Impact assessment of a Swedish capacity remuneration mechanism

Report

3 March 2025

Contents

1.

Context and our mandate

Context: Adequacy concerns in Sweden and considerations regarding a capacity market

Adequacy concerns in Sweden

- Svk’s Long-term Market Assessment (LMA) of 2024 suggests that adequacy concerns may occur mainly in the future electrification scenarios (EP, EF) with limited flexibility
  - High values of Loss of Load Expectation (LOLE) exceeding the Swedish Reliability Standard of 1 hr/year LOLE are expected as soon as 2035 and 2045.
  - Specific zones are more concerned than others. For example, adequacy concerns in SE1 are driven by considerable inflexible demand from hydrogen
  - Adequacy concerns strongly depend on the assumptions of the flexibility of the demand (smart charging, hydrogen, etc.)
- Addressing the identified adequacy concerns in the Swedish power system could therefore require both adequacy and flexibility solutions

Specificity of the Swedish reliability standard

- Loss of load expectation (LOLE) is a key adequacy metric, defined in Sweden as ≤1 hour/year.
- This LOLE target, one of the lowest in Europe, is determined by key assumptions of the value of lost load (VOLL) and the cost of new entry (CONE), which are both relatively low from a European perspective.

Considerations for a market-wide capacity mechanism in Sweden

- On December 15 2022, the Swedish Government tasked Svenska kraftnät (Svk) to propose a design for a capacity mechanism that would replace the strategic reserve to ensure resource adequacy along the Swedish Reliability Standard of 1 hour/year LOLE.
- In March 2023, Svk submitted a report to the Swedish Government proposing a future market-wide capacity mechanism in Sweden, differentiated based on bidding zones, featuring reliability options and allowing forward-looking procurement of capacity under long-term contracts for new-build capacity for 7 to 15 years.

Context: To ensure electricity security of supply in an increasingly electrified system, both adequacy and flexibility are needed

Adequacy and Flexibility

Adequacy is the ability of the electricity system to supply the aggregate electrical demand within an area at all times under normal operating conditions. Going beyond capacity to meet peak demand, it implies also **adequate flexibility resources** to follow variations of load and generation.

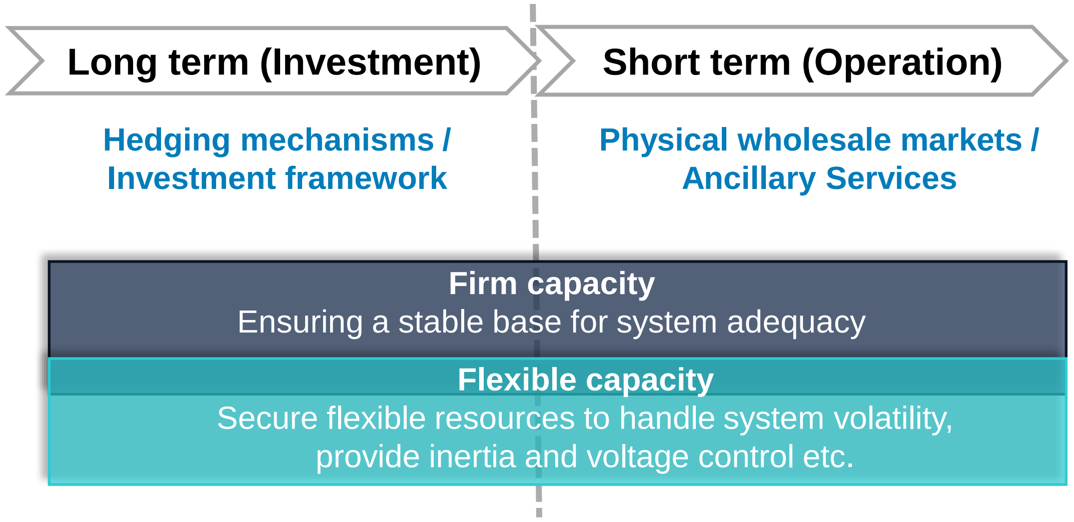
“Flexibility” is the ability of an electricity system to **adjust to the variability** of generation and consumption patterns and to grid availability, across relevant market timeframes

Focus of this study

Often **adequacy and flexibility are bundled** together as they are often delivered by the same resources – but not always.

This **study focuses on adequacy** (it is not a study assessing flexibility needs) but considers the **flexibility needs** to ensure adequacy.

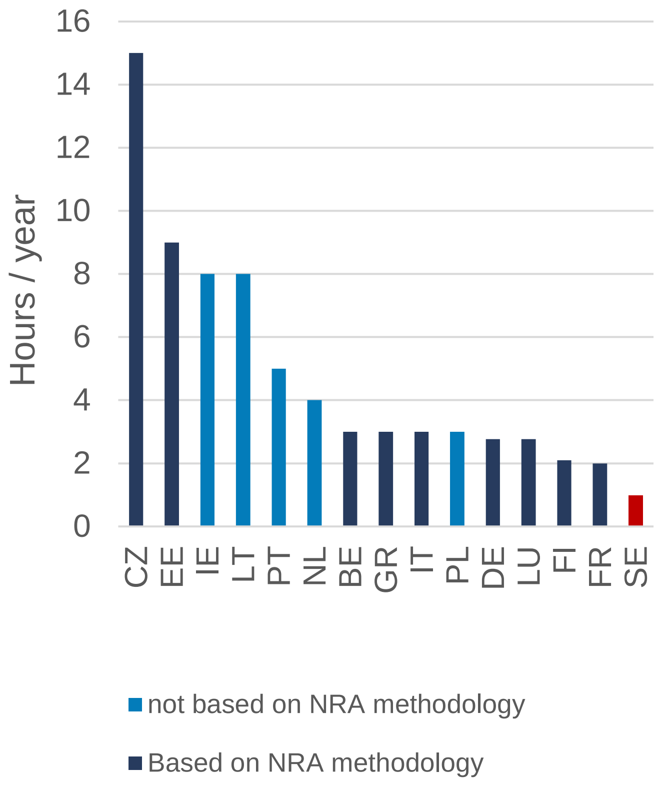
The overlap of flexibility and adequacy



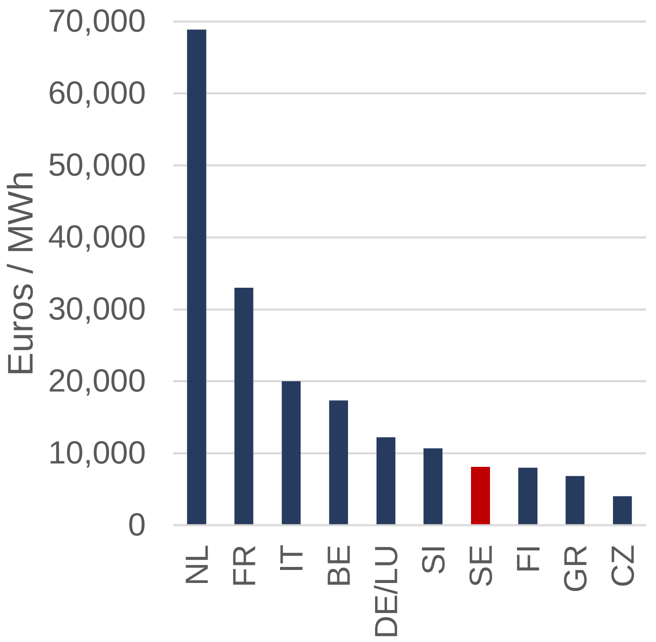
Context: Sweden features the lowest LOLE target in Europe (1h/year) despite low VOLL but due to the lowest CONE in Europe

The Reliability Standard in Sweden is based on the VOLL and CONE studies performed in 2021. The questionnaire-based VOLL study focuses on the Willingness to Pay analysis and is much driven by extremely low VOLL estimation for the household customer segment. The CONE analysis in turn used Demand Response as reference technology with costs quite below the European benchmarks.

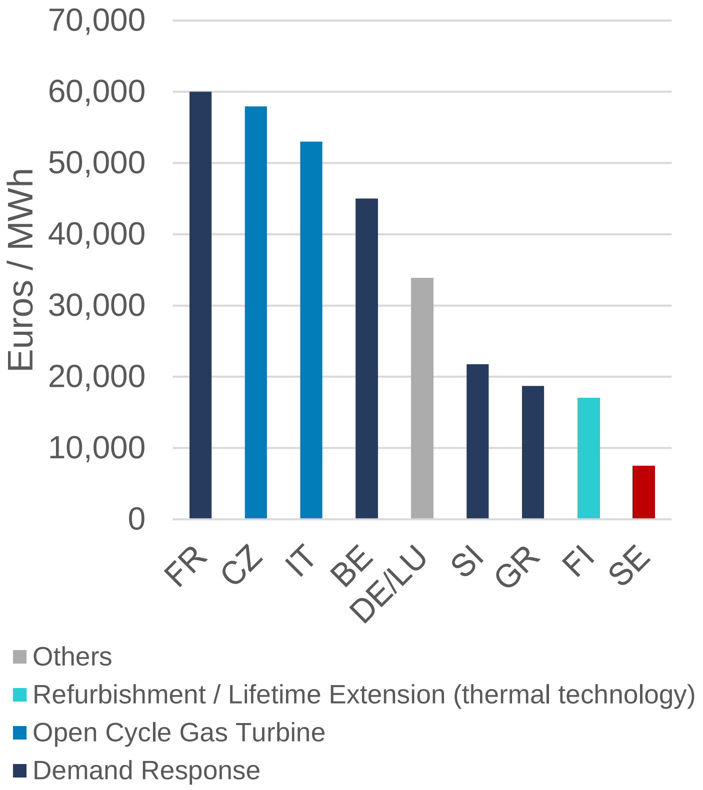
Reliability Standard LOLE targets



Value of Lost Load of selected countries



Cost of New Entry of selected countries



Source: *ACER 2022*

Objectives and mandate

Our mandate

- Compass Lexecon and DNV have been mandated by Svk to develop an **impact assessment of different possible approaches to ensure adequacy in Sweden**, ranging from **energy only, strategic reserve, to the introduction of a market wide capacity market**.
- Specifically, the study develops a **model-based impact assessment** of implementing a new Capacity Mechanism in Sweden, considering multiple factors such as security of supply, electricity prices, economic welfare, and environmental aspects.
- In particular, the impact assessment compares three potential market design options for a Capacity Mechanism:
  - **Energy Only -** where investment in capacity is driven only by energy market revenues.
  - **Strategic Reserve –** a limited volume of supplementary capacity, which is only dispatched in periods of scarcity and is otherwise out-of-market.
  - **Market-wide CRM –** a centralised entity acquires the total capacity assumed to be required to ensure that the Swedish reliability standard of LOLE≤1 hour/year is met.
- The study focusses on the **total economic welfare and identify potential distributional impacts** of these different possible approaches:
  - The study models the consumer welfare (incl. energy price, capacity price, and the value of the Energy Not Served), producer welfare (profits from energy and capacity markets), and congestion rents.
  - A set of sensitivity analyses are conducted to assess the impact of some key market design parameters including day-ahead price cap and risk aversion of investors on the results.

Objectives of this report

- This report provides an overview of the study's context, details the key inputs and assumptions, outlines the assessment approach, and highlights the main findings.

2.

Our approach

Approach overview: Modelling the impact of the market design options on the equilibrium capacity mix and the resulting impact on several KPIs

Overview of the applied methodology

Model Inputs

Baseline scenario

- Demand and external capacity assumptions (RES, hydro, nuclear) based on LMA scenarios for Sweden and TYNDP scenarios for the rest of Europe
- **DE/EF** – high RES, nuclear phase-out
- **GA/EP** – lower RES, new nuclear
- **DE/EF flex** – high demand flexibility

Market design options considered by Svk

- **EOM** - investment in capacity is driven only by energy market revenues
- **SR** - limited out-of-market DSR or storage capacity dispatched in periods of scarcity
- **CRM** - centralised capacity market

Equilibrium capacity mix and dispatch

Economic dispatch

- Model of the European power market based on Plexos platform
- Provides the optimal production schedule and estimation of the spot market prices based on the marginal SRMC

Iteration on capacity mix

Economic viability assessment

- Assessment of viability of technologies for which investment decision is market-driven: carbon-free OCGT and CCGT, 4-hour storage and DSR
- Assessment of long-term cash-flows from market revenues and fixed costs

Impact assessment KPIs

KPIs

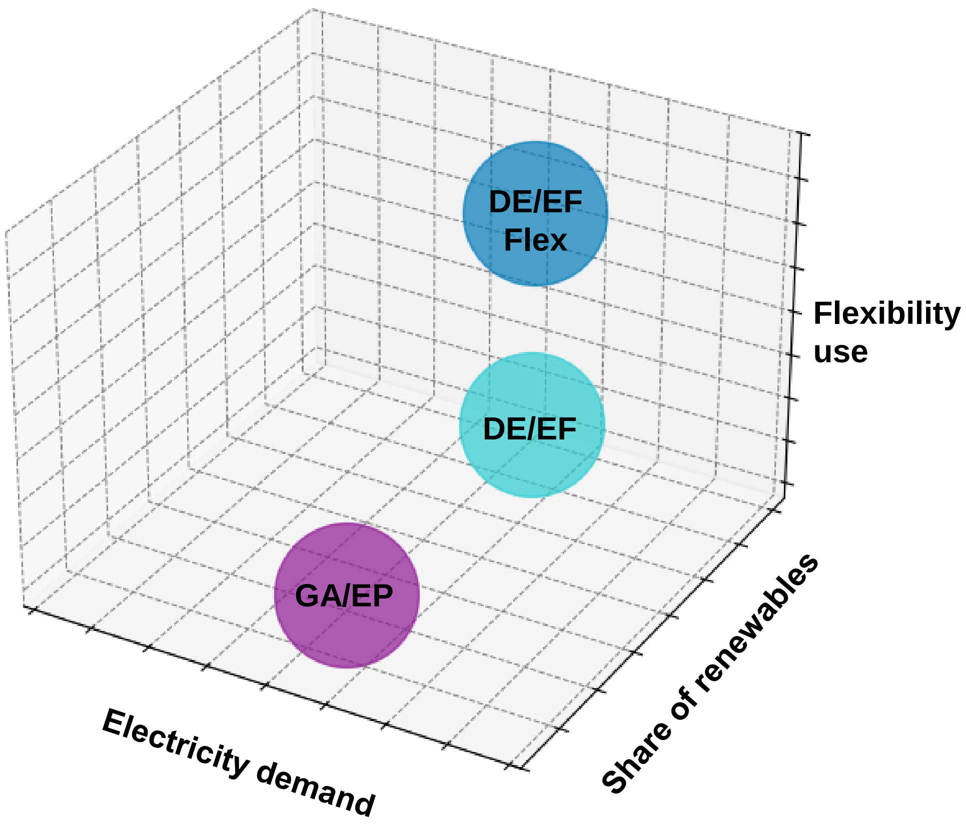
- Available capacity and impact on investments in Sweden
- Security of supply in Sweden
- Costs of capacity mechanism
- Impact on energy prices
- Impact on trade flows
- Generation mix and environmental impact
- Economic welfare impact in Sweden

