution to resource adequacy is complex as it depends on both production capacity and the size of the energy storage (duration). Figure 15 shows examples of how the de-rating factor varies with the duration of energy storage in different countries. The distribution between small and large storage in the electrical system also needs to be considered, as refilling energy storage is becoming increasingly difficult during low-load hours without increasing LOLE.

Figure 15. Examples of how the de-rating factor varies with the duration of energy storage in France, the UK, Ireland and Poland.



Source: Compass Lexecon.

One solution used in Belgium for energy-constrained resources is that the resource owner can choose from a menu of different SLAs depending on a facility's duration in hours, where the de-rating factor increases with the resource's duration. Belgium also allows resource owners at the time of tender to determine the energy price at which the resource can be activated, which also determines the strike price for when to activate, see section 4.3.2.

Table 9. Example of menu of different SLAs used in Belgium.

Service level agreement, duration in hours	De-rating factor
1	11%
2	19%
3	28%
4	36%
6	52%
8	65%
Unlimited	100%

4.4.2 Environmental requirements in the procurement

With regard to environmental requirements in capacity markets, EU law focuses on climate impact and stipulates limits for CO_2 emissions per kWh. A potentially lower limit is an important design choice to consider in market-wide capacity mechanisms as it affects which technologies are given incentives for new investment.

The basic question regarding CO_2 emission limits is whether gas-fired and other fossil-fired power plants should be permitted to participate in the capacity mechanism. According to American data from 2021, gas-fired power plants emitted an average of 440 g of CO_2 per kWh (U.S Energy Information Administration, 2023). A modern gas-fired combined cycle power plant is thus below the limit of 550 g of CO_2 per kWh set out in the Electricity Regulation. If gas-fired power plants are allowed to participate in the procurement process, this may involve incentives for new investment in capital-intensive and long-lived facilities with a high climate impact. This entails a risk of stranded costs borne by customers if the limit needs to be lowered in the future in order to achieve environmental targets at European or national level. However, a lower limit may also affect the option for existing and new generating facilities that run on waste or biofuels to participate, depending on the technical design and method used to calculate CO_2 emissions.

A lower limit for CO_2 emissions should reasonably exclude several of the reference technologies used in Ei's reliability standard calculation. It is possible that net CONE could be calculated on the basis of batteries or some other reference technology with relatively higher costs, which leads to a lower reliability standard (i.e. LOLE is allowed to increase), all other things being equal.

Unlike most national electricity systems in Europe, the Swedish electricity system is largely free from fossil-based production. Therefore, from a Swedish perspective, new investment in fossil-based production would move us towards a system with increased climate impact. In light of this, the government should consider whether it is justified to impose stricter requirements regarding CO_2 emissions than the EU's minimum requirements.

4.4.2.1 Legal prerequisites

The Electricity Regulation sets limits for the maximum amount of CO_2 a facility may emit in order to be included in a capacity mechanism. The limits are different for new and older facilities. Article 22(4) of the Electricity Regulation stipulates that generation capacity that started commercial production on or after 4 July 2019 may not emit more than 550 g of CO_2 per kWh. For generating facilities that started commercial production before 4 July 2019, the limit has been tightened from 1 July 2025. Facilities must either be below the limit value of 550 g of carbon dioxide per kWh or not emit more than 350 kg CO_2 on average per year per installed kW. This tightening means that older fossil-fuelled facilities that do not comply with the limit of 550 g of CO_2 per kWh may only be run for a limited number of hours per year in order to comply with the second limit of 350 kg CO_2 per year per installed kW. The limits set out in the Electricity Regulation do not exclude stricter national requirements for a facility to be included in a capacity mechanism.

In connection with the publication of the communication with Guidelines on State aid for climate, environmental protection and energy in 2022, the European Commission acknowledged that whilst gas fulfils a function during a transitional period, its use may jeopardise the achievement of the EU's climate goals for 2030 and 2050 (European Commission, 2023). It is therefore important that State aid through a capacity mechanism, for example, does not lead to lock-in effects as a result of new investment in capital-intensive and long-lived generating facilities with a high climate impact. In order to approve a mechanism involving fossil-fuelled power plants, the European Commission may require commitments relating to carbon capture and storage, a plan to replace natural gas with hydrogen gas or a timetable for the phasing out of facilities.

4.4.2.2 International outlook

Table10 provides a summary of the limits for those countries in Europe that have a market-wide capacity mechanism. As can be seen from the table, most countries have chosen to comply with the limits in the Electricity Regulation. Only France has chosen a significantly lower limit.

Table10. CO2 emission limits applied in European countries with a market-wide capacity mechanism.

Country	CO2 emission limit (g CO_2/kWh) for participation in the capacity mechanism
France	200 g from the 2020 auction for delivery in 2024
Italy	550 g from 2021 auction for delivery in 2024/25
Belgium	550 g
United Kingdom	450 g for new generating facilities
Ireland	550 g from 2021 auction for delivery in 2024/25
Poland	Compromise through a special clause securing capacity contracts with coal-fired power plants entered into before 31 December 2019. Extension of long-term contracts by two years (15+2 years) for capacity below 450 g.

Source: Compass Lexecon.

4.5 Auction design

When designing a centralised capacity auction, a number of different design choices will need to be made and these will need to be investigated further before final conclusions can be made on appropriate design.

4.5.1 Marginal pricing or pay-as-bid

A fundamental auction design question is whether the price should be determined on the basis of marginal pricing ('pay-as-cleared') or whether the respective operator is paid on the basis of their individual bid ('pay-as-bid').

A common misconception in this context is that the average price will be significantly lower in the case of pay-as-bid compared to marginal pricing. This is, however, based on the fact that operators choose to bid based on their costs also in the case of pay-as-bid. In fact, it should be expected that the operators will make an assessment of the marginal price and adjust their bids based on their expectations of this price. In a theoretical world with no uncertainty, the outcome for pay-as-bid and the marginal price would then be identical.

Introducing uncertainty, there are a number of different issues that make it difficult to express an opinion on whether pay-as-bid or pay-as-clear is the preferred option. Pay-as-bid can generally be expected to reduce efficiency in the market, benefit operators with relatively strong resources and extensive analytical capacities, and that the reduced price transparency can act as an entry barrier.

In some specific cases, pay-as-bid may be preferable in spite of these clear negative effects. This applies, for example, to markets with a very high degree of market power, especially in combination with entry barriers for low-cost technologies.

In order to ensure that pay-as-bid can reduce procurement costs, some form of regulation of the bidding is likely to be needed, for example that bids must be made on the basis of costs. However, this assumes that the procuring entity (or regulatory authority) has sufficient ability and expertise to scrutinise cost statements and in practice it is likely to be possible to only challenge fairly serious errors in the bidding process. One possible outcome, however, is that a pay-as-bid design could potentially avoid reimbursing existing facilities based on the cost of a new investment.

The main arguments regarding marginal pricing and pay-as-bid are summarised in Table 11.

Table 11. Marginal pricing and pay-as-bid.

	Marginal price	**Pay-as-bid**
Principle	All accepted bids are paid according to the marginal price in the auction	Accepted bids are paid in accordance with the respective bid price
Advantages	Provided there is sufficient competition: • Incentives for operators to offer their marginal cost • Easier for operators to participate and bid – especially for smaller operators • A clear reference price based on the price of the marginal unit	• If there is potential for market power, the incentives and opportunity to exercise market power may be reduced • Potential reduction in price volatility • Under certain conditions may limit procurement costs and inframarginal rent for cheaper resources
Disadvantages	• Prices likely to fluctuate more • Especially in a situation with entry barriers (at least in the short term) may lead to higher costs and excess profits	• Complex bidding strategies. Bidders will try to bid at the expected marginal price to maximise profit/cover as much fixed cost as possible • Less effective outcome. Different operators have different expectations and will adjust their bids based on this – more expensive resources are likely to be accepted rather than cheaper • Larger operators benefit over smaller operators, which is likely to lead to a deterioration in competition over time

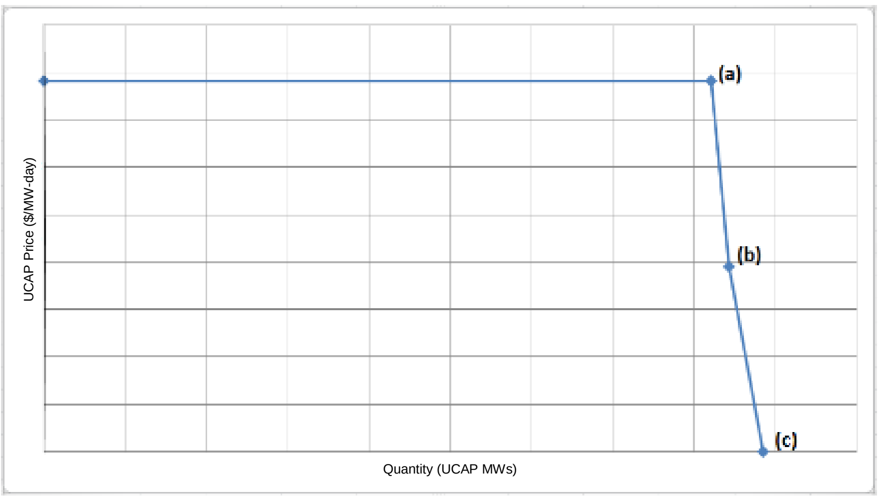
4.5.2 Definition of demand curve

Initially when capacity markets were established, it was common for demand for capacity to be fixed (price inelastic), but there was a price cap. However, the outcome of this market design was not very successful and modern capacity markets typically have price elastic demand for capacity, i.e. a downward demand curve. There are a number of key concepts in the definition of the demand curve:

- Gross Cost of New Entry (Gross CONE): Yearly annuity to cover investment plus fixed operating and maintenance costs for building and maintaining new capacity resources
- Adjustment for revenues from energy and ancillary services markets: Expected net revenue from participation in energy and ancillary services markets
- Net CONE: Gross CONE minus adjustment for revenue from energy and ancillary services markets. This represents the net capacity payments needed to attract new resources to the capacity market.
- Reference technology: The technology used to estimate net CONE.