Source: Compass Lexecon
Notes: TYNDP (Ten-Year National Development Plan), DE/EF (Distributed Energy scenario), GA/EP (Global Ambition scenario), LMA (long-term market analysis), SRMC (short-run marginal cost)

Three forward scenarios

The study develops and compares three scenarios with varying assumptions on share of renewables and flexibility use

Scenarios overview



- For Sweden, LMA24 scenario EP (GA) and EF (DE) are used, while the rest of Europe is modelled with TYNDP22 DE/EF and GA/EP scenarios assumptions
- All scenarios assume **365 TWh electricity demand in Sweden in 2050** → Fossil-free steel, hydrogen production, electrification, new datacentres and battery factories.
- **Commodity prices** are based on latest studies WEO2023 and TYNP2024
- **Technology costs** (CAPEX, OPEX) and **technical assumptions** are based on EC Impact Assessment 2040 and TYNDP2024

Renewable electrification (DE/EF)

365 TWh Sweden 2050, less-plannable power mix, high need for grid/flex:

- High renewable potential
- No new nuclear power, all reactors decommissioned after 55-60 years of lifespan

Plannable electrification (GA/EP)

365 TWh Sweden 2050, planned power, less need for grid/flex:

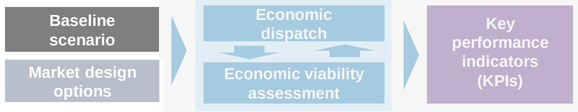
- Lower renewable potential
- 14.7 GW nuclear power 2050 through lifetime extension of all reactors to 80 years and new reactors

Renewable electrification with flexibility (DE/EF Flex)

365 TWh Sweden 2050, less-plannable power mix, high use of grid/flex:

- All assumptions same as in EF except flexibility
- **EV** from 25% in 2030 to 70% flexible in 2050
- **HP** from 25% in 2030 to 50% flexible in 2050
- **DSR** 200h/year activations (compared to 43h/year in baseline)
- **Datacentres** from 0% flexibility in 2030 towards 10% flexible in 2050
- **Electrolysers –** 20% flexible without storage limits and 80% as baseline with storage limits for all period

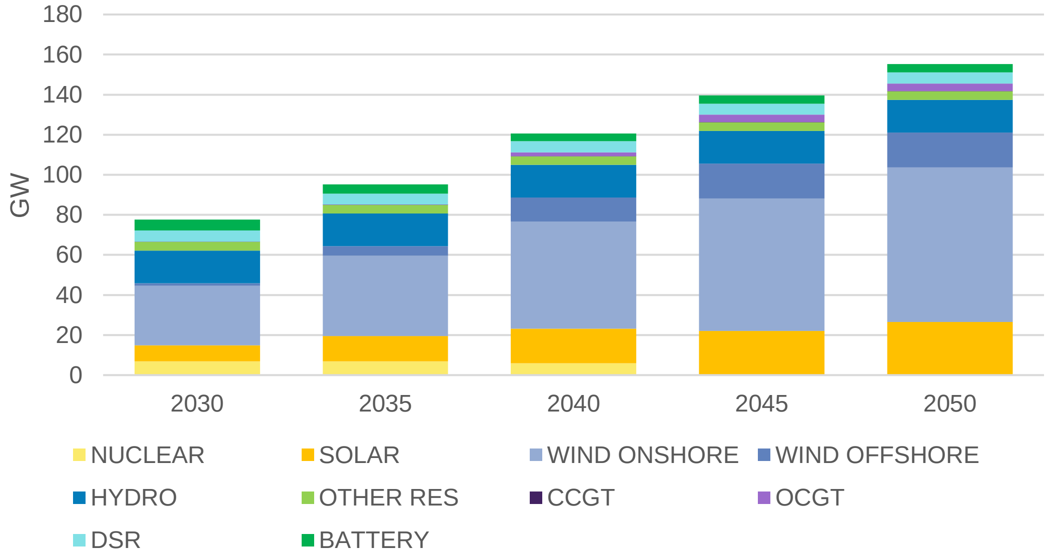
Sources: Compass Lexecon analysis based on 1 Svk, 2024. LMA; 2 ENTSO-E, 2022, TYNDP2022. 3 Ei, 2021, Proposal for reliability standard. 4 EC,2024, Impact assessment 2040. 5 ENTSO-E, 2024. TYNDP2024. 6 IEA, 2023. WEO 2023.



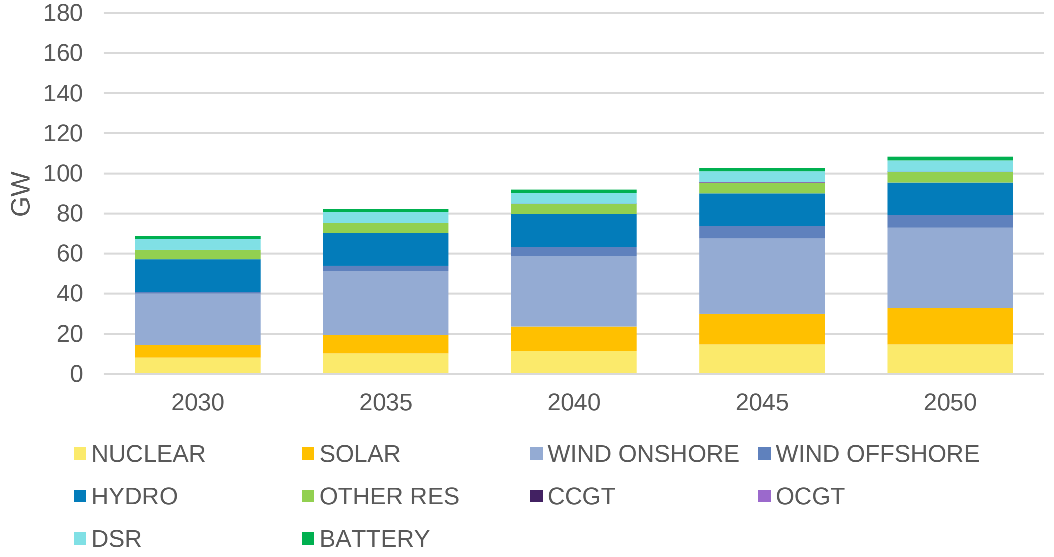
Overview of baseline scenarios (1/2)

Capacity mix evolution

Installed capacity in SE – DE/EF scenario (in GW)



Installed capacity in SE – GA/EP scenario (in GW)



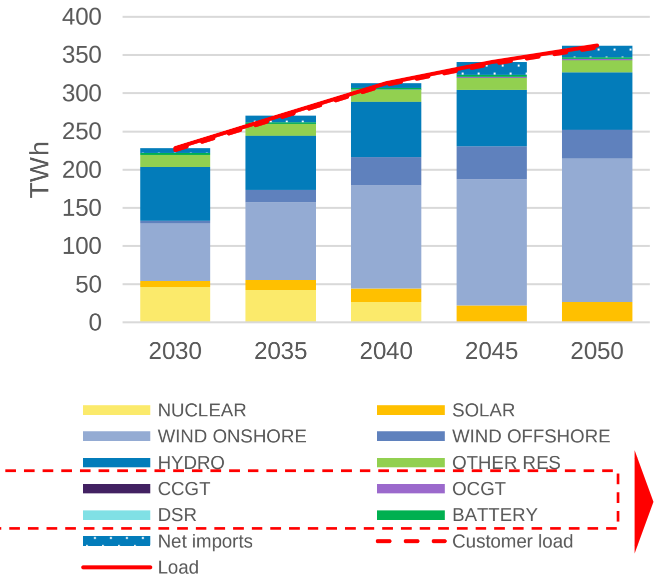
- In the DE/EF scenario, nuclear capacity fully exits by 2045, while in the GA/EP scenario, nuclear capacity is expanded and gradually deployed in the four Swedish bidding zones until reaching c.15GW in 2050
- Solar, onshore and offshore wind capacity increases in both scenario, although at a faster pace in the DE/EF scenario to compensate for the decreasing nuclear capacity
- No thermal capacity (OCGT or CCGT) is expected in the baseline GA/EP model, while 3.7GW of OCGT is expected to be commissioned in the DE/EF scenario in 2050
- DSR capacity stands as 5.5GW across the entire horizon, similarly to the DE/EF scenario, while battery capacity is slightly inferior to the one deployed in the DE/EF scenario, with 1.9GW deployed in 2050.
- Biomass CHP capacity is present in all four Swedish bidding zones to provide additional power during winter and system tensions.
- The capacity mix of the DE/EF Flex scenario is identical to the one in the DE/EF scenario.

Note 1: Wind and solar capacities in Sweden are based on LMA24 EF scenario. However, considering that CL model and LMA24 EF scenario used different capacity factors for wind and solar (e.g. c.40% for onshore wind in LMA24, c.30% in CL modelling), installed capacities were increased to match the renewable generation in LMA24.
Note 2: Results are based on a weighting average of three climate years (40% 2009, 37% 2008, 23% 1995).

Overview of baseline scenarios (2/2)

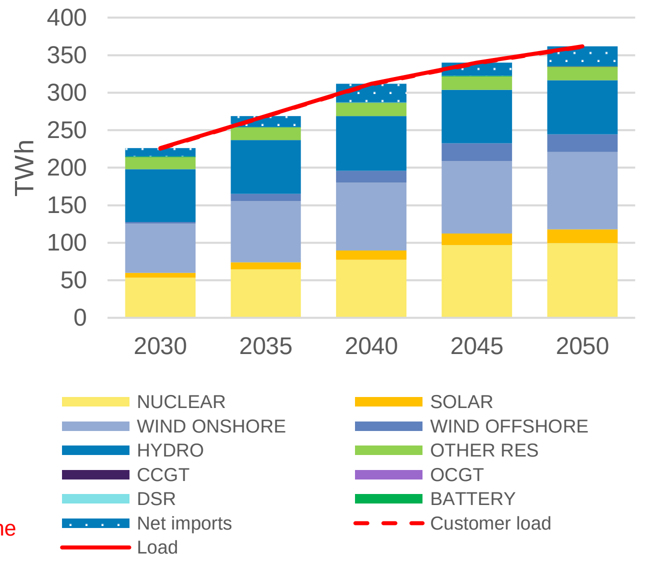
Generation mix evolution

Generation in SE – DE/EF scenario (in TWh)

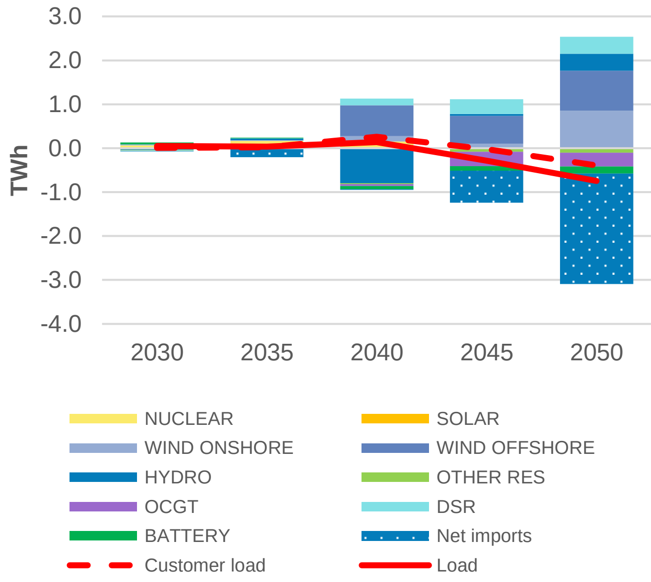


These four technologies will be optimised in the EVA

Generation in SE – GA/EP scenario (in TWh)



Difference in generation between DE/EF Flex and DE/EF scenario in SE (in TWh)



- In the DE/EF scenario, the production of onshore and offshore wind increases throughout the horizon and represents the backbone of the Swedish generation mix, alongside hydro power which remains stable across the years with an annual production of c.70TWh.
- Despite the commissioning of OCGT capacity in 2040 in the DE/EF, generation remains rather low as wind and hydro imports from Finland and Norway respectively are cheaper.
- In the GA/EP scenario, nuclear generation covers between 25% and 30% of the Swedish load all along the horizon.
- Hydro generation remains stable across the years with an annual production of c.70-75TWh in all scenarios.
- In the DE/EF flex scenario, RES generation (wind offshore and onshore) is higher in the DE/EF Flex scenario due to more optimal load patterns of flexible object, leading to less curtailment of RES. DSR is also more activated in the DE/EF Flex, on the contrary to OCGTs.

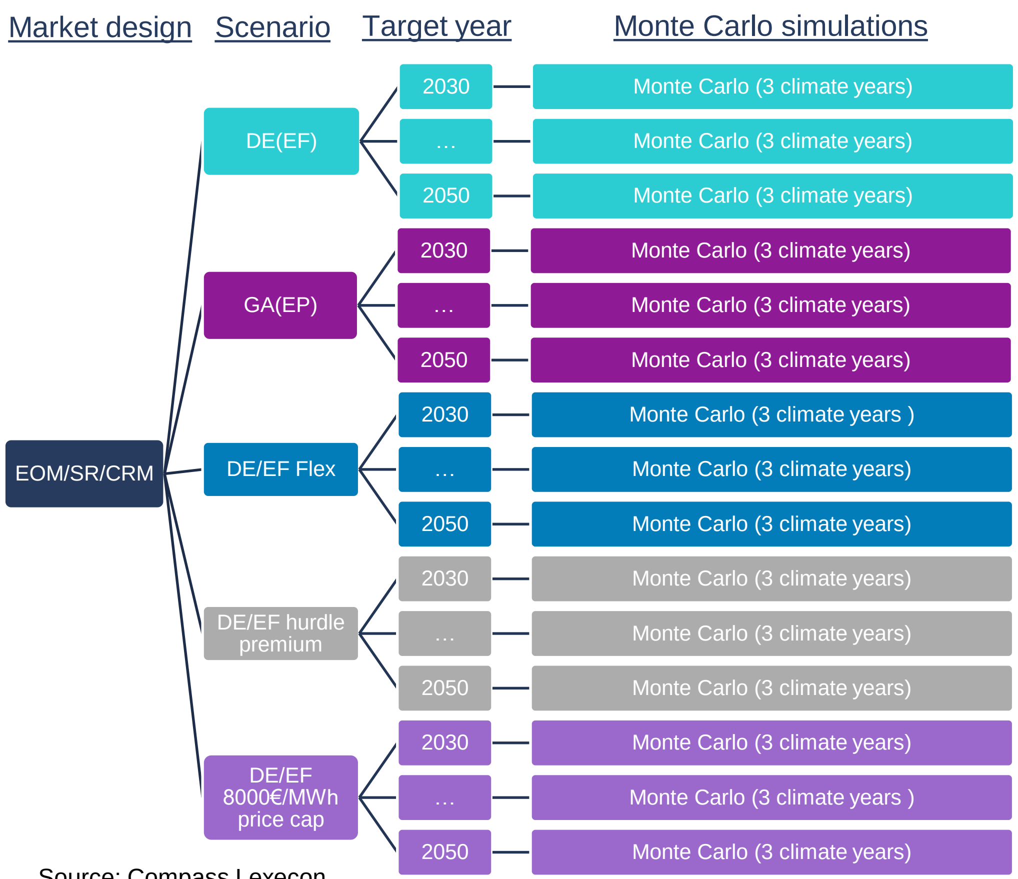
Note 1: Wind and solar capacities in Sweden are based on LMA24 EF scenario. However, considering that CL model and LMA24 EF scenario used different capacity factors for wind and solar (e.g. c.40% for onshore wind in LMA24, c.30% in CL modelling), installed capacities were increased to match the renewable generation in LMA24.
Note 2: Results are based on a weighting average of three climate years (40% 2009, 37% 2008, 23% 1995).