Figure 16 shows the price elastic demand curve in PJM's capacity market. The cap price in point (a) is defined here as the largest of gross CONE or 1.5 times net CONE adjusted for a de-rating factor based on expected unavailability and the quantity is slightly lower than the margin considered necessary to meet the reliability standard applicable to PJM. In point (b), the price is 0.75 times net CONE adjusted for expected unavailability and the quantity is slightly higher than the margin considered necessary to meet the reliability standard. In point (c), the price is zero and the quantity is slightly higher.

Figure 16. Illustration of demand curve in a capacity market.



Source: PJM Manual 18 (PJM Manual 18: PJM Capacity Market).

A number of parameters need to be determined when defining the demand curve. Two fundamental features of the demand curve are that it should result in a suitable volume of capacity being procured, i.e. a volume that meets the defined reliability standard, and partly that the slope of the curve is derived from gross and net CONE for the selected reference technology.

In order to determine how the demand curve should be designed, more in-depth analyses will be required than have yet been done, and the demand curve may need to be reviewed regularly.

When Ei developed its proposed reliability standard, the relevant reference technology was demand response for heating households, and this has thus formed the basis for defining the applicable reliability standard in Sweden. According to Ei, the fixed CONE for demand response for household heating amounted to SEK 79,100/MW, as well as an activation cost of SEK 2,700/MWh (Ei, R2021:05). The potential for demand response is limited and if more expensive resources are needed in order to meet the reliability standard, the next type of resource is gas turbines (single cycle, 300 MW) with a fixed CONE of SEK 204,000/MW. This illustrates how important the choice of reference technology will be for the demand curve, and consequently on the prerequisites for meeting the reliability standard.

Figure 17. Swedish Energy Markets Inspectorate CONE calculation results

Table 13 Results of CONE calculations

Technology	Fixed CONE CONE $_{\text{fixed, RT}}$ [SEK/W]	Variable CONE CONE $_{\text{variable, RT}}$ [SEK/MWh]
Battery storage	1 100 000	1 320
Demand response, residential heating	79 100	2 700
Demand response for building ventilation	2 040 000	5 400
Demand response, electricity-intensive industry	35 400	108
Demand response, other industry	6 050	19 200
Thermal power – piston engine	1 780 000	849
Thermal power – gas turbine single cycle 150 MW	254 000	838
Thermal power – gas turbine single cycle 300 MW	204 000	838
Thermal power – gas turbine combi cycle 300 MW	658 000	605
Wind power	11 500 000	121
Thermal power – condensing power plants	4 480 000	480

Source: Ei (R2021:05).

4.5.3 Management of excess profits and market power

Capacity markets can be expected to be characterised by scarcity as it is unlikely there will be significant overcapacity in the market. This means there is a real risk of exercising market power. It may therefore be appropriate to introduce various types of measures to restrict the exercise of market power. A number of design choices that can influence incentives to exercise market power, such as marginal pricing or pay-as-bid, as well as a price-dependent demand curve, have already been discussed above.

4.5.3.1 Bid caps

In addition to the general price cap, it may be possible to impose bid caps for existing operators who are considered able to exercise market power. Such bid caps can be based, for example, on the costs that can be avoided by not operating the facility, such as fixed operating and maintenance costs. However, this requires bidders to submit information regarding these costs, and that the procuring organisation has the capacity and competence to assess the information submitted. Alternatively, or in addition, different standardised costs can be applied. If the bid then exceeds an established bid cap, and this affects the clearing price for capacity, countermeasures are taken.

4.5.3.2 Requirements to participate in the procurement process

Another way of exercising market power may be to hold back capacity, i.e. to not submit bids for existing capacity. There are several different options to limit the possibility of holding back resources from the bidding process.

One option is that existing capacity that either does not qualify for the auction, or which, after qualification, does not participate in the auction, is still implicitly included in the supply curve. Participation in the capacity auction is voluntary, but existing resources that do not participate are considered zero bids. However, they do not receive any capacity payment, but are also not subject to any specific commitments in relation to keeping capacity available. This procedure is used in the Italian capacity market, for example. Belgium also applies a rule making it mandatory for all facilities above 1 MW to prequalify for the auction, but where participation in the auction is voluntary.

Another option is to impose requirements for existing capacity resources to participate in the auction, which are primarily applicable to production resources. In PJM’s capacity market, there is such a 'must-offer' requirement, provided that the facility does not meet the criteria for exemption from the requirement.

An in-depth analysis needs to be carried out of various alternative measures, but Svenska kraftnät's tentative assessment is that the first option with voluntary participation, but where non-participating resources are included in the supply curve, is most appropriate for a Swedish capacity market.

4.5.3.3 Dividing the market with respect to existing and new resources

Payment according to the marginal price has several advantages, as shown in section 4.5.1. In order to limit the ability of operators to exercise market power and limit the redistribution effects from consumers to owners of existing capacity resources, the capacity market can be divided, at least for existing and new production resources. If the marginal price is set separately for these respective categories of resources, it avoids high costs for new facilities having a full impact on the capacity price for the whole of the existing production fleet. In order for such a model to work, however, some form of bidding regulation must be introduced, as otherwise strong incentives would be created for strategic bidding.

When the capacity market was introduced in Italy, a *first implementation phase* and a *full implementation phase* were defined. The lead time to full implementation was four years. During the first implementation phase, auctions were conducted with relatively short lead times and short delivery periods, with the aim of phasing in the capacity market. The lead time between the auction and the delivery period was during the first implementation phase from a few months up to three years. Delivery periods were one year for existing capacity and 15 years for new capacity. In the main auctions with a lead time of less than three years, and in the supplementary auctions, the interim bid cap for existing capacity also constituted a price cap, i.e. existing capacity could not receive a higher capacity payment even if the auction cleared a higher price overall. The reason was that given the short lead time, it was unlikely that any new capacity could actually be built up and thereby exert effective competitive pressure on existing capacity. The price cap limited the possibility of exercising market power. In the main auctions with a lead time of at least three years, existing capacity can only receive a higher price than the bid cap if at least one bid from new capacity exceeding the bid cap is accepted.

In the subsequent phase (full implementation), the lead time for the main auctions is three years and the delivery periods are three years for existing capacity and 15 years for new capacity. Bid caps for existing and new capacity are also present in this phase, and existing capacity will receive higher remuneration than the bid cap only if new capacity is contracted.

4.5.4 Type of auction

Two main models in terms of the structure of the auction appear relevant to consider for a capacity market. One is a model with simultaneous closed bids (single-round sealed bid auction) and the other is a model with several rounds where bidders can lower their prices in each round (multi-round descending clock auction).

The former is simply a model in which all bidders submit a bid at the same time without being aware of the bids submitted by other bidders. In a descending clock auction, the bidders basically lower their bid in each round, or say whether they are willing to accept the lower price announced by a bidder in each round. Such a model is used in the Italian capacity market. In the first round, each participant states a price (EUR/MW/year) and volume (MW/year). The capacity cannot be adjusted in the next rounds, but participants can reduce the price.

The two models have different pros and cons. In simple terms, a descending clock auction can be more sensitive to the exercise of market power, but at the same time this model allows bidders to learn during the auction process, which can result in a more effective outcome.

Svenska kraftnät has so far not conducted any more detailed analysis of which of the two auction models would be preferable for a Swedish capacity market.

Table 12. Comparison of single-round sealed bid and multi-round descending clock auctions.

	Single-round sealed bid	**Multi-round descending clock**
General design	• Each bidder submits a bid with capacity and a price at which it is willing to sell. • The auctioneer gathers all the bids, creates an aggregated supply curve and matches it against the target capacity to be purchased.	• The auctioneer begins by stating a high price and asks the bidder what capacity they are willing to sell at that price. • If the capacity offered exceeds the target capacity, a new round opens in which the auctioneer gives a lower price and asks what capacities the bidders are willing to sell. • The process continues until the offered capacity comes down to the target capacity.
Advantages	• Simple auction model. • The cost of participating tends to be lower than in more complex auction models. • Limits information asymmetry and potential for 'gaming' or collusion in an anti-competitive manner.	• Bidders can adjust their bids based on information disclosed during the auction, which improves the efficiency of the auction and counteracts the so-called 'winner's curse'. • In a multi-product model, simultaneous descending clock auctions have the advantage that bidders can practice arbitrage between different products, i.e. if a capacity is not accepted in the auction for one product, a bidder can choose to bid more 'aggressively' for the other product.
Disadvantages	• Risk of ineffective outcome as there is no process where bidders are informed about the price during the auction. • Winning an auction can be bad news for the winner (winner's curse) - suggests that an optimistic estimate of the future has been made (e.g. high future energy prices => willing to accept lower prices for capacity).	• If competition is limited, disclosure of information may be counterproductive as bidders can use the information to coordinate their bidding => higher price.

Source: Based on data from Compass Lexecon.

4.5.5 Secondary market

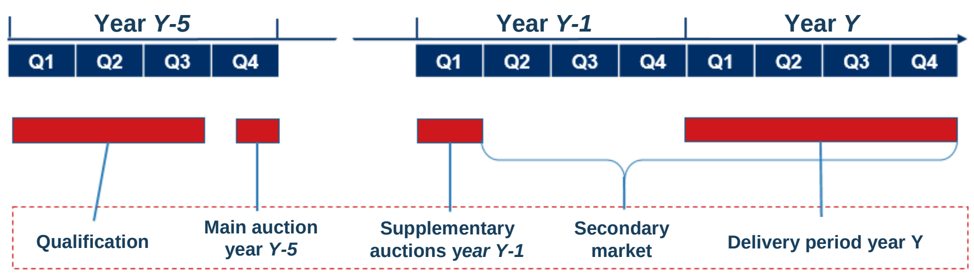
In order to reduce the risk for capacity providers associated with a long-term commitment, a secondary market can be introduced. The ability to transfer capacity obligations between eligible capacity providers is also a requirement under Article 22(3) of the Electricity Regulation. This would enable a capacity provider that has lower availability than expected/contracted to cover the difference by transferring the commitment to another party.

This is the case, for example, in the Belgian capacity market. The Belgian TSO has no organised marketplace, but the actual agreement between the parties is concluded bilaterally or via any trading venues that arrange trading. At the request of the parties, a transfer of the obligation is then registered, after the transaction has been approved by the TSO. Approval of the transaction requires that a number of conditions are met, including that the 'capacity market unit' that assumes the commitment is prequalified. A transfer means that all commitments, including remuneration according to the original capacity auction, are transferred to the new provider.

4.6 Contract duration and auction lead time

Key design choices in the design of capacity markets include the lead time between the auction and the delivery period, as well as the duration of the assigned capacity contracts. Both design choices are important for enabling new investment. Figure 18 includes an example of a timeline based on Poland's capacity market.

Figure 18. Example of timeline with a forward main auction (Y-5) and supplementary auctions closer to the delivery period (Y-1).



4.6.1 Auction lead time

The typical design is that main auctions are held around 3–5 years before the start of the delivery period, with supplementary auctions closer to the delivery period. One example is the capacity market in PJM where the main auction, 'base residual auction', is held three years before the delivery period and incremental supplementary auctions are held 20, 10 and 3 months before the start of the delivery period. In the Polish capacity market, the main auction is held five years before the delivery period.

The choice of lead time is fundamentally a balance in terms of uncertainty concerning capacity requirement and the ability of operators to make new investments. Based on the uncertainty surrounding requirements, it would be desirable to perform auctions as close to the delivery period as possible, but to improve competition and enable new investment, a forward-looking mechanism is needed. Different types of resource owners may also have different preferences regarding how forward-looking a mechanism should be. An operator who intends to call for tenders for a new production facility is likely to require a lead time that enables the facility to be built in the period between the contract being awarded and the start of the delivery period. A demand resource from an industrial facility may be dependent on the market situation for its products and may therefore be reluctant to enter into contracts several years into the future.

In the Italian capacity market, a cascade system is applied. Main auctions in the first implementation phase are held for years *T+1*, *T+2* and *T+3* where 1/3 of demand is expected to be met in the respective auction, i.e. the requirement is met gradually[14]. The existing capacity may therefore only bid 1/3 of its total capacity at each auction.

4.6.2 Contract duration

All capacity markets studied have long-term contracts to support the financing of new or refurbished/renovated facilities. Even though approval of capacity mechanisms is given for a maximum period of ten years, contracts may therefore run over a longer period.

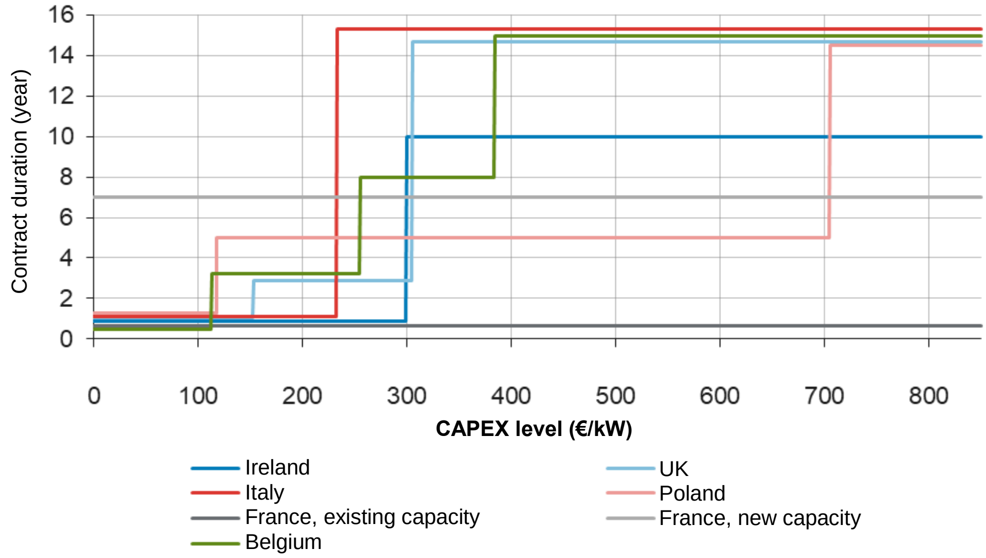
The overall risk is a combination of risks associated with expected revenues, construction and facility-related risks, as well as operational risks, all of which need to be managed. The risks associated with revenue come both from the price level, but also from the number of hours the facility will run. These can be most obvious for a peak load facility that is expected to produce for relatively few hours and with great variation between years. The revenue streams can then be associated with a very high risk.

With longer contract durations, the financial risk for investors is reduced, which can be expected to lead to lower capital costs. This risk will then be borne by customers instead. The duration of a contract is therefore a balance between reducing capital costs and the extent to which it is appropriate for customers to assume this risk. However, from a customer perspective, a system with more installed capacity can be expected to lead to reduced variations in energy prices.

[14] In this context, T refers to the first year of the mechanism.

It is common for contract duration to be defined in relation to the capital costs of the capacity providers. However, the duration of contracts varies greatly between markets. In the USA, for example, ISO New England has contracts of up to seven years, while PJM has contracts of up to three years. Ontario and the UK have contracts of up to 15 years, while the Polish capacity market has contracts of up to 17 years[15]. Figure 19 provides a summary of how contract duration varies for a number of European capacity markets.

Figure 19. Contract duration and threshold values for CAPEX (€/kW).



Source: Compass Lexecon based on European Commission decision.

Depending on the country we look at, long-term contracts are in some cases already awarded with relatively low capital costs (200–300 €/kW), while in other cases significantly higher capital costs are required (700 €/kW). We can compare this with the capital costs for new electricity production in Table 13 which is presented in the Energiforsk report, Electricity from new facilities (Energiforsk, 2021:714). Based on the threshold values applied in other countries, investments in completely new electricity production would have longer contracts, while long contracts may be more questionable when upgrading an existing hydropower station (new aggregates). Most measures

[15] In order to reward resources with good environmental performance, Poland is extending contract terms by two years for capacity that emits less than 450 g of carbon dioxide per kWh so that the total contract term is 17 years (15+2 years).

involving demand response based on this would probably only have shorter contracts.

Table 13. Capital costs for different technologies (SEK/kW).

Technology	Low	Medium	High
Solar power, detached house system	9,918	16,496	23,294
Solar power, parks	6,952	7,262	7,380
Onshore wind power	9,823	10,911	12,308
Offshore wind power	25,033	26,411	27,789
Combined heat and power*, wood chips	41,250	45,625	50,000
Cogeneration*, waste	94,750	105,625	116,500
Hydropower, new power station in same location as previous power station		18,729	
Hydropower, upgrading of aggregates	2,656	3,354	3,518
Nuclear power	40,000	47,500	55,000

**Cogeneration also includes capital costs for district heating-related parts.*

Source: Energiforsk report 2021:714.

4.7 Financing of capacity mechanism

The net cost of a capacity mechanism needs to be financed via tariffs or charges. A charge for the existing power reserve is imposed by balancing responsible parties who are active in the Swedish bidding zones. The charge is based on customers' measured consumption within metering grid areas, excluding grid losses. This charge is imposed during the period 16 November to 15 March on weekdays between 6 am and 10 pm.

Financing a capacity market can be based on similar principles. However, one change that can be expected to take place over time is that the capacity requirement will not necessarily be as closely linked to peak periods in winter, but power scarcity may also arise during other periods, primarily linked to low availability for weather-dependent production.

A basic principle, however, should be to strive for a dynamic charge that is imposed primarily during periods when scarcity can be expected. It is also possible to differentiate the charge between different periods depending on the likelihood of scarcity. In the shorter term, this would mean that the highest charge is imposed in the winter and the lowest charge or no charge is imposed in the summer. In addition, it may then be possible to define one or more charge levels for the autumn and/or spring. Over time, adjusting the charge structure based on how the electricity system is developed will likely be justified, for example, increasing the temporal granularity over time may be justified.

As the proposed capacity market is geographically divided, it can also be argued that the financing charge should be differentiated in a similar way, but it is also an option that financing takes place jointly and severally across the whole customer base.

In the event of periods with high prices where the capacity providers are required to pay back (potential) revenues in excess of the defined strike price, this means that the net cost of the capacity mechanism is reduced. The simplest administrative procedure is to take this into account when determining the charge for the following year. However, in the event of longer periods of very high prices, it may be preferable to return this surplus to customers more directly. However, the possibility of a more direct return of surplus to customers may be affected if a stop-loss function is introduced (see section 4.3.3).

Regardless of which party is to pay the charge, the net cost will be passed on to end customers. Two main options can be identified. The first is to allow the charge for the capacity market to be paid by the balancing responsible parties, as is the case today with the charge for the power reserve. The balancing responsible parties can then be expected to pass on this cost to the electricity suppliers and end customers. One option is that the charge is paid via the network operators, which is more similar to how the electricity tax is currently managed.