Overview of our modelling runs: Scenario tree

Our methodology combines 3 market design options, 3 scenarios, and 3 climate years

- 3 market design options (EOM, SR, CRM)
- 3 forward scenarios (DE/EF, GA/EP, and DE/EF Flex)
- Target years: 2030/35/40/45/50
- Use 3 climate years (1995, 2008, 2009) with 1-3 random outage scenarios based on computation time
- Geographical scope: : EU + NO + GB
- **Total of 225 runs** (5 target years x 5 forward scenarios x 3 market designs * 3 climate years)

Scenario tree



Source: Compass Lexecon

Three market design options are considered

- Based on Svk's past market design study[1], 3 market designs were selected for this impact assessment study:

Energy-only market (EOM)

Energy-only market (EOM) is a market design where electricity providers primarily earn revenue from energy sales, supplemented by payments for balancing and ancillary services.

Key Principles:

- Price Signals: Market prices, including scarcity pricing, drive investment and operational decisions.
- Supplementary Revenues: Additional income can be earned through balancing and ancillary service markets.
- Limited Capacity Payments: Payments for capacity are allowed under certain conditions but are not central to the design.
- Demand Response: Promotes consumer flexibility and active participation in the market.
- Market-Driven Reliability: Relies on competitive dynamics and price incentives to ensure system adequacy.

Strategic reserve (SR)

Strategic reserve is a targeted capacity mechanism where limited capacity providers are contracted and remunerated for availability, dispatched only in cases of extreme system imbalance.

Key principles:

- Activated only when balancing resources are near exhaustion.
- Imbalances during activation settled at least at the value of lost load or higher than intraday price limits.
- Output attributed to balancing responsible parties via imbalance settlement, not wholesale markets.
- Resources are excluded from wholesale and balancing markets during the contract period.
- Designed to minimize market distortions while ensuring system reliability.

Market-wide capacity remuneration mechanism (CRM)

A market-wide CRM is designed to ensure long-term system adequacy by involving all eligible capacity providers across the market.

Key principles:

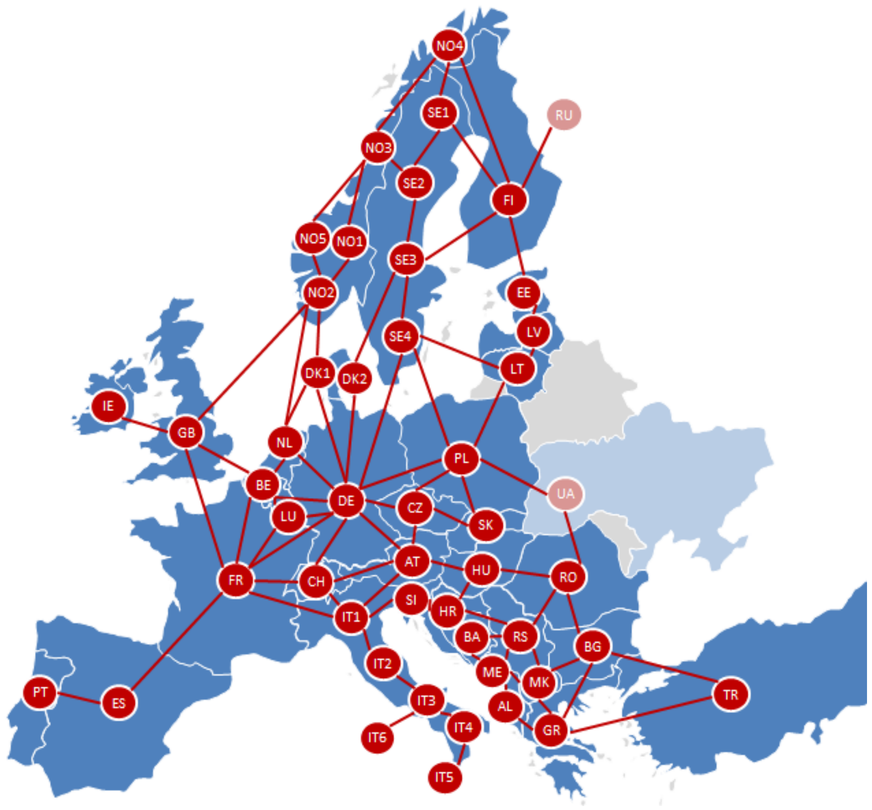
- Inclusive Participation: Open to a wide range of capacity providers, ensuring comprehensive system coverage.
- Market Integration: Operates within the wholesale market framework, allowing providers to earn both market revenues and capacity payments.
- Central Coordination: Typically managed by a central authority to balance supply and demand effectively.
- Adaptability: Design varies by country, tailored to national energy policies and system requirements.
- Cost Recovery: Funded through charges to consumers or market participants, aligning incentives for reliability and affordability.

Source: Svk, 2023.

Our European power market model

CL European power market model covers the power markets of EU27+ including the four Swedish bidding zones, with fine granularity

Geographic scope of the model



Source: Compass Lexecon

- **CL's power market model covers the EU-28 countries as well as the UK, Switzerland, Norway, the Balkans and Turkey.**
  - Countries beyond this geographic scope are modelled at an aggregate level.
  - The model is run on a commercial modelling platform Plexos® using data and assumptions constructed by FTI-CL Energy for demand, supply, commodity price and interconnection.
- **CL's power market model constructs supply in each price zone based on individual plants and simulates the market with hourly resolution**
  - European power plants database containing technical parameters of all thermal European plants.
  - Zonal prices are found as the marginal value of energy accounting for generators' bidding strategies.
  - Model takes into account cross-border transmission and interconnectors and unit-commitment plant constraints.
- **CL's power market model uses ENTSOE Pan-European Climate Database (PECD)** for hourly time series for wind and solar production, hydro inflows and demand pattern.

Economic Viability Assessment (EVA)

Capacity mix optimisation

Overall approach for all market designs

To determine the capacity mix in the EOM, SR, and CRM designs, we perform iterations to converge toward a situation in which generators, batteries, and DSR operators have **positive net present value (NPV)**, based on their avoidable costs and market revenues, but where no additional investment would have a positive NPV.

The capacity mix is determined so that:

- **No existing plant** has a negative NPV when considering its fixed operation and maintenance (FOM) costs;
- **No new build plant** has a negative NPV when also considering investment costs; and
- If **additional capacity** was built or not retired, its **NPV would be negative.**

For all CRM and EOM market designs, **the installed capacity of CCGT, OCGT, DSR and large-scale 4h batteries are optimised.** Both OCGT and CCGT are running renewable fuel, namely biomethane or green hydrogen. For SR market design, DSR and batteries are considered on top of the economically viable mix achieved in EOM.

The other technologies, such as nuclear, RES, hydro, CHP biomass and Behind the Meter (BTM) batteries **are not optimised in the analysis and their capacity correspond to LMA24 or TYNDP22** (for BTM batteries) assumptions.

Technologies optimised in the EVA

OCGT	CCGT
DSR	Large-scale batteries (4h)

Market design eligibility

Capacity Remuneration Mechanism

Energy-Only Market

Strategic Reserve (for DSR and batteries only)

Impact assessment: Key performance indicators (KPIs)

- The following KPIs are assessed for each scenario:

	Key output from analysis	Approach options
3.1	**Available capacity** and impact on investments in Sweden.	Evaluate the impacts of market design options on available capacity by studying investment, retirement and mothball decisions in Sweden based on market revenues and avoidable costs (NPV)
3.2	**Security of supply** in Sweden	Impacts of market design options on security of supply, LOLE
3.3	**Costs of capacity mechanism**: the procured volume and capacity price (per bidding zone)	The procurement costs of a capacity mechanism will depend on the specific parameters of the design elements and 1) capacity price, and 2) volume of contracted capacity which secure the Swedish reliability standard. This would have to potentially account for long-term contracts.
3.4	Impact on **energy prices** per bidding zone in Sweden and all neighbouring countries	Hourly prices are simulated for each bidding zone and used in quantifying social welfare
3.5	Impact on **trade flows** within Sweden as well as cross-border to all neighbouring countries, including impact of cross-border participation	Impact on trade flows and cross-border participation are studied
3.6	**Generation mix** and **environmental impact**	Estimates of CO_2 emissions from electricity generation and the underlying capacity/generation mix
3.7	**Economic welfare** impact in Sweden	The economic welfare analysis quantifies total economic welfare and identifies potential distributional impacts: **Consumer welfare** (incl. energy price, capacity price, and the value of the Energy Not Served), **producer welfare** (profits from energy and capacity markets), and **congestion rent**

3.

Modelling assumptions

Assumptions on demand flexibility : DE/EF and GA/EP scenarios are based on LMA flexibility, whilst DE/EF flex scenario has higher flexibility

CL baseline assumptions in scenarios DE/EF and GA/EP

Demand category	Flexibility	Description
EV	**25%** of the fleet until 2050	Within each day, 25% of the EV fleet charges at the hours with lowest power prices. Only intraday flexibility is assumed.
HP	**25%** of the fleet until 2050	Within each day, 25% of the HP fleet consumes at the hours with lowest power prices. Only intraday flexibility is assumed.
Electrolysers		All electrolysers have a monthly load factor of 56.8% (assumption deduced from LMA consumption and capacity) and a weekly load factor not less than c. 30%. Under these constraints, electrolysers optimise their consumption when the hourly prices are the lowest.
Demand Side Response (DSR)		Load factor limit (43h/year) and activation price 395€/MWh
Data centres	**0%**	No flexibility

CL assumptions in DE/EF Flex

Demand category	Flexibility	Description
EV	**25%** of the fleet in 2030; **70%** in 2050	Within each day, 25% of the EV fleet charges at the hours with lowest power prices in 2030 (70% in 2050). Only intraday flexibility is assumed.
HP	**25%** of the fleet in 2030; **50%** in 2050	Within each day, 25% of the HP fleet consumes at the hours with lowest power prices in 2030 (50% in 2050). Only intraday flexibility is assumed.
Electrolysers	**20%**	20% of electrolysers are free to optimise their consumption of electricity annually considering an annual load factor of 56.8%. 80% remaining are modelled the same ways as baseline with monthly and weekly storage constraints.
Demand Side Response (DSR)		Higher load factor (200h/year) and same activation price
Data centres	**0%** in 2030 to **10%** in 2050	Starting without any flexibility and moving towards 10% flexible load in 2050.

Assumptions on costs and potential of Demand Side Response (DSR) are based on external reference studies

DSR potential

- The overall DSR potential in Sweden is based on Ei[1] and is **5540MW**
- The DSR potential is distributed by SE zones based on proportions of DSR defined in TYNDP22*, namely SE1: 12%, SE2: 19%, SE3: 54%, and SE4: 15%.
- DSR potential capacity is kept constant between 2030 and 2050 and is identical in both DE/EF and GA/EP scenarios.

DSR fixed costs

- DSR fixed costs assumptions originate from ERAA23[3], which uses average value from several European CONE & VOLL studies.
- The **CAPEX is 20€/kW** and FOM is **13/kW/year**

DSR activation price

- The activation price of 3000 SEK/MWh (**363 real 2023 €/MWh)** is calculated as a weighted average of DSR considered in the Ei and DNV 2021 studies.

DSR activation cost (€/MWh) and potential in Sweden for 2030-2050 (MW)[1,2]

DSR activation costs	€/MWh (2023)	Potential, MW
Domestic heating	279	3800
Ventilation in buildings	557	65
Electricity-intensive industries	363[2]	1375
Other	1982	300
Total capacity, MW		**5540**
Weighted average DSR activation cost, €/MWh	**395**	

DSR fixed cost (€ 2023/kW) and economic life (years) assumptions

Technology	CAPEX (in € 2023/kW)			FOM (in € 2023/kW)			Economic life
	2030	2040	2050	2030	2040	2050	
DSR	20			13			15

Source: Compass Lexecon analysis based on data from 1 Ei 2021 and 2 DNV 2021; ERAA23 Annex 2, p45,
Notes: * The potential of incentive-based DSR in the TYNDP22 is much lower than in our study based on the Ei study, e.g. in the DE/EF scenario TYNDP22 assumes below 2GW in contrast to our 5.5 GW).

Technology cost assumptions and economic life are based on reference studies

Technology cost assumptions (in € 2023/kW) and economic life of flexible technologies

Technology	CAPEX (in € 2023/kW)			FOM (in € 2023/kW)			Economic life
	2030	2040	2050	2030	2040	2050	
CCGT	913	897	880	31	30	29	20
OCGT	484	468	451	8.5	8.3	8.1	20
CHP biomass	2284	2157	2157	51	50	49	20
DSR	20	20	20	13	13	13	15
Large-scale batteries (4h)	719	630	539	18	16	13	15

- CHP biomass technology cost assumptions come from the 2040 Impact Assessment of the EU
- Large-scale batteries (4h), OCGT and CCGT costs assumptions come from TYNDP24.
  - CCGT CAPEX and FOM refer to H2-ready CCGT.
  - To obtain H2-ready OCGT CAPEX and FOM, standard OCGT cost assumptions are inflated by a similar percentage than CCGTs between H2-ready and standard CCGTs.
- DSR costs assumptions come from ERAA23.

Source: ERAA23 Annex 2, p45, TYNDP24, EU 2040 Climate target

4.

Results – Impact assessment

Overview of the impact assessment

The labels in the top right corner indicate which scenario is being presented.