An important question is how directly you want the cost of the capacity market to be passed on to customers. In a model where the charge goes through the balancing responsible parties, it is possible that the passing on of the charge for the capacity mechanism is incorporated into the overall commercial agreements between balancing responsible parties, electricity suppliers and end customers. With such an approach, it is more difficult to ensure a dynamic charge structure or a more direct payback of any surplus income should this be preferred. Of course, there is an option to control this charge even if it is paid via balancing responsible parties to ensure a more direct passing on, but this entails introducing a controlled element in an otherwise free pricing structure.

If the charge is paid via the network operators instead, it will need to be regulated. However, it should be managed outside the revenue regulation of network operators, as such a charge is not linked to grid operations.

Another question is who will be responsible for the financial settlement of the capacity mechanism? It could be managed by Svenska kraftnät, through the existing balancing settlement organisation (eSett) or a new organisation dedicated to the purpose (e.g. similar setup to Compensation Chamber in the UK).

5 Timetable and timings for the introduction of a Swedish market-wide capacity mechanism

5.1 Lead time for approval and development of a capacity market

The introduction of a capacity mechanism requires the approval of the European Commission. Currently, there is only one example where a market-wide capacity mechanism has been approved under the current regulatory framework (Belgium), even though there are a number that were approved before the new Electricity Regulation came into force on 1 January 2020. Section 2.1 describes the legal requirements and the main steps for approval.

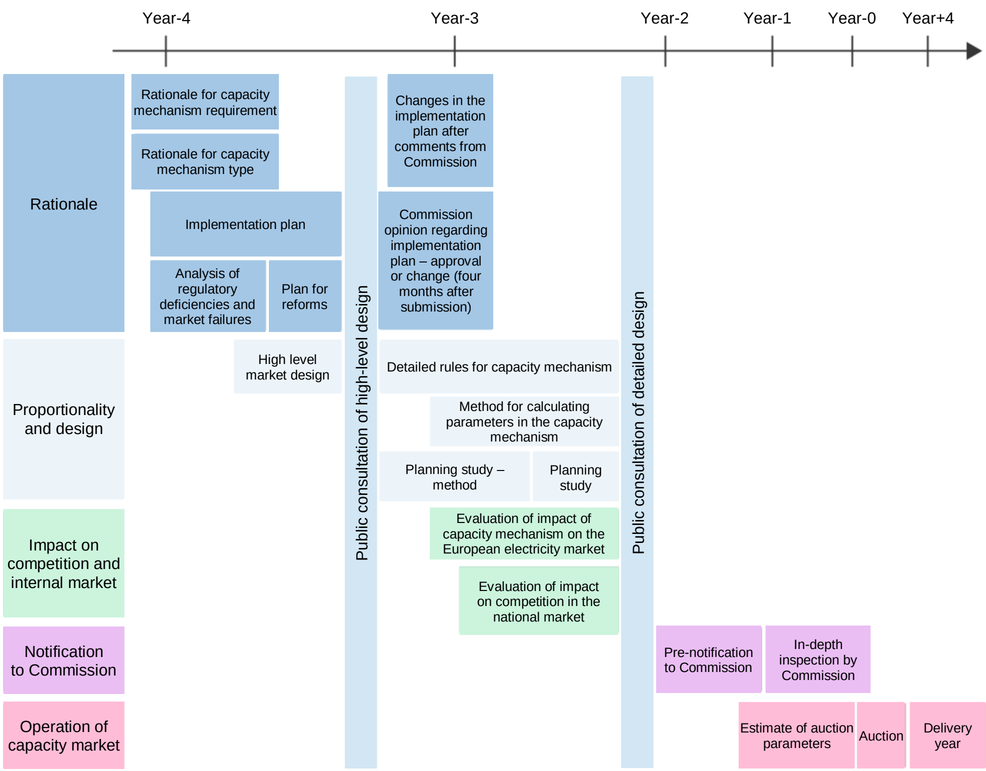
As Belgium's capacity market is the only one that has been approved since the present Electricity Regulation came into force, it is relevant to take a closer look at the lead time for Belgium. In 2017, the Belgian TSO, Elia, began warning of problems with adequacy and stated that action was required. In 2018, a federal energy strategy was adopted, which included monitoring the security of supply by the TSO, the regulatory authority and the ministry. In the same year, an agreement was also reached within the Belgian Council of Ministers on capacity mechanism legislation, which was then adopted by the parliament in April 2019.

However, the legislation itself is not a complete market design, as it lacks detailed regulations. At the end of March 2019, work began on developing the capacity market design, which continued until December 2019.

With regard to the process at the European Commission, Belgium made an advance application to the European Commission in July 2019. The European Commission then sent questions to the Belgian authorities and a number of meetings were organised between the European Commission and Belgium. Belgium then notified measures to the European Commission in December 2019. Belgium subsequently provided further information on several occasions at the request of the European Commission. In September 2020, the European Commission announced that it had decided to initiate the formal investigation process. Finally, the European Commission decided to approve the Belgian capacity market in August 2021, i.e. just over two years after the prior notification.

Based on the experience gained regarding the development of capacity markets, Figure 20 shows a possible schedule for the approval and introduction of a capacity market in Sweden. The approval and introduction process can be divided into three main phases. However, the steps can be carried out in parallel, to some extent, which may help shorten the lead time.

Figure 20. Possible schedule for approval and introduction of a capacity market.



Source: Compass Lexecon.

In the first phase, the introduction of a capacity mechanism needs to be justified, an implementation plan to take account of regulatory deficiencies or market failures needs to be drawn up, and a high-level design for the market/mechanism needs to be developed. European Resource Adequacy Assessment 2022 (ERAA 2022) and Svenska kraftnät's short-term market analysis 2022 (SMA 2022) are currently available as justification for the need for a capacity mechanism. However, the methodology used to carry out the ERAA is being implemented gradually, and for ERAA 2022 the methodology has not been implemented fully. Svenska kraftnät believes that the present assessments indicate the need for a capacity mechanism.

Furthermore, it is appropriate in this phase to develop a high-level design of the capacity market, which can be circulated among the relevant stakeholders.

This report can constitute a proposal for a high-level design for a Swedish capacity market. In this part, the question of a targeted mechanism in the form of a strategic reserve or a market-wide mechanism is naturally the first question. Since a Member State wishing to apply a type of capacity mechanism other than a strategic reserve needs to demonstrate that a strategic reserve does not address the resource adequacy concern, this becomes a central part of an application.

In this phase, an implementation plan to improve the electricity market's function will also be drawn up. Ei presented such a plan in 2020 (Ei, R2020:09). In June 2022, Ei was also commissioned by the government to report annually on nine measures in the implementation plan, which was submitted in December of the same year (Ei, R2022:09). Svenska kraftnät has previously mainly taken a positive view of the proposed measures. It is worth noting, however, that the measures identified in the implementation plan are fairly minor adjustments and Svenska kraftnät believes that these measures will only have a very minor impact on long-term investment incentives, if any at all.

On 22 February 2023, Sweden submitted an English version of the implementation plan (Ei, R2022:10) to the EU Commission (ref. no. KN2023/01982). At the time of preparing this report, the European Commission has not delivered an opinion on whether the measures are sufficient to eliminate regulatory distortions or market failures. The European Commission may also call on the Member State to amend its implementation plans accordingly.

In summary, a number of initial necessary steps have already been taken.

In the second phase, any adjustments are made to the implementation plan, but the most extensive work is intended to develop the detailed market design and to carry out supplementary and in-depth system studies. Assessments of the impact on the European electricity market and effects on competition also need to be carried out. This phase can be expected to take around one year. The detailed market design can then be submitted.

The proposal can then be notified to the European Commission and the final approval process carried out. Overall, experience has shown that the process from the initial assessments until the European Commission's approval takes around four years. However, the process has already been started for Sweden. Based on Svenska kraftnät's assessment, an application can be submitted to the EU Commission around one year after work on developing the detailed design has begun. Prior to this, a high-level design needs to be submitted, which could be done by submitting this report. The Swedish implementation plan may also need to be updated in accordance with the EU Commission's statement, which is expected shortly. It is also assumed that the necessary national legislation will be in place.

Following the approval and introduction of a capacity mechanism, it is customary for a market-wide capacity market to conduct auctions with a lead time of around four years. This means that the total lead time from the initiation of the process to the first delivery year is around eight years. However, different transitional solutions can be applied which mean that there is a mechanism in place before the end of a period of eight years. As far as Sweden is concerned, Svenska kraftnät sees a need for a transitional solution that can replace the current power reserve after 2025.

National legislation will also need to be introduced at national level.

5.2 Transitional solution

Given that the total lead time for introducing a market-wide capacity mechanism can be expected to be in the range of 5–8 years and the current power reserve will expire after the winter of 2024/25, some form of transitional solution will be required in order to avoid a hiatus before a market-wide mechanism is introduced.

When fully implemented, the market-wide mechanism entails a lead time between auctioning of contracts and delivery year of approx. four years. This gives a lead time to full introduction of approx. eight years. As in Italy, the first transitional solution is to carefully phase in the long-term capacity market by carrying out intermediate procurements of capacity with shorter lead times between the auction and delivery year. By having intermediate auctions with a lead time of 1–3 years, the lead time can be shortened to around five years. The main scenario would then be that the first auctions can be conducted with a delivery year of 2028, which would involve a hiatus of three winter seasons.

The second transitional solution is to extend the existing power reserve for a further three years. Some amendments to the national regulations/conditions for the power reserve may be needed, but the regulations are already very much adapted to EU law and any changes that may be required are therefore expected to be minor. However, an extension of the power reserve may also require State aid approval, as Finland received for its strategic reserve on 11 October[16]2022.

A third transitional solution, which should perhaps be regarded as a parallel system, is to implement a grid reserve in order to contract resources in the long term to solve specific grid-related problems.

There are two main options in terms of State aid approval. One is to directly submit an application for a market-wide capacity market and to include an extension of the current power reserve as an explicit transitional solution in this application. The second alternative is to submit a separate application for an extension of the power reserve. This may certainly describe the long-term need, and that the power reserve is expected to be a transitional solution, but no application for approval of a market-wide capacity market has been submitted at this stage.

Given the need for greater development with regard to the market-wide capacity market, it may be advantageous to first submit a separate application for an extension of the power reserve, and then an application for a market-wide capacity market. However, Svenska kraftnät has not had the opportunity to analyse the various alternative approaches in more detail.

5.3 Responsibility and mandate for Svenska kraftnät

The introduction of a capacity mechanism may involve changes to Svenska kraftnät's responsibility, mandate and access to information.

5.3.1.1 Responsibility and mandate for Svenska kraftnät

According to the letter of appropriation for the 2023 financial year, Svenska kraftnät will aim to ensure that relevant socio-economically motivated measures are taken to ensure that Sweden has good security of supply and that the risk of power shortages can be reduced in both the short and long term. In practice, the number of measures Svenska kraftnät can take within the framework of the mandates it has is limited. In general, in accordance with Chapter 3, of the Swedish Electricity Act, in terms of their own grid, network operators shall be responsible for:

1. operation and maintenance,
2. expansion if required,

[16] State Aid SA.55604 (2022/N) - Finland Finnish strategic reserve.

3. any connections to other grids
4. ensuring that the grid is safe, reliable and efficient, and
5. that the grid can meet reasonable requirements for the transmission of electricity in the long term.

The responsibility and mandate for Svenska kraftnät is limited to measures in its own grid. As Svenska kraftnät is appointed system operator in accordance with Chapter 8, Section 1 of the Swedish Electricity Act, it is responsible for ensuring that electricity plants work together in an operationally safe manner so that a balance between production and consumption of electricity across Sweden as a whole or parts of the country is maintained in the short term. It also has responsibility on the basis of the Electricity Regulation and associated Commission regulations to contribute to a well-functioning European electricity market. Examples of activities with the potential to affect resource adequacy in the long term are regular bidding zone reviews so that the bidding zones reflect structural transmission constraints and measures to increase liquidity on financial markets. Examples of activities with the potential to affect resource adequacy in the short term are calculation and allocation of transmission capacity between bidding zones, taking into account the operational security of the transmission system.

As regards measures to strengthen resource adequacy by procuring production capacity or flexible electricity consumption, Svenska kraftnät has, at the time of producing this report, in principle no responsibility or mandate to independently determine which volumes need to be procured in a capacity mechanism in order to ensure resource adequacy in the electricity market. The Lag (2003:436) om effektreserv states that Svenska kraftnät must ensure that there is a power reserve. This act is valid until 16 March 2025. The Förordning (2016:423) om effektreserv sets out the detailed requirements for the procurement of power reserves, and also indicates the volume.

5.3.1.2 Modelling competence and access to information

Svenska kraftnät, or the organisation responsible for implementation, needs to be able to make advanced electricity market simulations of national resource adequacy. The implementation of a methodology to assess European resource adequacy is something ENTSO-E does over a number of years, which shows the complexity of these assessments.

A simulation model needs high-quality input data and access to detailed information about the electricity system needs to be ensured, for example sound forecasts of how production and consumption are expected to develop over time for each connection point in order to be able to see where transmission constraints occur.

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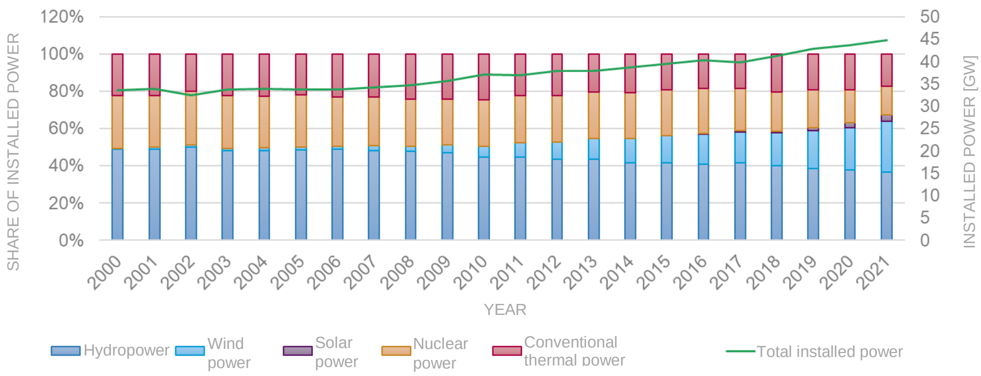
Appendix 1. Reduced resource adequacy in Sweden over time

This Appendix contains a bibliographical review of resource adequacy and what assumptions about the future form the basis for why margins are expected to decrease over time. The summary includes a description of the electricity system's historical development, as well as future-oriented reports such as short-term and long-term market analysis.

Development of the electricity system in the 2000s

The electricity system underwent development during the 2000s, partly because the proportion of renewable production has increased. Figure 21 shows the development of installed production capacity in Sweden during the period 2000-2021. As the figure shows, the total installed capacity has increased, with the increase consisting mainly of new wind power. Hydropower's share of capacity has fallen, but is largely constant in absolute terms at around 16 GW. Nuclear power has fallen in both relative and absolute terms from having had a maximum installed capacity of 9,768 MW in 2016 to 6,899 MW in 2021.

Figure 21. Installed production capacity and share per technology.

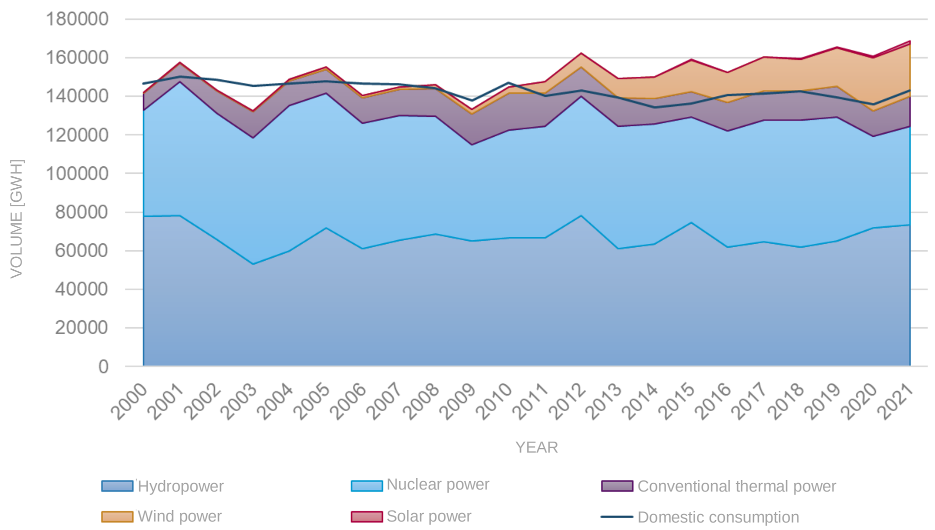


Source: Data from Statistics Sweden.

Nuclear power has been shut down in southern Sweden. The two reactors in Barsebäck, each with a capacity of 600 MW, were shut down in 1999 and 2005 respectively, resulting in a 1,200 MW reduction in production capacity in the current SE4. Two of the four reactors at the Ringhals nuclear power plant have been decommissioned: R2 in December 2019 and R1 in December 2020, which corresponded to a total of 1,781 MW being decommissioned in the current SE3 bidding zone. With regard to the nuclear power plant in Oskarshamn, reactor O1 with a capacity of 437 MW was taken out of operation in 2017 and a reactor with a capacity of 638 MW in 2015. In recent years, the installation of wind power has mainly taken place in SE1 and SE2. During the period 2015–2021, 6,276 MW of wind power was added in Sweden; 48% in SE2 and 23% in SE1. Overall, the development of production capacity in Sweden has meant more weather-dependent production, primarily in the northern bidding zones, and reduced capacity of dispatchable production, particularly in the southern parts of the country.

The development is also reflected in the volumes that have been produced, as shown per technology in Figure 22. One clear trend is the increased amount of wind power generation that has been added in the past decade. The figure also shows that Sweden's total electricity consumption has remained relatively stable since the turn of the millennium. Variations between years occur due to factors such as different weather conditions and temperatures during the winter season. In the 2000s, the highest ever domestic electricity consumption on an annual basis was just over 150 TWh, which occurred in 2001. In 2020, electricity consumption fell to around 135 TWh, which can be attributed to the COVID-19 lockdown. However, there is much to indicate that electricity consumption will increase in the coming decades due to the electrification of the transport sector, industry and the emergence of new commercial operations such as data centres.

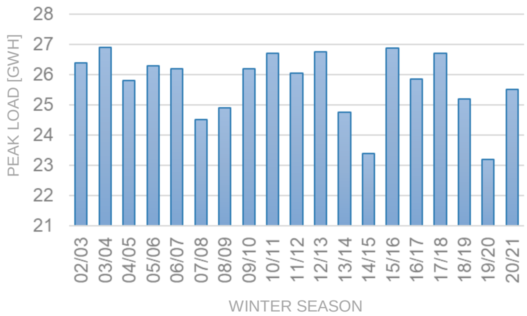
Figure 22. Annual electricity production and consumption.



Source: Data from Statistics Sweden.

The maximum consumption in Sweden during the year can be studied through the 'peak load hour', which historically has occurred during the winter season either during one morning hour or one afternoon/evening hour. The level of consumption during this hour depends, among other things, on temperature and wind, which has a major impact on heating demand and consequently on consumption. Figure 23 shows consumption during peak load hours for each winter season. It is not possible to discern any clear trend in peak load based on the data from the last 20 years. However, it is possible that there will be higher levels in the future with electrification and therefore both a generally higher consumption level, but also an increased power requirement as a consequence of electric car charging, etc.