This section presents the key impact assessment results for the three scenarios (DE/EF, GA/EP, and DE/EF Flex). The results are grouped into the following sections presented by scenario:

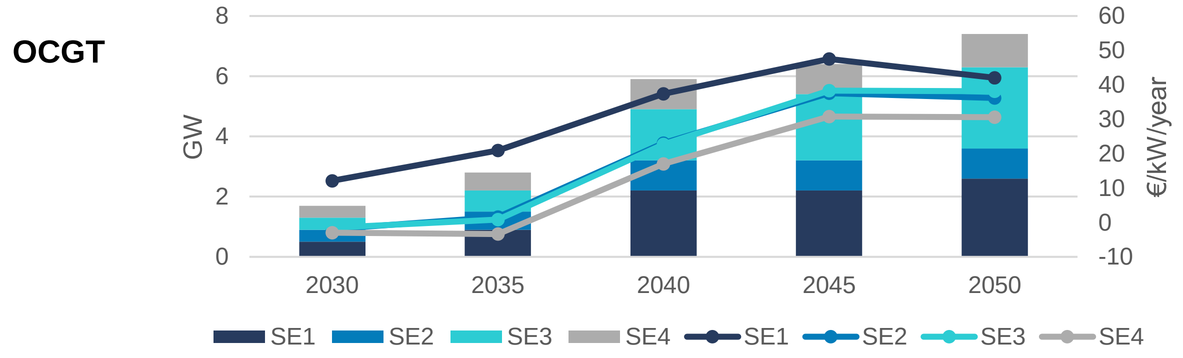
- Investment decisions in Sweden (results of the economic viability assessment EVA)
- Security of supply in Sweden (results of the loss of load expectations LOLE and energy not served EENS)
- Impact on energy prices in Sweden (results of electricity price impacts in energy-only market EOM (identical in strategic reserve SR) and market-wide capacity remuneration mechanism CRM)
- Sensitivity analysis of results (sensitivity of the results to changes in investors' risk aversion and day-ahead price cap in the DE/EF scenario)
- Welfare effects (economic costs and benefits of strategic reserve SR and market-wide capacity remuneration mechanism CRM)
- Sensitivity analysis of results to changes in value of lost load VOLL

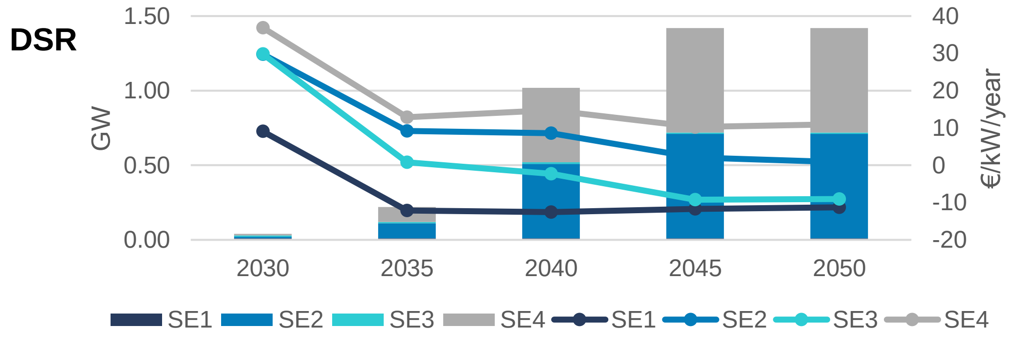
Investment decisions in Sweden: EOM

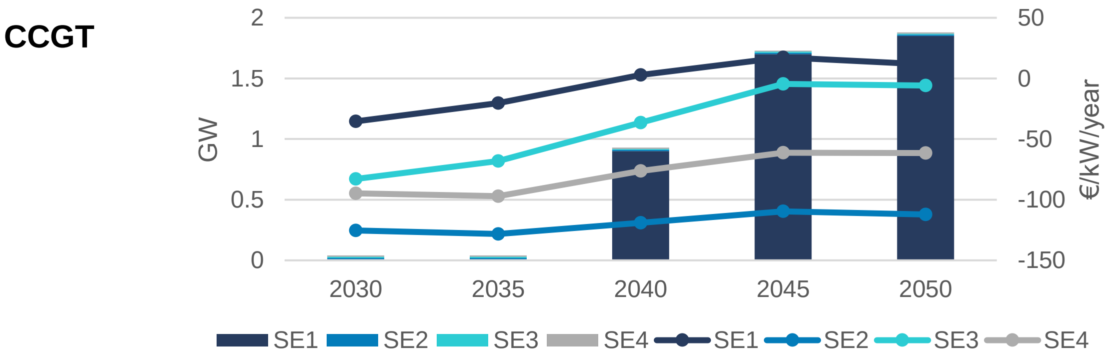
OCGTs across all Swedish bidding zones and CCGTs are profitably built, including some DSR

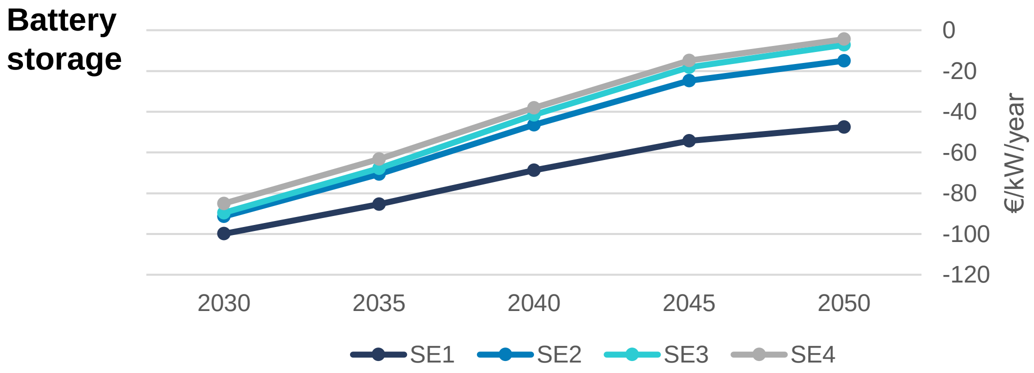
- The iterations on the investment model result in the entry of mainly thermal units (OCGTs and CCGTs). The new OCGT capacity is used almost exclusively during periods of system tension with 1%-5% capacity factors. New CCGT capacity has a capacity factor of 15%-17%, which is higher compared to OCGT due to greater efficiency.
- Battery storage is not profitable due to smaller daily spreads compared to countries with more solar capacities, leading to less utilisation during the year and thus lower profitability.
- DSR capacity is left in SE2 and SE4 while it is removed from SE1 and SE3.

EOM: New installed capacity (GW) and its economic viability (€/kW/year) in Sweden, DE/EF scenario







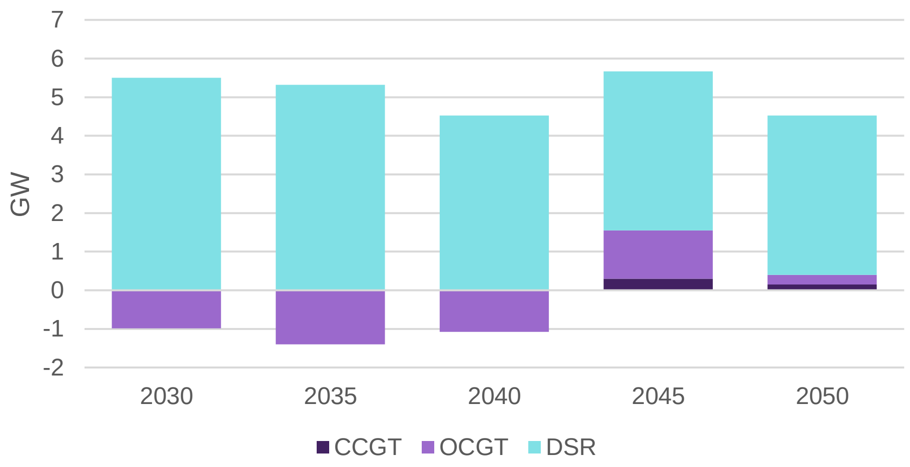


DE/EF scenario results: CRM and SR design options induce more peaking capacity (DSR, OCGT & battery storage) to meet the Reliability Standard

CRM market design option

- Compared to EOM, CRM induces a higher capacity of peaking technologies, mainly DSR.
- After assumed nuclear decommissioning in 2045, CRM also induces additional OCGT and CCGT capacity.
- In years 2030-2040, the CRM seem to make some OCGT capacity less profitable than in EOM due to the reduction of the energy price peaks and a relatively low CRM price.
- In the EOM analysis, as reaching 0-1 LOLE is not an objective, **the system does not need as much peaking technologies and finds it more profitable to reduce the amount of DSR across the horizon.**
- Furthermore, while the EOM scenario finds it profitable to deploy more OCGT capacity before 2040 than in the CRM, **the pace of deployment slows in 2045 and 2050, as achieving security of supply in 2045 is not a core objective.**

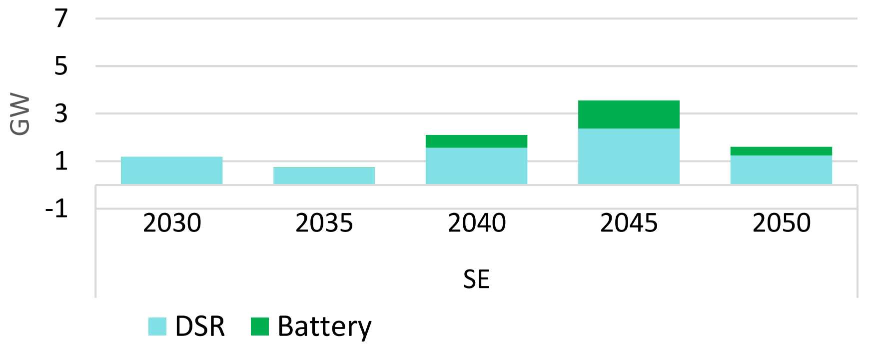
CRM-EOM difference: Installed capacity (GW) in SE



SR market design option

- Compared to the EOM, SR requires additional DSR and storage capacity to reach the Reliability Standard
- The zonal nature of SR allows to address the locational adequacy issues in specific zones.
- The short-term nature of SR contracts (**1-3 years) means that the total volume of SR procured fluctuates** over the years according to the adequacy need.
- The **plants under the SR framework are assumed to stay out of the EOM** entirely.
- DSR could possibly require higher compensation for being in SR (compared to EOM) due to the lost opportunity cost from energy markets. When being out-of-market in SR, DSR's missing presence from EOM could also distort electricity prices in EOM.
- **Caveat**: Once the capacity procured in previous years is not needed in the future years, we assume that the previously procured capacity under SR is not returning to EOM (current simplification)

SR-EOM difference: Installed capacity (GW) in SE



Security of supply in Sweden: EOM

The Swedish reliability standard is not met in the EOM of DE/EF scenario

- As in EOM, only the profitability of technologies drive the decision to invest in additional flexible capacity (OCGT/CCGT/DSR/large-scale batteries), it is not surprising to observe LOLE and EENS.
- **Between 5 and 14h of LOLE are observed at the national level in Sweden between 2030 and 2050**, while the **yearly EENS in Sweden is comprised between 3.2GWh and 13.8GWh** on the entire horizon.
- Solving LOLE and EENS would require extra-capacity which would drive down the profitability of the already existing plants
- The resulting cost of EENS lies between **26 and 110 € M per year**, which shall be compared to the cost of any new mechanism answering this additional need of energy.

CL: Security of Supply metrics, DE/EF scenario in EOM

LOLE (in hours)	2030	2035	2040	2045	2050
SE1	8	3	4	4	6
SE2	0	1	2	2	2
SE3	3	0	2	6	2
SE4	0	0	2	2	2
SE (individual BZs)	12	5	10	14	12
SE (national)*	11	3	7	10	11

EENS	2030	2035	2040	2045	2050
EENS, GWh	7.5	3.2	8.8	13.8	5.4
Cost of EENS, €M	60.17	25.61	70.43	110.16	43.02

Source: Compass Lexecon analysis
Note: *Overlap of LOLE events across BZs; Cost of unserved energy **in € M** is measured as EENS*VOLL, where VOLL is equal to 8000 €/MWh in Sweden.

Security of supply in Sweden: CRM

DSR left at full potential in CRM contributes to bringing down LOLE below the 1h threshold in all years, all bidding zones

- In CRM, **the extra-DSR capacity in all four Swedish bidding zones, coupled to the extra OCGT and CCGT capacity from 2045 helps the system to be more resilient in periods of tension.**
- As a result, LOLE is brought down to 0 in all years but 2045, where 1h of LOLE is visible in SE1, SE2 and SE4, with a total EENS of 2.7GWh.
- Peaking technologies help to reduce the EENS compared to EOM, which is mostly due to two factors, being
  - the **intermittence of renewables** during peak demand periods (e.g. lack of wind),
  - the **load curtailment sharing mechanism**, which may lead to some load curtailment in Sweden in times of system stress in Finland.
- The cost of EENS is thus null in all years except in 2045 when it amounts to 21.2 € M.

CL: Security of Supply metrics, DE/EF scenario in CRM

LOLE (in hours)	2030	2035	2040	2045	2050
SE1	0	0	0	1	0
SE2	0	0	0	1	0
SE3	0	0	0	0	0
SE4	0	0	0	1	0
SE (individual BZs)	0	0	0	4	0
SE (national)*	0	0	0	2	0

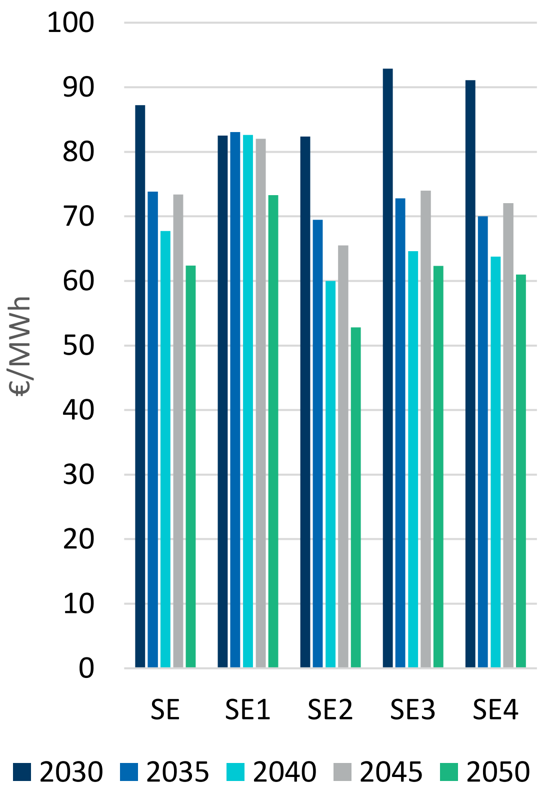
EENS	2030	2035	2040	2045	2050
EENS, GWh	0.0	0.0	0.0	2.7	0.0
Cost of EENS, €M	-	-	-	21.2	-

Source: Compass Lexecon analysis
Note: *Overlap of LOLE events across BZs; Cost of unserved energy is measured as EENS*VOLL, where VOLL is equal to 8000 €/MWh in Sweden.