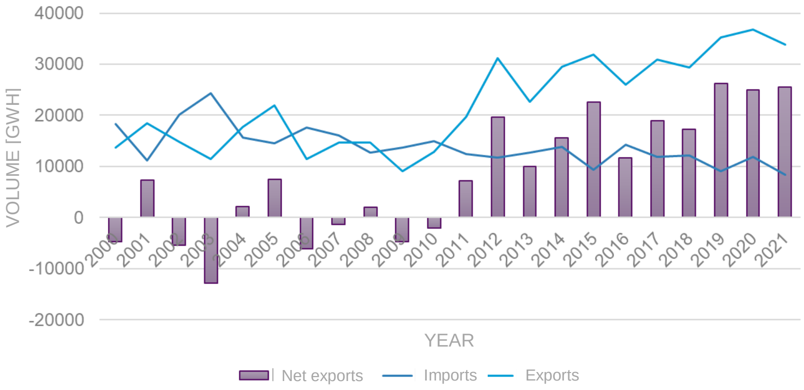
Figure 23. Highest hourly electricity consumption per winter season.



In terms of demand in 2022 and 2023 and the energy crisis that Europe is experiencing, the high market prices and increased awareness have led to reductions in consumption. Svenska kraftnät has reported clear trends compared with previous years regarding reductions for Sweden of a maximum of 8.2% to date, which occurred in December 2022 (Svenska kraftnät, 2023).

The differences between domestic production and consumption are exports or imports, which can be found in Figure 24 for the period 2000-2021. During all years, Sweden has both imported and exported electricity, but exports of electricity have increased over the past ten years and Sweden has been a net exporter since 2011, viewed on an annual basis. In term of energy over a longer period of time, Sweden therefore has a surplus, but it should be noted that supply can vary greatly over shorter time horizons due to variations in wind power production, among other things.

Figure 24. Annual imports and exports.



Source: Data from Statistics Sweden.

In summary, the development over the past 20 years can be described as the consumption side having remained relatively unchanged over the period, but that there have been major changes in production and imports/exports. The production mix has changed to include more weather-dependent electricity production, primarily in the northern and central parts of the country, and with reduced dispatchable production capacity in the southern parts of the country. Overall, production has increased as have annual export volumes.

The change in the production mix also entails new requirements with regard to adequacy. This development has resulted in reduced margins and thus greater risks of power shortages. This applies in particular to the southern parts of Sweden where dispatchable production has been shut down. Current and future adequacy challenges are discussed in more detail in the next section.

European adequacy studies

At European level, adequacy studies are carried out as part of the European Resource Adequacy Assessment (ERAA), which is conducted each year by the European association for the cooperation of TSOs, ENTSO-E. The purpose of the ERAA is to provide stakeholders and decision-makers with a basis for informed decisions on various investments and policy measures. The ERAA is also key in terms of the ability of Member States to establish or maintain capacity mechanisms in that the results of the ERAA in terms of LOLE (and EENS) can be used to justify the introduction of capacity mechanisms if LOLE exceeds the nationally established reliability standard. Thus, ERAA plays a role from a legal perspective, as the results form part of the basis for the approval process at EU level that is required in order to introduce capacity mechanisms.

The methods used to carry out the ERAA were approved by ACER in October 2020, including the application of a probabilistic method. Methods are being developed to make this possible both internationally at ENTSO-E and at Svenska kraftnät. After ENTSO-E has conducted assessments, the results from the ERAA must be approved by ACER.

The process for the ERAA follows three main steps. The first step is data collection from the European TSOs regarding consumption, production resources, flexibility and transmission capacities for the assessment year covered by the ERAA. ENTSO-E compiles the data and carries out quality checks. The next step is to analyse how different economic drivers affect capacities in different countries through an Economic Viability Assessment (EVA). The aim is to assess the economic viability of various capacity resources involved in an energy-only market[17]. The financial viability of different facilities is assessed through a planning model for long time horizons, in which capacities for different resources are optimised based on a cost minimisation perspective for the whole system. The results of the EVA therefore represent information about whether different resources, per bidding zone and analysis year, can be decommissioned, mothballed (or demothballed), invested in or prolonged. The results of the EVA then form the basis for adequacy assessments, which form the third stage of the ERAA process. These assessments are carried out by simulating the European system on an hourly basis given the resources resulting from the EVA. The simulations are stochastic in order to represent various outages in production resources and transmission possibilities. Furthermore, the assessment is carried out using a number of weather years in order to cover varying weather conditions. The results of the adequacy assessments are summarised using the metrics LOLE and EENS at bidding zone level.

It should be noted that the method and models included in the ERAA are highly complex and comprehensive. The assessments include 37 countries divided into 56 zones. All Member States are included, as well as countries outside the EU that are connected to EU countries. However, the modelling of countries outside the EU is highly simplified in order that modelling and data management can remain manageable. Although such simplifications have been introduced, the overall model at European level constitutes a large collection of complex and complicated relationships. The methods and models are still under development.

[17] Resources included in a capacity mechanism are exempted from the EVA for the duration of their inclusion in the capacity mechanism.

Results from ERAA 2021

The ERAA was first conducted in 2021 and includes adequacy assessments for 2025 and 2030 (ENTSO-E, 2021). The assessment is based on four scenarios, where national forecasts collected from TSOs were used as a starting point. These were then developed to represent different levels of market interventions with and without a capacity mechanism, and in accordance with the EVA method. Furthermore, there is a scenario representing low thermal production capacity which, in the same way as the national forecasts, was collected from the TSOs by ENTSO-E. The analyses for 2025 included all four scenarios, while the analyses for 2030 only included the national estimates with static assumptions about installed capacity (i.e. without the dynamics of the EVA).

For the scenarios involving an EVA, the installed capacities in SE2 were reduced by 54 MW and in SE3 by 141 MW, all capacity relating to gas-fired power plants. This is therefore a result of the model used to analyse and assess the economic viability of different technologies for different years and bidding zones based on the forecasts provided at national level by the different TSOs.

The final results from ERAA 2021 for Sweden's future can be summarised in accordance with Table 14 [18]which shows LOLE for SE4. As shown in the table, LOLE amounts to a maximum of 0.4 hours/year in the assessment for SE4. However, it should be noted that parts of the ERAA methodology in accordance with the Electricity Regulation were not implemented in the execution of ERAA 2021 and the results should therefore be considered with this in mind.

Table 14. LOLE in hours/year from ERAA 2021.

Scenario	2025	2030
National forecasts	≤ 0.1	0
EVA without capacity mechanism	0.1	N/A
EVA with capacity mechanism	0.1	N/A
National forecasts – low thermal capacity	≤ 0.1	0.4

Results from ERAA 2022

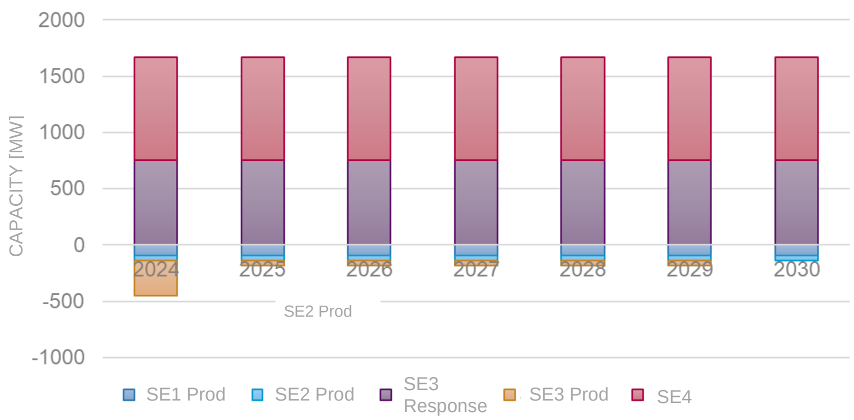
The methodology for the ERAA was developed further prior to the analyses that were carried out in 2022. The analyses in the ERAA 2022 were carried out for

[18] All other Swedish bidding zones had LOLE = 0 hours/year in ERAA 2021.

one scenario: Central Reference Scenario Without Capacity Mechanism (CM). This scenario is based on the assumption that no capacity mechanisms exist, which, in the case of Sweden, means that no capacity payments for a strategic reserve are included. Thus, the scenario in the 2022 ERAA corresponds to the 'EVA without CM' scenario from 2021. As in 2021, the starting point was national forecasts obtained from the TSOs in Europe, which were then developed within the framework of an EVA. The number of years considered by the adequacy assessments changed to include 2025, 2027 and 2030.

In the EVA phase of the analyses, capacities were adjusted in relation to the reported forecasts for resources in the different bidding zones in Sweden as shown in Figure 25. As the figure shows, the economic evaluation model generates a decommissioning of certain production capacities in SE1, SE2 and SE3, while large volumes of demand response enter the market in SE3 (750 MW) and SE4 (920 MW) in all years. The production that is decommissioned is thermally dispatchable production. The total capacity for demand response increases 1,670 MW, which represents a considerable amount of flexibility.

Figure 25. Adjustments of capacities from annual forecasts expressed in MW per bidding zone and year.



Source: Data from ERAA 2022 Edition: Appendix 3 – Detailed results.

From an adequacy perspective, the reduction in dispatchable gas-fired production means that there are less opportunities to maintain adequacy, while greater demand response increases it. However, demand response is constrained in terms of duration, and therefore also in terms of the opportunities to compensate for the decommissioning of flexible production in order to offset longer periods of low wind power generation, for example.

The results regarding adequacy for Sweden in ERAA 2022 are shown in Table 15. In comparison with the results from ERAA 2021, adequacy has deteriorated significantly in the case of southern Sweden. For example, there is an increase in LOLE in SE4 for 2030 from 0.4 hours/year in ERAA 2021 to 5.5 hours/year in ERAA 2022 in comparable scenarios (i.e. without capacity mechanisms). The differences between ERAA 2021 and 2022 can be explained partly by the fact that the methodology changed during the period between the two assessments, and partly by differences in the national forecasts on which the scenarios are based. Svenska kraftnät's forecasts regarding production and consumption are updated during and prior to the annual ERAA process, which gives rise to new conditions for the assessments. The methodology used can be found in the methodology reports published in conjunction with the ERAA[19]. One such update between 2021 and 2022 that is significant in terms of LOLE is how the distribution of energy shortages in shortage situations between different areas and countries is calculated.

Table 15. LOLE in hours/year from ERAA 2022 for SE3 and SE4. Other bidding zones in Sweden have LOLE=0 for all assessment years.

Bidding zone	2025	2027	2030
SE3	1.9	2.5	1.2
SE4	2.0	5.1	5.5

The integration of different countries and regions in Europe means that countries have the option to contribute to adequacy in other countries through imports and exports via interconnectors. It is therefore important to also consider the situations of neighbouring countries when analysing and discussing adequacy. The greatest adequacy challenges for Sweden are in SE3 and SE4, and LOLE for countries and areas directly linked to SE3 and SE4 can be found in Table 16. As the table shows, there are also challenges for adequacy in the surrounding countries and areas, which indicates that the possibility of imports into Sweden may be limited during periods of system stress.

In the ERAA, correlation analyses have been carried out at regional level to analyse the extent to which shortage situations coincide for different parts of Europe. One of the conclusions from these analyses is that there are high positive correlations for when shortage situations arise in different regions. Consequently, there are also limited opportunities to rely on imports from other regions in such situations, as there is a big risk that exporting regions will be experiencing a shortage situation too. This therefore indicates that Sweden can rely on imports to a limited extent during periods of system stress.

[19] See ENTSO-E, European Resource Adequacy Assessment 2021: Appendix 3 – Methodology, and ENTSO-E, European Resource Adequacy Assessment 2022: Appendix 2 – Methodology.

Table 16. LOLE in hours/year for countries and areas adjacent to SE3 and SE4.

Area	2025	2027	2030
NO1	0	0	0
DK1	9.8	13.4	2.3
DK2	7.4	11.1	10.9
FI	3.5	1.6	2.1
DE	10.5	13.7	20.4
PL	≤ 0.1	0.2	2.0
LT	3.8	6.2	6.0

National adequacy assessments

Svenska kraftnät carries out various adequacy assessments and follow-ups that have different time perspectives and a national focus. Below are brief descriptions of the respective assessments and results linked to resource adequacy.

Power balancing report 2022

Svenska kraftnät reports every spring to the government on power balancing in Sweden for the previous winter, a forecast for the coming winter and over the longer term. The latest report was provided at the end of May 2022 and therefore contains the latest follow-up on adequacy during peak hours (Svenska kraftnät, 2022:2).

During the winter 2021/22, the peak load was 25,600 MWh/h, which occurred between 17.00 and 18.00 on 7 December. Net imports to Sweden were 1,600 MWh/h at the time, which is an increase from winter 2020/21, when net imports during peak hours were 500 MWh/h. The outcome for import and export volumes is usually based on a market outcome, i.e. that it has been economically advantageous to import instead of using remaining domestic resources. Flows between the bidding zones in the country were in a north-south direction, with full transmission on average two between SE2 and SE3. SE3 and SE4 therefore represented zones with imports, and in order to study the adequacy of the system, it is of extra interest to study SE3 and SE4 in more detail.

With regard to the situation in southern Sweden during the peak load hour, the power balancing report concludes that 710 MW in the form of available upregulation bids and power reserves were available in southern Sweden, and theoretically another 1,300 MW in imports from other countries. This means that approx. 2,000 MW of additional net consumption could have been handled. However, it should be noted that the temperature at the time was slightly higher than normal for peak load hours in a normal winter and that wind power was generated at a higher level (22% of installed capacity) than is normally used for availability assessments (9% of installed capacity). Temperatures in accordance with a normal winter would have resulted in higher consumption and a reduction in wind power production at the time from 22% to 9% would have resulted in 1,600 MW lower production which could not have been covered by the available balancing resources and power reserve without disconnecting consumption.

Short-term market analysis

Svenska kraftnät publishes annual short-term market analyses (SMA) to analyse developments in the electricity system over the coming five years based on known plans and decisions. The latest version was published in December 2022 and covers the years 2023-2027.

Data input for an SMA consists of forecasts for electricity generation, consumption and interconnectors, and is obtained from Svenska kraftnät, the Swedish Energy Agency, Svensk Vindenergi and the Swedish Bioenergy Association. Since weather conditions have a major impact on both electricity generation and electricity consumption, historical weather data are also used as input values, which are then adapted to resemble the climate in 2030. With regard to electricity consumption in Sweden, this is largely based on the Swedish Energy Agency's short-term forecast[20] plus applications to connect to Svenska kraftnät. The number of applications for very large increases in power consumption received by Svenska kraftnät has increased significantly over the past two years. On the basis of estimates based on lead times for grid development and applications for increases in power consumption that have been received, Swedish electricity consumption may increase significantly during the period, where the main increase is assumed to come from industrial establishments. However, experience from major investment projects shows that uncertainties can postpone schedules, which can then result in the increased electricity consumption being postponed. As far as uncertainties are concerned, the report also states that the energy situation in the EU is very uncertain and therefore difficult to forecast. The energy crisis that has arisen

[20] Swedish Energy Agency, 'Kortsiktsprognos i siffror vinter 2022', 2022.

means that developments in the global situation and rapid changes have a major impact on the electricity system.

To calculate the risk of power shortage, a probabilistic method similar to the one described in the Electricity Regulation is applied. Assessments include stochastic simulations of the electricity system during a number of different weather years and outages at production facilities and interconnectors. Overall, assessments in KMA 2022 show that the risk of power shortage for Sweden is lower than the adopted reliability standard of 1 hour/year at the start of the period, but then increases sharply towards the end of the assessment period. In Table 17 shown in terms of LOLE and EENS. As can be seen, LOLE is 1 hour/year in 2026, which equates to the current reliability standard, but increases to 9.6 hours/year in 2027. The assessments therefore show a drastic deterioration in the resource adequacy of the system by 2027. Preliminary assessments indicate that an additional 2,500 to 3,000 MW of dispatchable production capacity is required to reach the LOLE level of 1 hour/year in 2027. As the table shows, assessments are also carried out to determine sensitivity in the assessments concerning the power reserve and reduced electricity consumption. In spite of reduced electricity consumption, LOLE also exceeds the reliability standard in 2027.

Table 17. Results from SMA 2022.

	2023	2024	2025	2026	2027
LOLE (hour/year)	0.2	<0.1	0.4	1.0	9.6
EENS (GWh/year)	0.1	<0.1	0.1	0.4	6.6
LOLE (sensitivity of remaining power reserve)			0.1	0.5	5.9
LOLE (sensitivity of reduced electricity consumption)	<0.1	<0.1	<0.1	<0.1	1.9

The assessments in KMA 2022 therefore reinforce the picture from the power balancing reports that the margins in the system are decreasing and that the risks of power shortages will increase over time.

Long-term market analysis

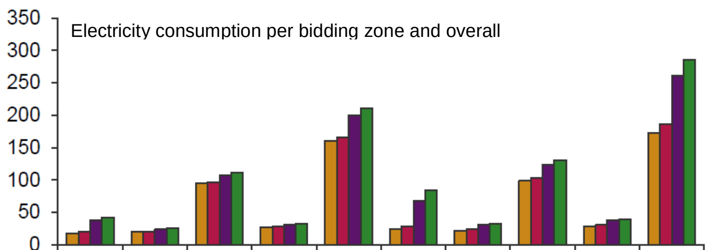
The challenges for resource adequacy are also highlighted in Svenska kraftnät's long-term market analysis (LMA), which is published every two years. Different potential development routes for the system are presented and analysed here.

The latest LMA was published in 2021 and a new one is scheduled for autumn 2023. The LMA has a longer time horizon and looks at different scenarios up to 2050 with a view to evaluating investment options and facilitating a proactive way of working. The starting point for the analyses are four different scenarios that are considered to represent four different development routes for the electricity system: Small-scale renewables (SR); Roadmaps mixed (RM); Electrification dispatchable (EP); and Electrification renewables (ER). The scenarios differ in terms of electricity consumption, investment in production capacity, etc.

It should be noted here that, unlike the SMA, the LMA is based on *scenarios,* not on forecasts. The difference is that a forecast constitutes an estimate of a reasonable, albeit uncertain, future (a best guess of what will happen), while a scenario constitutes one possible development from many possible developments. The starting point for forecasts and scenarios is therefore different, where scenarios are used to define possible outcomes that differ significantly.

A key driving force in the development of the electricity system is the strong current trend of electrification of the transport sector, industry and new operators such as data centres. The defined scenarios include different assumptions about the scope of this electrification, but all scenarios include an increase in electricity consumption. To represent different levels of this electrification, there is a range of use between 173–286 TWh/year for 2045 for the different scenarios, as shown in Figure 26.

Figure 26. Electricity consumption for scenarios in LMA 2021.



	2035 SE1	2035 SE2	2035 SE3	2035 SE4	2035 Tot	2045 SE1	2045 SE2	2045 SE3	2045 SE4	2045 Tot
SR	18	20	95	28	160	24	22	99	29	173
RM	20	21	97	28	166	29	24	104	31	187
EP	38	24	107	31	200	68	31	124	38	261
ER	42	25	112	33	211	84	32	130	39	286

With regard to production, all scenarios include an increase in wind power, but the levels of investment in wind power vary between scenarios within a range of 22.6 GW to 55.3 GW in installed capacity for 2045. A summary of installed production capacity for each scenario can be found in Table 18.