Impact on energy prices

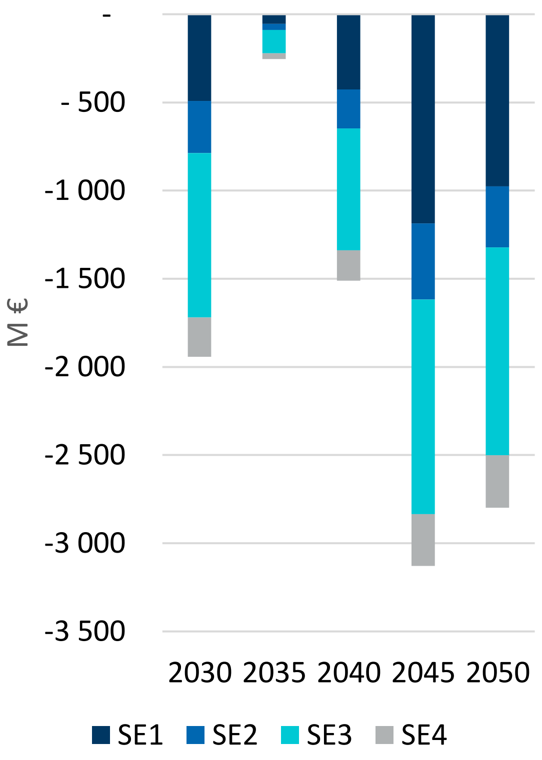
Impact on energy prices per bidding zone in Sweden

EOM: Baseload electricity prices [€/MWh]



CRM-EOM: Baseload electricity prices [€/MWh]

CRM-EOM: Customer's energy cost [M €]



- EOM and SR scenarios feature identical price patterns since the capacity under SR is kept outside of the market and cannot impact the market price
- The capacity mix induced in the CRM scenario results in the energy price consistently lower than in the EOM scenario
- The price difference is on average 4,8 €/MWh ranging from 8.9 €/MWh in 2030 to 7.7 €/MWh in 2050 considering the time-weighted average zonal price over all Swedish bidding zones
- The CRM impact on the price is the highest in SE1 bidding zone and the lowest in the SE4 bidding zone.
- The energy price difference multiplied by the Swedish yearly demand provides the estimation of the impact of the CRM on the customers' energy cost, representing aggregated 1,93 €bn per year on average, ranging from 0,25 €bn/y to 3,1 €bn/y.

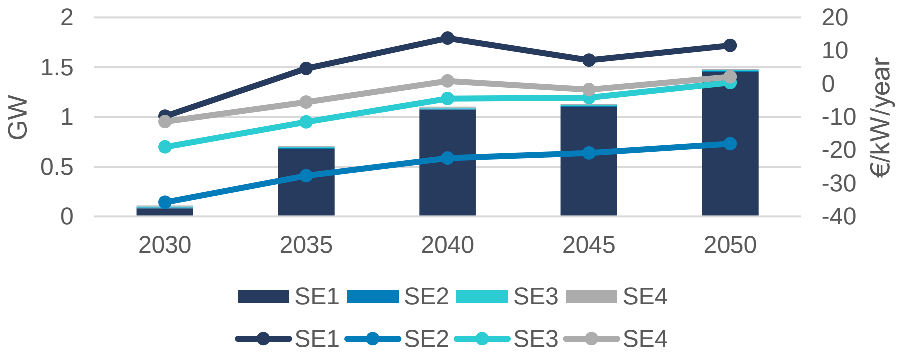
Investment decisions in Sweden: EOM

SE1 attracts new OCGTs while DSR gets built in SE2 and SE4

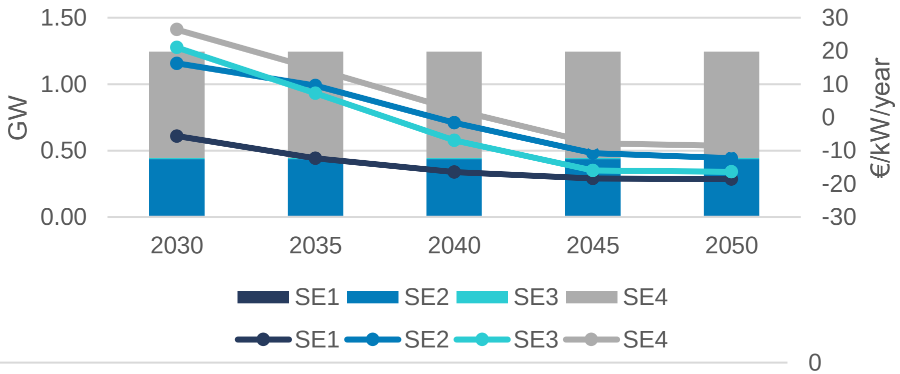
- The iterations on the investment model result in the entry of both OCGTs and DSR, reaching 1.5GW and 1.2GW respectively by 2050.
- Battery storage and CCGTs are not profitable, and thus not competitive with OCGTs and DSR, which explains their absence in the energy mix.

EOM: New installed capacity (GW) and its economic viability (€/kW/year) in Sweden, GA/EP scenario

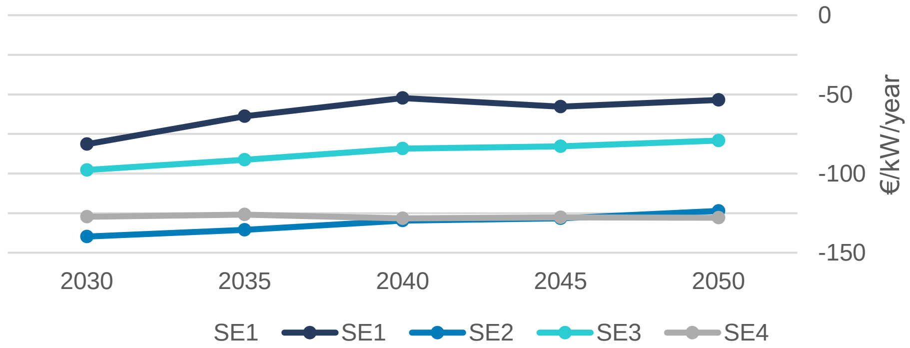
OCGT



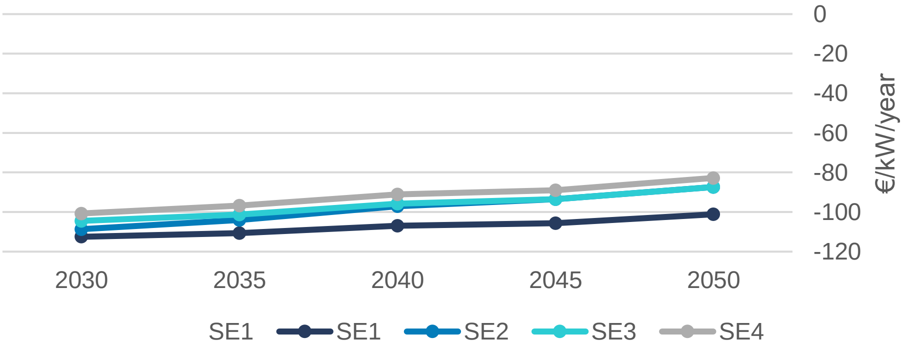
DSR



CCGT



Battery storage

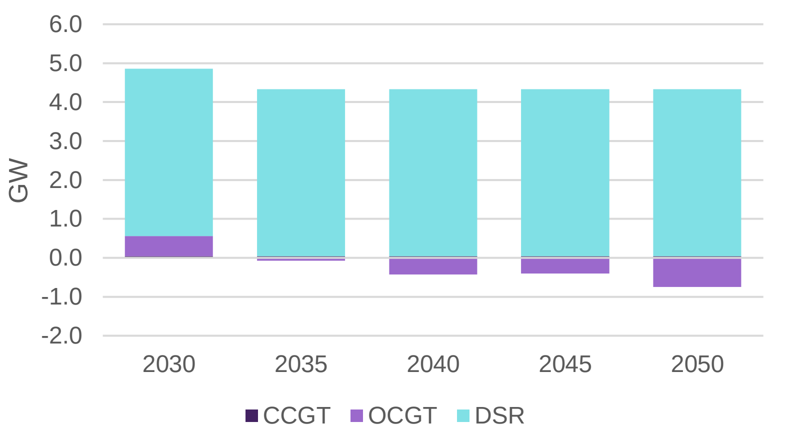


GA/EP scenario results: CRM and SR design options induce more peaking capacity (DSR, OCGT & battery storage) to meet the Reliability Standard

CRM market design option

- Compared to EOM, CRM induces additional capacity of **peaking technologies**: OCGT and DSR in 2030, **while lower installed DSR capacity in EOM** allows it to have **more profitable OCGTs** from **2030 to 2050.**
- As **most of the flexibility** is already **provided by hydro, net imports and behind-the-meter storage**, peaking technologies such as **DSR or OCGT are needed in CRM** to reduce LOLE to 0-1 h in times of system stress.
- From 2035 onwards, the reduction of the price peaks in the CRM reduces the profitability of OCGTs that is not fully compensated by the CRM revenues, causing a somewhat smaller OCGT capacity.
- In the **EOM analysis**, since achieving **0-1 LOLE** is not an objective, the system **does not need** as much **peaking technology** and finds it more profitable to **reduce the amount of DSR** across the horizon.

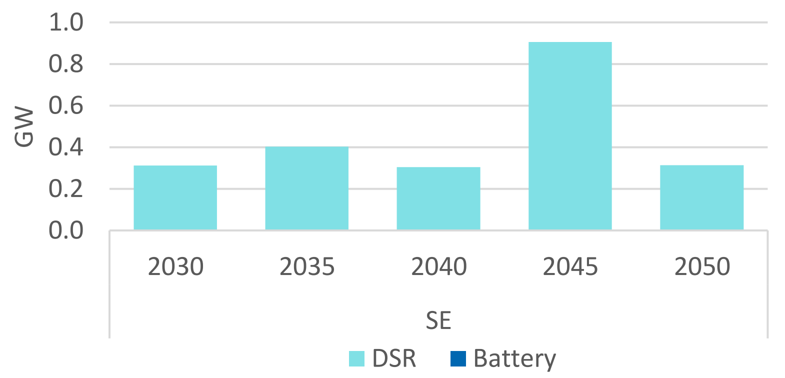
CRM-EOM difference: Installed capacity (GW) in SE



SR market design option

- As compared to the EOM, SR requires additional DSR and storage capacity to reach the Reliability Standard
- The zonal nature of SR allows to address the locational adequacy issues in specific zones. **SE4** has approximately the **same installed DSR capacity** in both **EOM and CRM**, which allows it to guarantee adequacy and maintain profitability. Therefore, it does **not require SR**.
- The short-term duration of the SR contracts (**1-3 years) results in the** total **SR procured volume therefore fluctuating** across years following the adequacy need
- The **plants under the SR framework are assumed to stay out of the EOM** entirely.
- **Caveat**: Once the capacity procured in previous years is not needed in the future years, we assume that the previously procured capacity under SR is not returning to EOM (current simplification)

SR-EOM difference: Installed capacity (GW) in SE



Security of supply in Sweden: EOM

The Swedish system is slightly inadequate in the EOM of GA/EP scenario

- In the **GA/EP scenario**, security of supply is **improved** compared to the **DE/EF scenario** due to **increased nuclear base load and RES** capacity until **2050**.
- Achieving the **1 LOLE** target requires **significant flexibility**, as unmet demand **reached 1 GW multiple times in 2030**.
- This scenario aims to preserve the profitability of our installations, yet a **capacity shortfall** remains from **2030 to 2050**.

CL: Security of Supply metrics, GA/EP scenario in EOM

LOLE (in hours)	2030	2035	2040	2045	2050
SE1	2.4	0.8	2.4	1.6	0.0
SE2	0.5	0.0	0.2	0.7	1.2
SE3	1.9	0.6	0.7	0.5	0.5
SE4	0.2	0.0	0.4	0.2	0.0
SE (individual BZs)	5	1	4	3	2
SE (national)*	4	1	4	3	2

EENS	2030	2035	2040	2045	2050
EENS, GWh	3.1	0.7	1.9	1.0	0.4
Cost of EENS, €M	24.44	5.97	15.28	7.64	3.42

Source: Compass Lexecon analysis
Note: *Overlap of LOLE events across BZs; Cost of unserved energy **in € M** is measured as EENS*VOLL, where VOLL is equal to 8000 €/MWh in Sweden.

Security of supply in Sweden: CRM

With more DSR and slightly different investment dynamics of OCGTs, the system becomes adequate

- In the **GA/EP scenario**, security of supply is **improved** compared to the **DE/EF scenario** due to **increased nuclear base load and RES** capacity until **2050**.
- In the **CRM model** there is **no major evolution of the total installed capacity.**
  - **DSR remains at baseline** capacity for the 5 target years.
  - **OCGTs** increase in **SE1 from 600MW to 700MW**
- The presence of **LOLE hours in 2030 and 2045** indicates that there is **no overcapacity to reach the 0-1 LOLE target**, keeping **thermal capacity and non-cost-effective** technologies **as low as possible**.

CL: Security of Supply metrics, GA/EP scenario in CRM

LOLE (in hours)	2030	2035	2040	2045	2050
SE1	0	0	0	0	0
SE2	0	0	0	1	0
SE3	1	0	0	0	0
SE4	0	0	0	0	0
SE (individual BZs)	1	0	0	1	0
SE (national)*	1	0	0	1	0

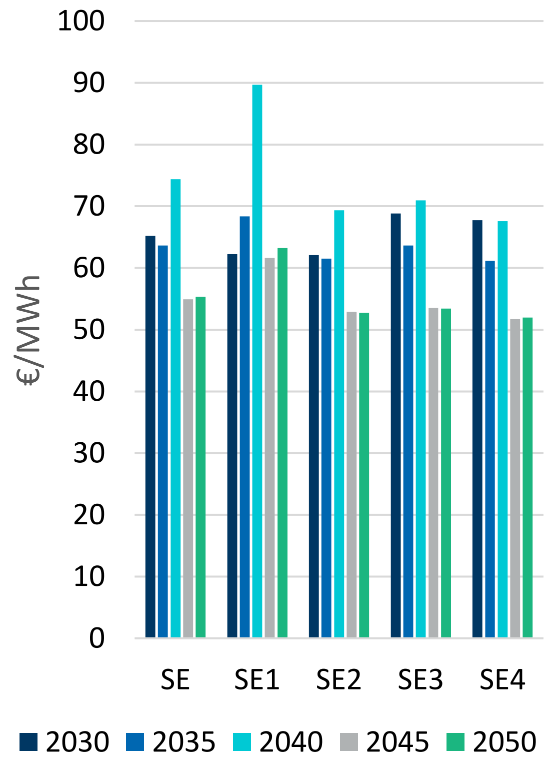
EENS	2030	2035	2040	2045	2050
EENS, GWh	0.1	0.0	0.0	0.4	0.2
Cost of EENS, €M	0.8	0.0	0.0	2.9	1.7

Source: Compass Lexecon analysis
Note: *Overlap of LOLE events across BZs; Cost of unserved energy is measured as EENS*VOLL, where VOLL is equal to 8000 €/MWh in Sweden.

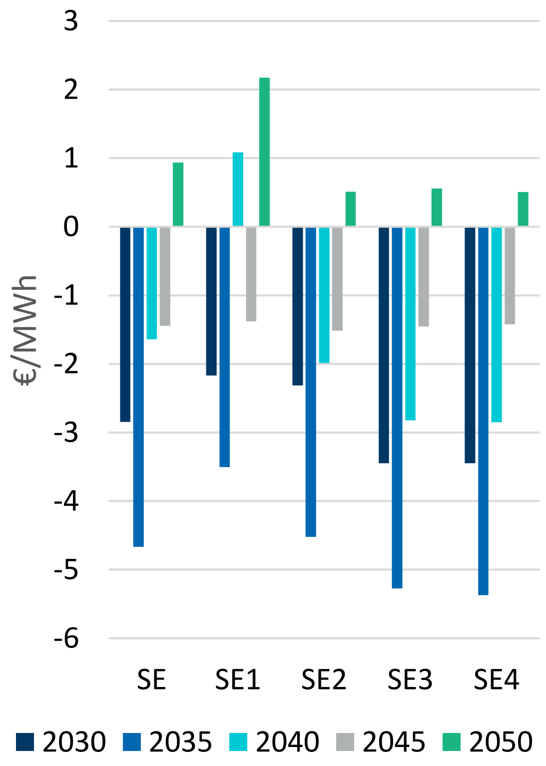
Impact on energy prices

Impact on energy prices per bidding zone in Sweden

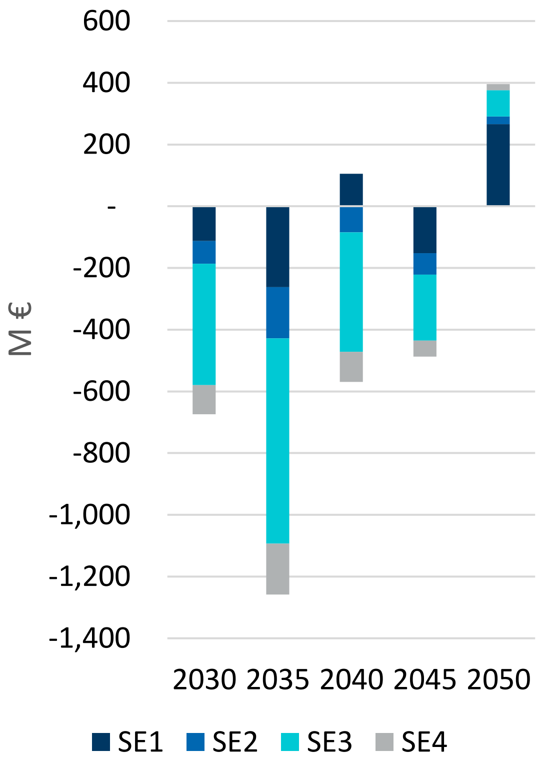
EOM: Baseload electricity prices [€/MWh]



CRM-EOM: Baseload electricity prices [€/MWh]



CRM-EOM: Customer's energy cost [M €]



- The capacity mix induced in the **CRM scenario** results in the energy price **consistently lower than in the EOM** scenario except for **2050 due to the DSR losses.**
- **The lower price of CRM in 2050 can be explained by**
  - The **high level of OCGTs** in the EOM due to **their profitability.**
  - **While this amount** of capacity was **not needed due to the installed DSR** required for the first target years.
- The price difference is on average **1.9 €/MWh ranging from -0.9 €/MWh in 2030 to 4.7 €/MWh in 2035** considering the load-weighted average zonal price over all Swedish bidding zones
- The energy **price difference multiplied by the Swedish yearly demand** provides the estimation of the **impact of the CRM on the customers' energy cost**, representing aggregated **511 €M per year on average, ranging from -0;34 €bn/y to 1.25 €bn/y**.

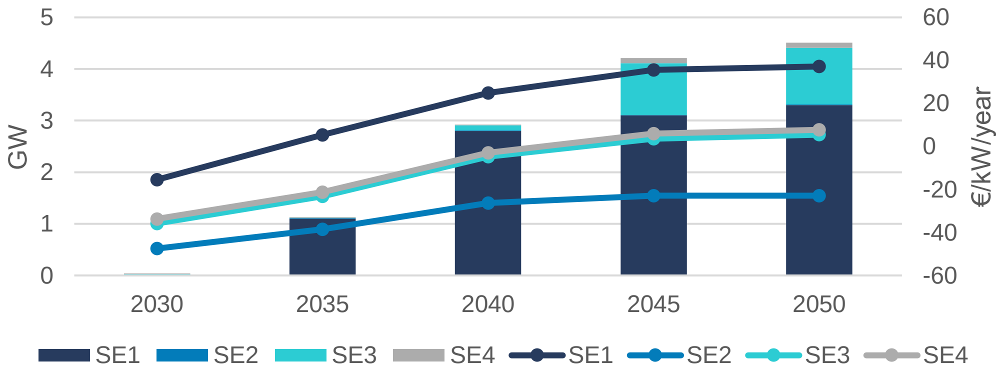
Investment decisions in Sweden: EOM

DE/EF Flex scenario attracts large capacities of DSR and new OCGTs in SE1 and SE3

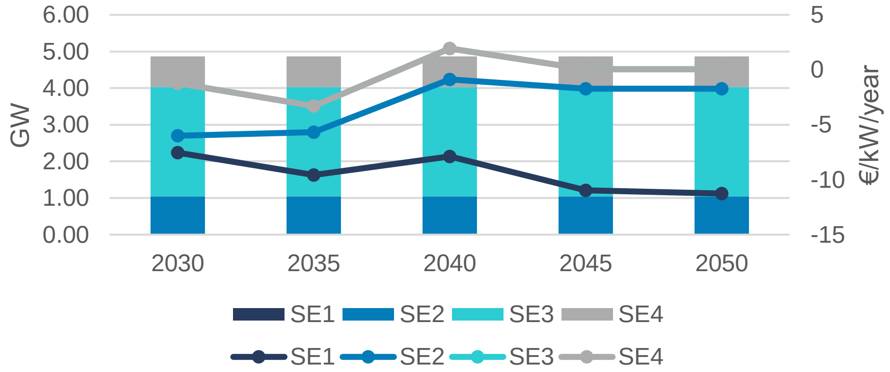
- The iterations on the investment model result in the entry of OCGTs in SE1 and SE3. CCGTs are not profitable and do not enter.
- DSR capacity is invested in into its full potential in SE2, SE3, and SE4. The DSR investments in SE1 remain unprofitable over the horizon.
- Battery storage is not profitable due to smaller daily spreads compared to countries with more solar capacities, leading to less utilisation during the year and thus lower profitability.

EOM: New installed capacity (GW) and its economic viability (€/kW/year) in Sweden, DE/EF Flex scenario

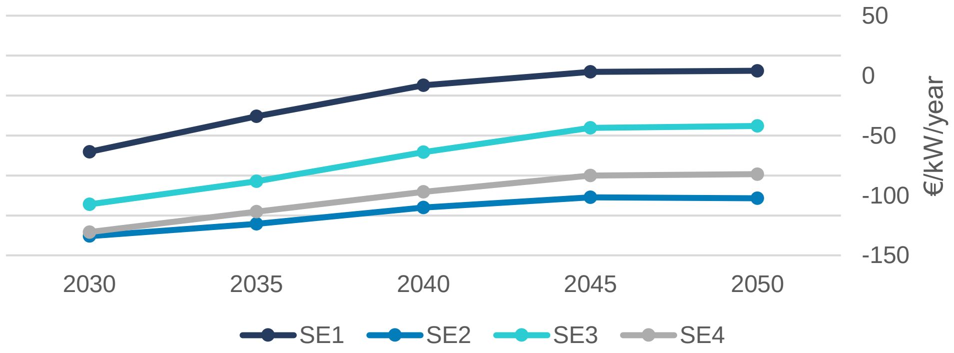
OCGT



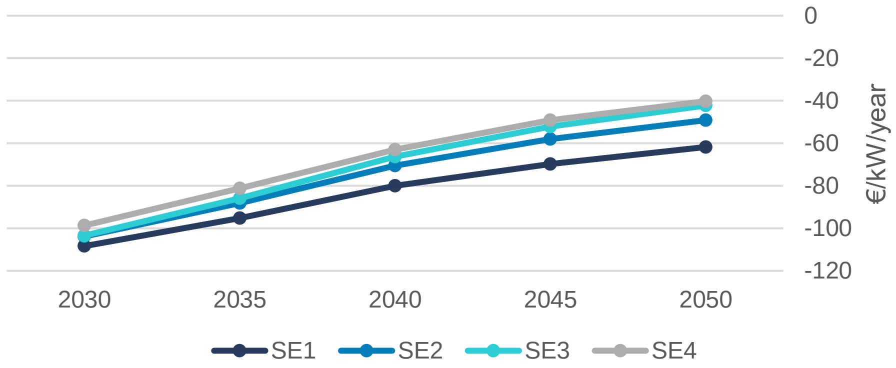
DSR



CCGT



Battery storage



Security of supply in Sweden: EOM

With sufficient flexible capacity the Swedish system is adequate in DE/EF Flex

- **The system is adequate in EOM market design** in the DE/EF Flex scenario and meets the Swedish reliability standard of 1h LOLE
- Because of the weighted average of three climate years, there are **some fractional LOLE hours, but none exceed the 1 hour** rounded to the first unit.
- In the years with some EENS, namely 2030 and 2040, the associated cost is **1.6 and 5.3 € M per year**, respectively.
- However, since the system is within the Swedish reliability standard in the EOM DE/EF Flex scenario, there is **no need for out of market investment mechanism**. This nevertheless rests on the **assumption that this level of flexibility can be achieved without any support mechanism** or with other support schemes not considered in this study.

CL: Security of Supply metrics, DE/EF Flex scenario in EOM

LOLE (in hours)	2030	2035	2040	2045	2050
SE1	0.4	0.0	0.4	0.0	0.0
SE2	0.0	0.0	0.0	0.0	0.0
SE3	0.4	0.0	0.8	0.0	0.0
SE4	0.0	0.0	0.0	0.0	0.0
SE (individual BZs)	0.8	0.0	1.2	0.0	0.0
SE (national)*	0.8	0.0	1.2	0.0	0.0

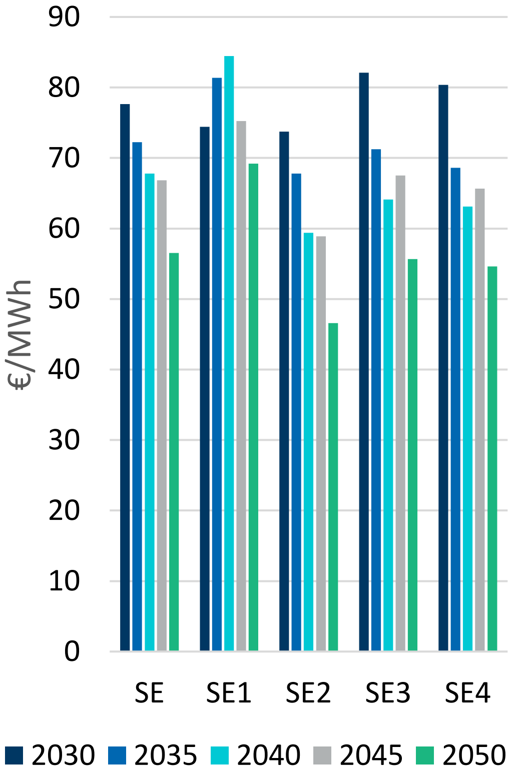
EENS	2030	2035	2040	2045	2050
EENS, GWh	0.2	0.0	0.7	0.0	0.0
Cost of EENS, €M	1.61	0.00	5.27	0.00	0.00

Source: Compass Lexecon analysis
Note: *Overlap of LOLE events across BZs; Cost of unserved energy **in € M** is measured as EENS*VOLL, where VOLL is equal to 8000 €/MWh in Sweden.

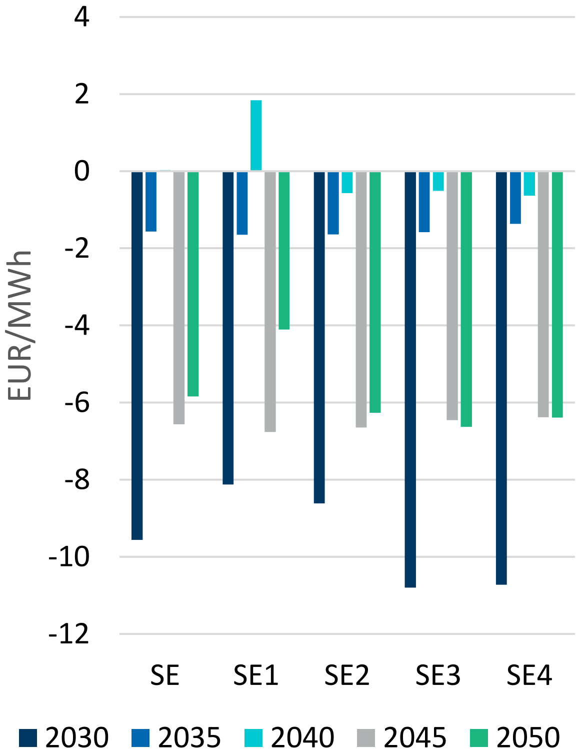
Impact on energy prices

Average prices in Sweden are lower in the DE/EF Flex EOM scenario compared to the DE/EF EOM

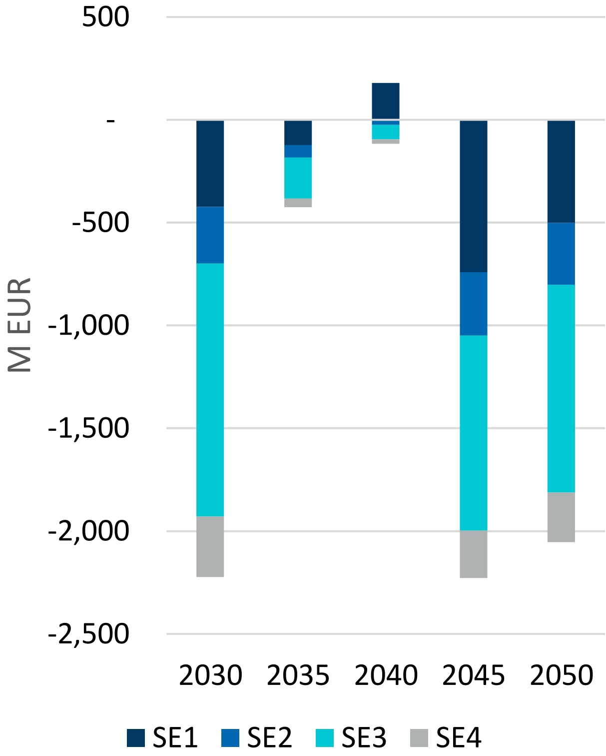
DE/EF Flex EOM: Baseload electricity prices [€/MWh]



DE/EF Flex EOM - DE/EF EOM: Baseload electricity prices [€/MWh]



DE/EF Flex EOM - DE/EF EOM: Customer's energy cost [M €]



- **Average prices in DE/EF Flex EOM** are generally highest in 2030 and then decline towards 2050 as more renewable capacity is being built, depressing the average prices
- **Comparing the DE/EF Flex EOM with DE/EF EOM** shows that DE/EF EOM has up to and over 10€/MWh higher average prices in some years and bidding zones, pointing to the **lack of more affordable flexibility sources**.