Table 18. Installed production capacity for scenarios in LMA 2021.

Technology, GW	2025	Scenarios 2035				Scenarios 2045			
		SF	FM	EP	EF	SF	FM	EP	EF
Hydropower[17]	16,3	16,3	16,3	16,3	16,3	16,3	16,3	16,3	16,3
Nuclear power	6,9	5,9	5,9	6,9	6,9	0,0	2,6	8,4	0,0
Wind power	16,0	17,1	19,3	23,6	28,8	22,6	31,5	33,8	55,3
– Onshore	15,6	16,7	17,6	20,1	20,3	21,2	24,3	23,7	26,8
– Offshore	0,4	0,4	1,7	3,5	8,5	1,4	7,3	10,1	28,5
Solar power	3,3	15,9	7,1	7,9	11,5	29,1	8,9	11,0	19,1
Other thermal	5,0	4,4	4,3	4,8	4,3	4,5	4,2	5,2	4,2
Dispatchable, *%*	*9*	*45*	*50*	*47*	*41*	*29*	*36*	*40*	*22*
Renewable, %	*85*	*90*	*89*	*88*	*90*	*100*	*96*	*89*	*100*

Model-based simulations are carried out on the basis of the scenarios, which result in hourly production volumes, energy balances, trading flows, market prices, etc.

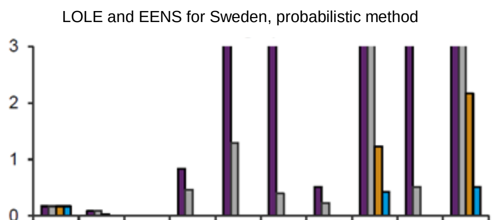
The LMA also includes resource adequacy assessments for the different scenarios. These assessments are carried out using two methods: A probabilistic and a static method. The probabilistic method includes simulations of the whole Northern European system and considers production losses and outages in transmissions in the same way as the SMA. The static method describes the difference between assumed available domestic production and electricity consumption during the hour with the highest electricity consumption, which is the method that has been used for a long time in the power balancing reports that are provided to the government each year. One difference between the methods is that the probabilistic method looks at the whole year and all its hours which the static method does not. The shutdown of nuclear power and repairs in the remaining reactors in combination with high ambient temperatures and work in the grid that reduces transmission capacity mean that there are challenges with resource adequacy even in summertime in southern Sweden. The probabilistic method takes this into account, as power shortages are simulated for all hours in the year. The static method describes the difference between assumed available domestic production and electricity consumption during the hour with the highest electricity consumption. The method can therefore be considered to assess the import requirement, rather than the risk of a power shortage.

Since the probabilistic method provides a more complete picture of resource adequacy, the results of these assessments are focused on here. The assessments include 35 weather years, which have been simulated seven times each with hourly granularity. Each assessment year is therefore simulated 245 times and for more than two million hours. This is to obtain a more secure statistical basis as outages at production facilities and interconnectors are created randomly for each simulation according to the input outage rates. The combined results of the adequacy simulations are presented in terms of LOLE and EENS.

Figure 27 shows the results from the simulations made with regard to LOLE and EENS for the years 2021, 2025, 2035 and 2045 for the respective scenario defined. Furthermore, increased levels of flexibility have been assumed in the assessments, where the impact on LOLE and EENS is presented.

As the figure shows, there are significant challenges in terms of adequacy in most of the scenarios. The simulation results show that flexibility is needed for a well-functioning system in 2045 in the majority of scenarios. However, for scenarios with the highest LOLE values, a considerable amount of flexibility is required in order to achieve LOLE values that meet the current reliability standard of 1 hour/year. The amount of flexibility that would be needed to keep LOLE at an acceptable level for the more extreme scenarios is so extensive that it can be considered unlikely that it can be achieved. For example, the ER scenario would require flexibility in the range of 13,700 to 15,000 MW in order to achieve LOLE of 1 hour/year by 2045.

Figure 27. Results regarding adequacy from LMA 2021.



	2021	2025	2035 SR	2035 RM	2035 EP	2035 ER	2045 SR	2045 RM	2045 EP	2045 ER
LOLE, no flex, h/year	0,2	0,1	0,0	0,8	12	16	0,5	28	229	889
+flex hydrogen	0,2	0,1	0,0	0,5	1,3	0,4	0,2	12	0,5	40
+flex certain industry/electric cars	0,2	0,0	0,0	0,0	0,0	0,0	0,0	1,2	0,0	2,2
+flex server centres	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,4	0,0	0,5
EENS, no flex, GWh/year	0,02	0,01	0,00	0,34	10	16	0,25	33	119	1607
+flex hydrogen	0,02	0,01	0,00	0,14	0,81	0,17	0,12	11	0,23	46
+flex certain industry/electric cars	0,02	0,00	0,00	0,00	0,00	0,00	0,00	0,86	0,00	1,70
+flex server centres	0,02	0,00	0,00	0,00	0,00	0,00	0,00	0,22	0,00	0,36

Overall, LMA 2021 also indicates that there is an increasing problem with regard to resource adequacy. This relates in particular to possible developments involving a sharp increase in electricity consumption combined with a sharp increase in the proportion of renewable and weather-dependent electricity generation.

Work on the next LMA is under way with scheduled publication in autumn 2023. A key change in the updated version is a significant revision of the demand trend, where electricity consumption volumes have increased compared with the levels in LMA 2021.

Appendix 2. Suggested questions to stakeholders in the context of a possible consultation

In view of the short time frame for this assignment, it has not been possible for Svenska kraftnät to consult the market's stakeholders during the course of the assignment. However, prior to the possible introduction of a capacity mechanism, it is necessary to seek the views of stakeholders.

During the work on the report, a number of questions have been identified where Svenska kraftnät sees a need for further analysis and where it is particularly desirable to get input from stakeholders.

General choice of direction

Question 1: Do you see a need for a continued capacity mechanism after 16 March 2025?

Question 2: Should a market-wide capacity mechanism be introduced?

Question 3: Should the current mandate for Svenska kraftnät be extended to plan, design and, if necessary, procure a capacity mechanism so that the reliability standard is met in the short and long term?

Choice of design for a market-wide capacity market

The questions in this section are asked on the basis of key design elements given that a market-wide capacity market is to be introduced.

Geographical division and management of transmission capacity within Sweden

Question 4: Should a potential capacity market be designed with geographical division within Sweden?

Question 5: If so, should the geographical division of the capacity market be based on bidding zones or do you have alternative suggestions regarding geographical borders?

Question 6: Do you have any comments on how the transmission capacity in Sweden should be managed within the framework of a capacity market?

Foreign participation

Question 7: What are your views on cross-border (foreign) participation in a Swedish capacity market?

Centralised or decentralised capacity market

Question 8: If a capacity market is introduced, do you have an opinion on whether a centralised or decentralised procurement model is preferable?

Incentive to be available

Question 9: Should the requirement of financial repayment at high prices be introduced in the form of reliability options?

Question 10: If reliability options are introduced, should this be combined with requirements for availability and penalties for unavailability in declared periods of system stress?

Question 11: If reliability options are introduced, how should the strike price be defined ('method') and/or what strike price level is appropriate?

Question 12: If reliability options are introduced, how should demand resources be managed in relation to reliability options?

Question 13: What are the pros and cons of introducing a stop-loss mechanism for repayments from reliability options and/or penalties for non-deliveries? Any views on the design of such a stop-loss mechanism?

Product definition and environmental requirements in the procurement

Question 14: Should a market-wide capacity mechanism be designed on the basis of one or more products?

Question 15: What aspects are important to consider when determining de-rating factors?

Question 16: Should a national capacity mechanism have a lower limit than the general EU requirements for a plant's maximum CO_2 emissions? How low should the limit be and why?

Auction design

Question 17: Should the auction design be based on marginal price, pay-as-bid or another alternative, e.g. differentiation between existing and new resources?

Question 18: What options do you see for bidding regulations to limit any problems with inframarginal rent and to ensure that bids are cost-reflective under a pay-as-bid mechanism?

Question 19: Should existing production resources that do not participate in the capacity market be implicitly included in the supply curve as zero bids and without capacity payment?

Question 20: Should requirements be introduced for participation in the capacity market by existing production resources?

Question 21: Do you have any views on which type of auction model would be preferable for a Swedish capacity market (single-round sealed bid, multi-round descending clock or other alternative)?

Contract duration and auction lead time

Question 22: What do you consider to be an appropriate lead time for capacity auctions?

Question 23: What do you consider to be appropriate contract durations for capacity contracts and what, if any, threshold values should be applied?

Financing of capacity mechanism

Question 24: Is it appropriate for the net cost of a capacity market to be financed via a charge imposed on balancing responsible parties or network operators?

Question 25: Should the charge to cover the net cost of a capacity market be regulated such that it is paid through the end customer, i.e. the charge is passed on directly to the end customer?

Question 26: Should any excess revenue from a capacity market (in the case of high energy prices) be returned to customers directly or through a reduction in future tariffs?

Question 27: In the event of a direct return, how do you assess the administrative costs for a network operator or balancing responsible party/electricity supplier for managing such a process?

Question 28: Should financing be divided based on the geographical division of the capacity market, or should it take place jointly and severally across the whole customer base?

Svenska kraftnät is a state-owned transmission system operator, with the task of managing, operating and developing a cost-effective, operationally safe and environmentally sound transmission system. The transmission system includes 400 kV and 220 kV power lines with substations and interconnectors. Svenska kraftnät develops the transmission grid and the electricity market to meet society's need for a reliable, sustainable and cost-effective supply of electricity. Svenska kraftnät therefore plays an

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