Summary: CRM or SR needed to reach Reliability Standard in DE/EF and GA/EP scenarios, while in the DE/EF flex scenario RS is reached in EOM

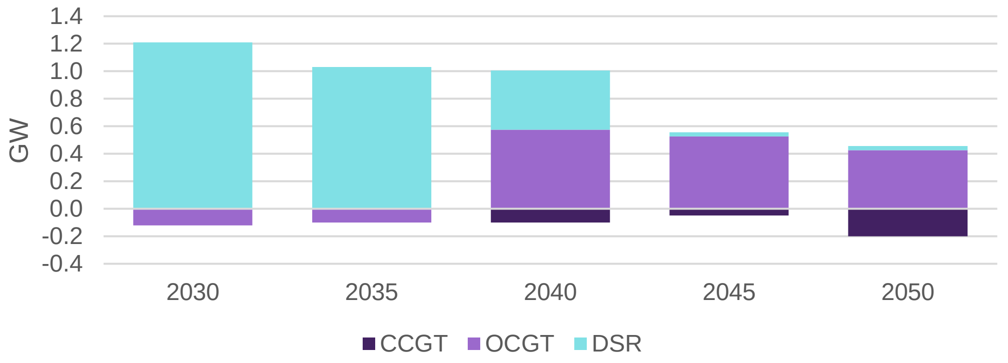
Scenario	EOM LOLE	CRM impact on the mix	SR impact on the mix	CRM price impact	SR welfare effect	CRM welfare effect
DE/EF	5-14	▪ Additional 4.5-5.5GW capacity ▪ Mainly DSR increase ▪ A small reduction of OCGT capacity before 2045 ▪ An increase in OCGT and CCGT after nuclear decommission in 2045	▪ 1-4GW Storage and DSR ▪ Highest in 2045 at the time of nuclear decommissioning	▪ Price reduction between 1-8€/MWh on average	▪ SoS benefits larger than SR costs in 2030 and 2035 but lower from 2040	▪ SoS benefits smaller than CRM costs during the studied period. ▪ Overall welfare loss from CRM
GA/EP	1-4	▪ Additional 3.5-4.5GW capacity ▪ Mainly DSR increase ▪ A small reduction of OCGT capacity after 2035	▪ 0.3-0.9GW Storage and DSR	▪ Price reduction between 1-5€/MWh on average	▪ SoS benefits larger than SR costs in 2030 to 2040 but lower from 2045	▪ SoS benefits lower than CRM costs ▪ Overall welfare loss from CRM
DE/EF Flex	0-1	Alternative market design options not considered since the Reliability Standard is reached in the Energy Only market design				

Results sensitivity: The EOM capacity mix is sensitive to key assumptions, such as the hurdle premium and the market price cap, but LOLE results are robust

Price cap sensitivity (8000€/MWh vs 4000€/MWh)

- An increase of the wholesale market price cap from the baseline assumption of 4 000 €/MWh to 8 000 €/MWh from 2030 to 2050 to align with Swedish VOLL and ERAA2023 assumptions of 7000 €/MWh in 2030 and 8500€/MWh in 2033.

Price cap sensitivity – EOM difference: Installed capacity (GW), DE/EF scenario

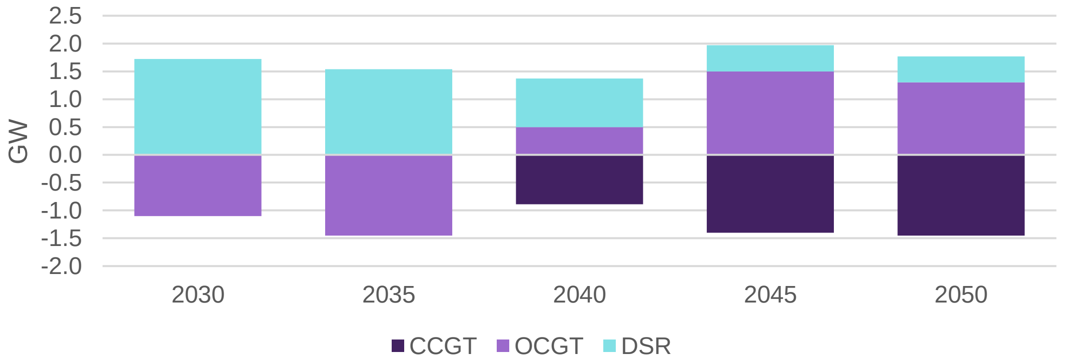


- The **8k** sensitivity **scenario** attracts **more peaking investment: DSR** in **2030, 2035 and 2040** and OCGT in 2040-2050. Increase of the DSR and OCGT leads to small displacement of the **less peaking technologies,** such as **CCGTs**.
- Capacity increase driven by the price cap of 8 000€/MWh reduces the LOLE by 5 hours on average. However, LOLE remains in the range between 1 and 10 hours, in most years exceeding the Reliability Standard

Hurdle rate sensitivity (increased hurdle rate by 2-4%)

- The investor's risk is reflected in the model through the hurdle rate consisting of WACC (6%) and a hurdle premium assumed 2% in CRM and 4% in EOM.
- This sensitivity tests the impact of a higher investor risk presented by hurdle premia of 4% in CRM and 8% in EOM.

Hurdle rate sensitivity – EOM difference: Installed capacity (GW), DE/EF scenario

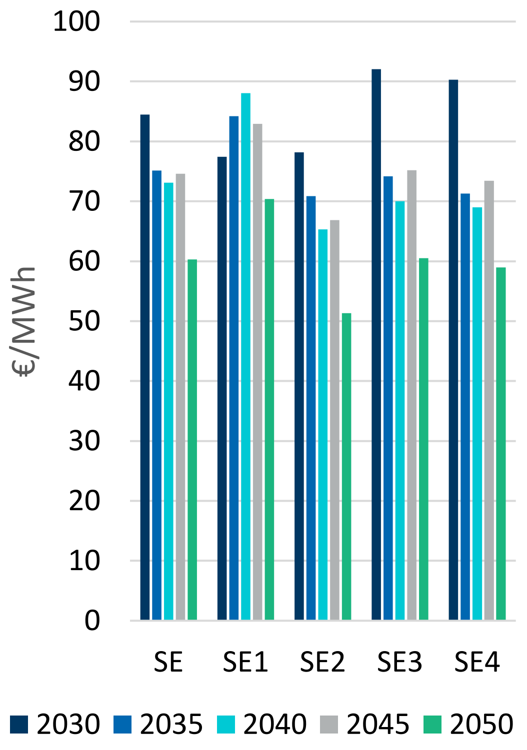


- A **higher hurdle premium results in more capital intensive technologies** being replaced by less capital intensive technologies. In 2030 and 2035, OCGTs are replaced by DSR and in 2040-2050, CCGTs are replaced by OCGTs.
- The resulting security of supply remains largely the same as in the baseline, ranging between 3 and 13 LOLE hours per year

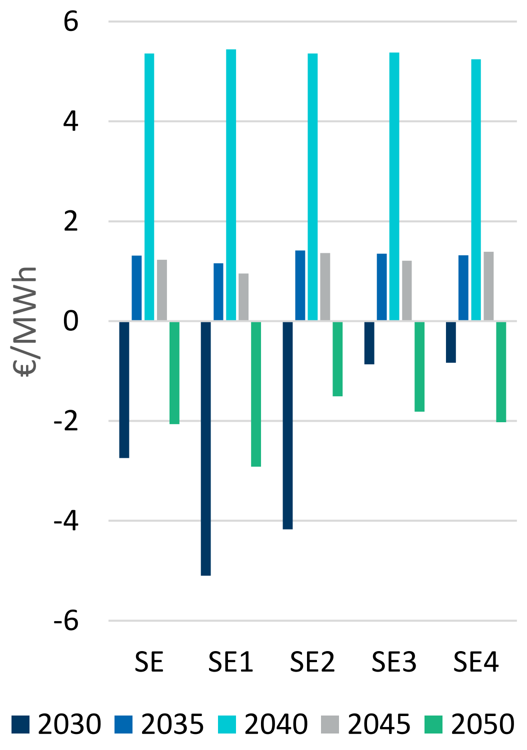
Impact on energy prices

Average prices in Sweden are generally higher in the DE/EF **8k EOM scenario** compared to the DE/EF EOM zone in Sweden

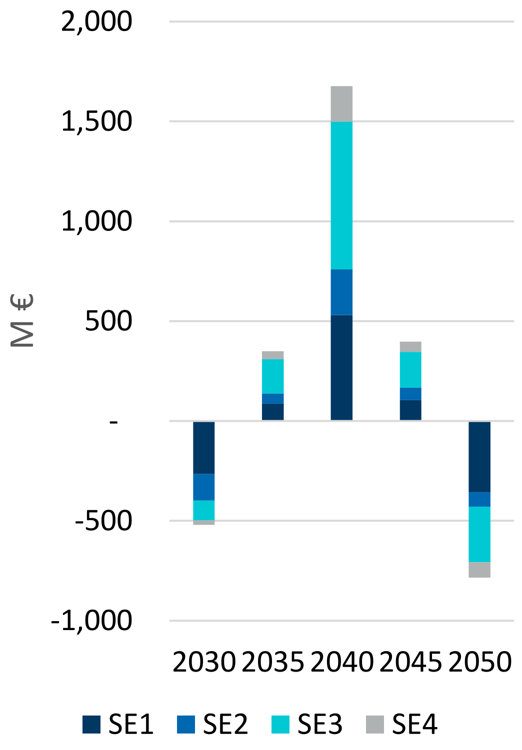
DE/EF 8k EOM: Baseload electricity prices [€/MWh]



DE/EF 8k EOM - DE/EF EOM: Baseload electricity prices [€/MWh]



DE/EF 8k EOM - DE/EF EOM: Customer's energy cost [M €]

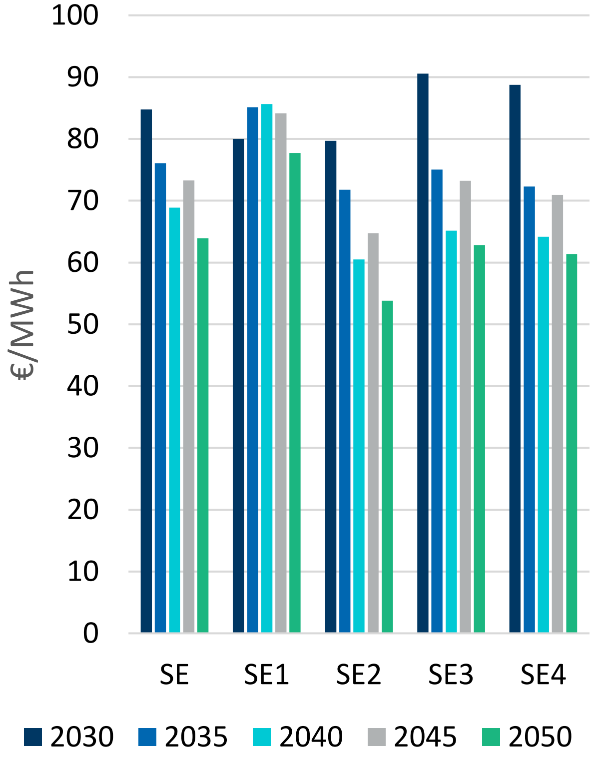


- Average prices in DE/EF 8k EOM are generally highest in 2035 to 2045 and lower in 2030 and 2050.
- The price difference is on average **0.62 €/MWh** and ranges from -2.74 €/MWh in 2030 to 5.36 €/MWh in 2040.
- The higher price for the 8k scenario can be explained by the higher number of hours above the counterfactual price ceiling in 2040 and 2045, leading to higher prices for the 8k scenarios.
- In addition, the higher number of DSR activations in the 8k model (**23 hours** in total across all bidding zones with **DSR installed**) contributes to **higher prices** in the **8k model**, while the **number of activation** hours in **2030** and **2050** are **closer to the counterfactual**.

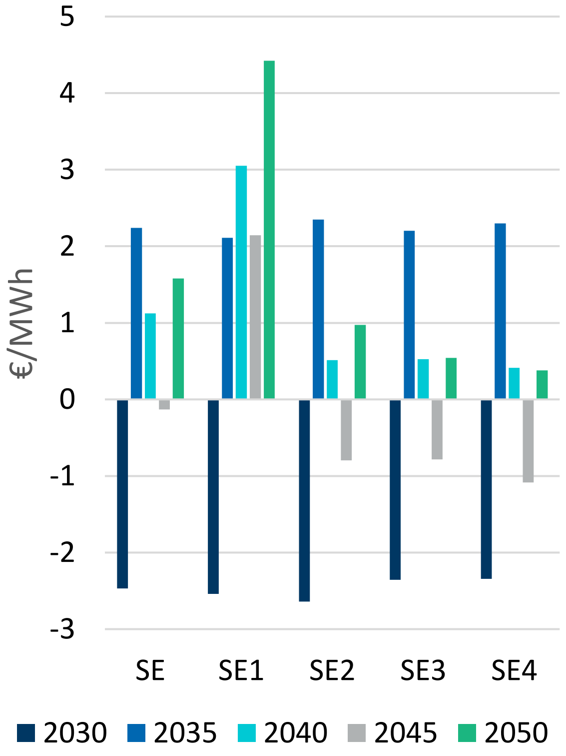
Impact on energy prices

Average prices in Sweden are generally higher in the DE/EF EOM **sensitivity with higher risk aversion** compared to the DE/EF EOM in Sweden

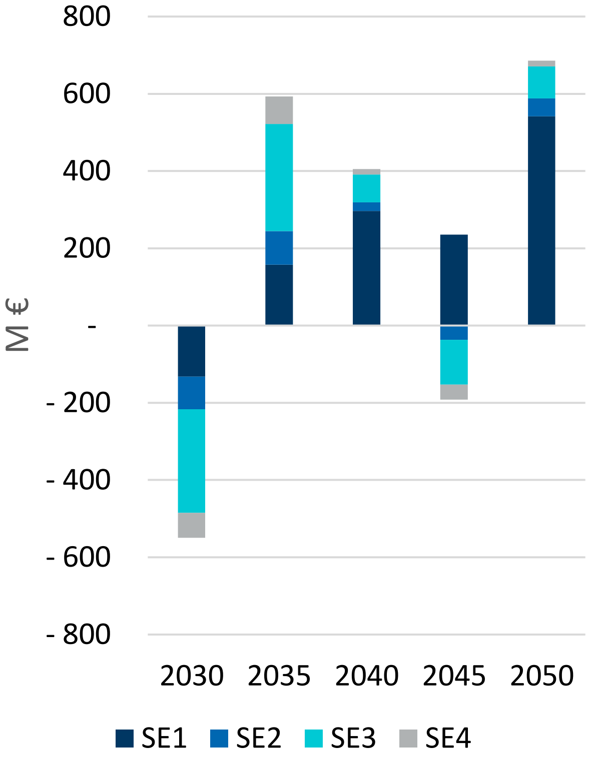
DE/EF EOM sensitivity: Baseload electricity prices [€/MWh]



DE/EF EOM sensitivity - DE/EF EOM: Baseload electricity prices [€/MWh]



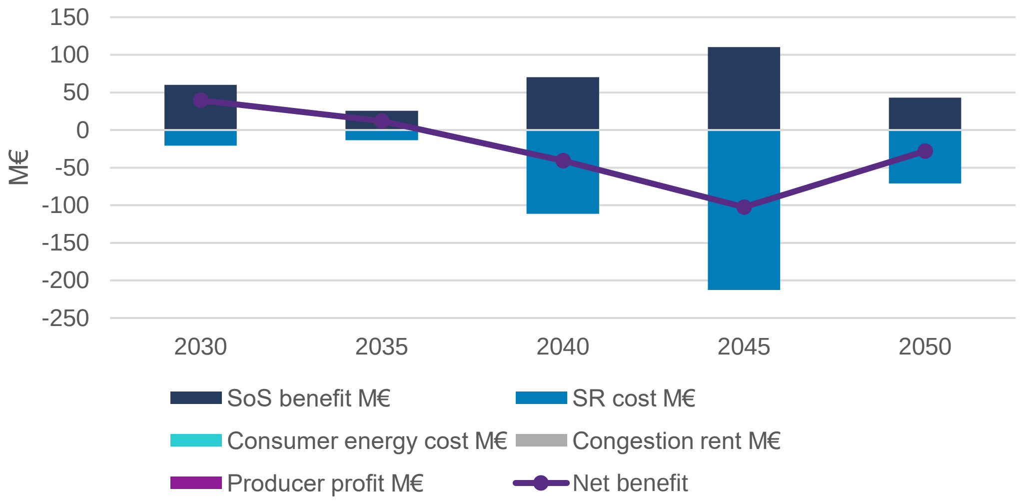
DE/EF EOM sensitivity - DE/EF EOM: Customer's energy cost [M €]



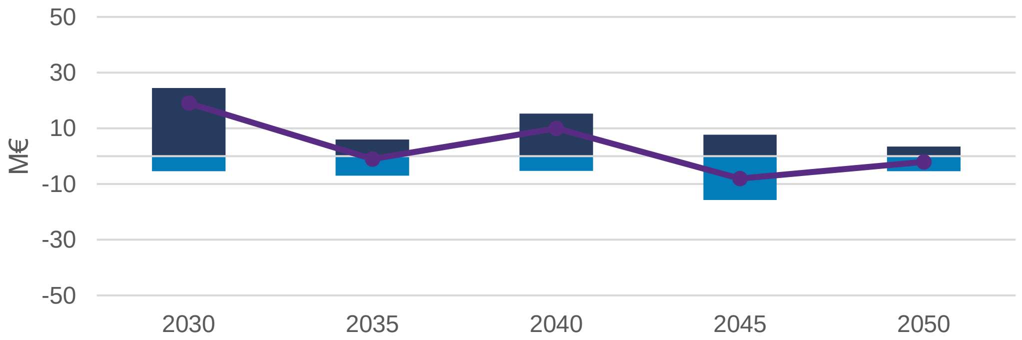
- Average price difference in Sweden is **0.47 €/MWh** and ranges from -2.47 €/MWh in 2030 to 2.24 €/MWh in 2035.
- While there is a drop in prices in 2030, mostly due to the substitution of OCGT by DSR, there is consistent increase in consumer's energy costs then after.
- The results imply that increasing investors' risk aversion leads to consumer's surplus reduction.

SR welfare effects: The greater Security of Supply (SoS) benefits of the SR outweigh the procurement cost in 2030 and 2035

DE: Consumer welfare impact of the SR, M€



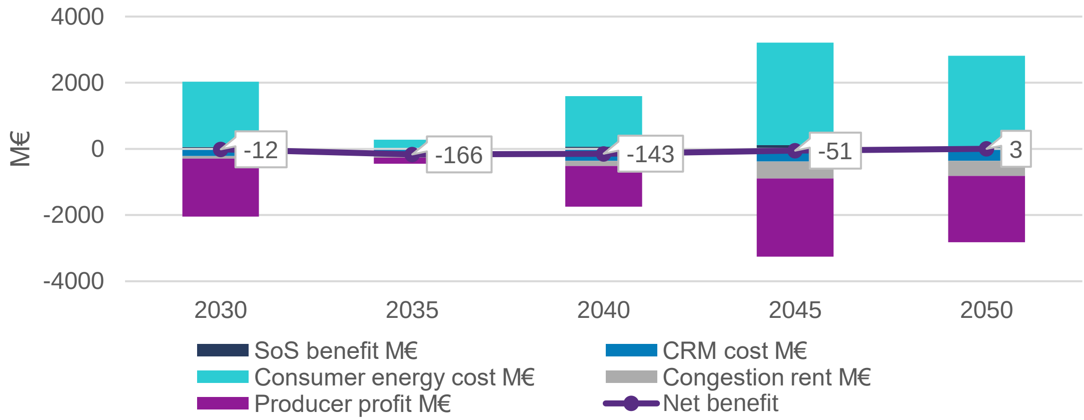
GA: Consumer welfare impact of the SR, M€



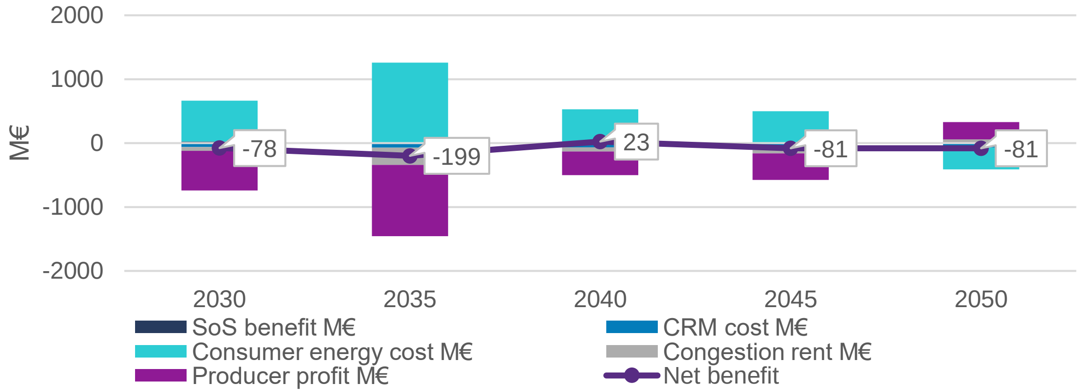
- **The welfare analysis of SR includes two components:** the SoS benefits and the SR procurement costs. Capacity not participating in the SR is assumed to operate the same as in the EOM with the identical market result, hence, with no other welfare impacts
- **The benefits of increased SoS in SR outweigh the costs between 2030 and 2040**
  - **Net benefit of 40M€ in DE/EF scenario and 20M€ in GA/EP scenario in 2030**
  - **Close to zero net benefit in 2035 in both scenarios**
  - **Net benefit of 10€ in GA/EP and net loss of 40M€ in DE/EF in 2040**
- The cost of procurement of the SR somewhat outweighs the benefits from the SoS improvements from 2045 in both scenarios
- **This is based on a simplifying assumption that the SR is efficient and has no other impact on the energy market**

CRM welfare benefits: The CRM is expected to create significant welfare re-distribution with an uncertain net effect

DE: Total welfare impact of CRM, M€

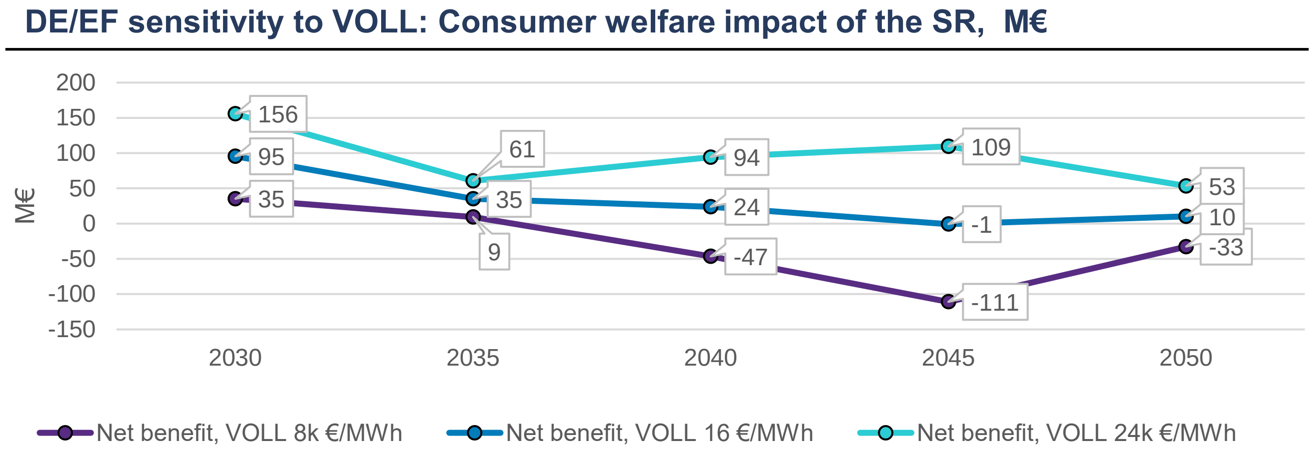


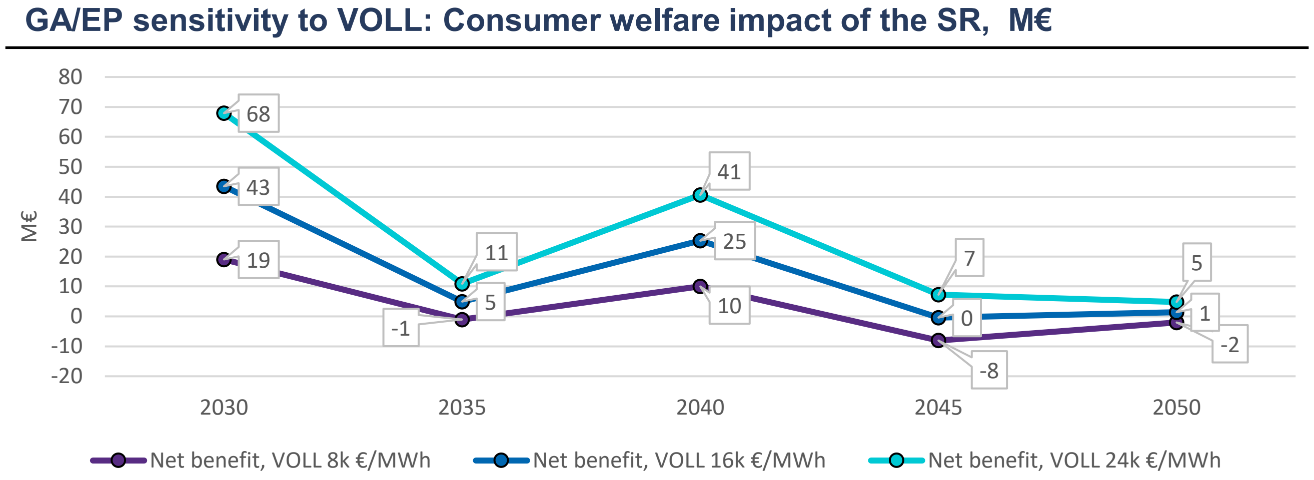
GA: Total welfare impact of CRM, M€



- In addition to the CRM procurement cost and SoS benefits, the CRM creates significant welfare re-distribution resulting from its long-term impact on the dispatch and reduction in energy prices:
  - An increase of the consumer benefit from the reduction of the cost of energy accessed at the hourly wholesale price
  - A reduction in the producer's benefits and congestion rents resulting from the reduction of the wholesale prices.
- **The CRM procurement costs outweigh the SoS benefits, especially depending on the eligibility of the CRM and the intermediate price caps for existing capacity**
- The total welfare combining the SoS benefits, CRM costs, energy costs and congestion rents, features **mainly net negative benefit of CRM in both the DE/EF and GA/EP scenarios.**

Higher VOLL estimation could lead to a positive SR's net welfare benefits

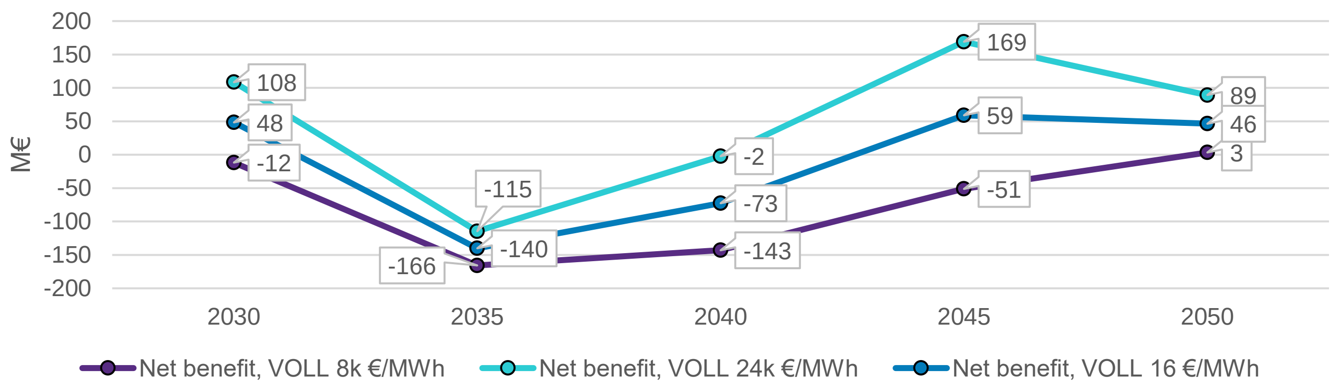




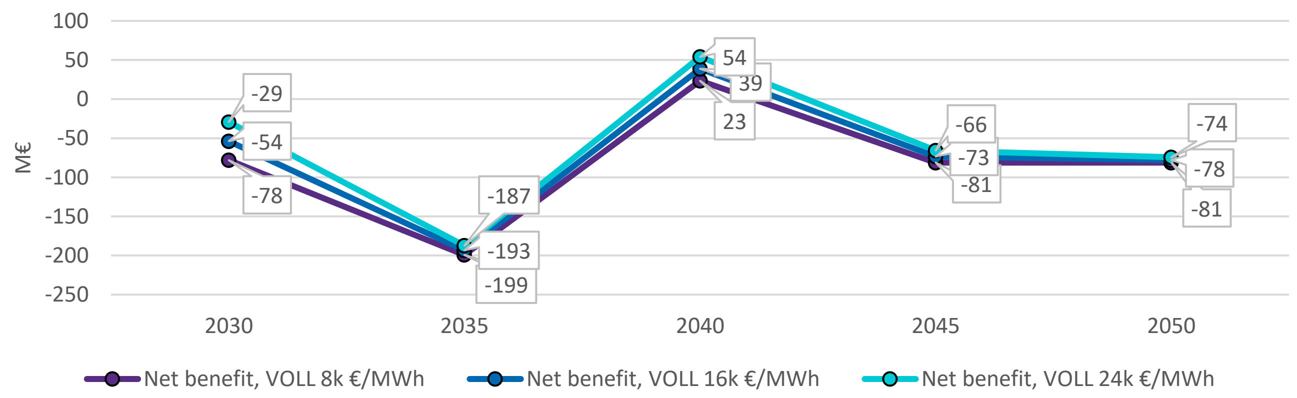
- The existing Swedish reliability standard of 1h is based on the value of loss load (VOLL) equal to approximately 8 000 €/MWh, which is one of the lowest in Europe.
- The sensitivity presented here shows how the net welfare benefit of SR changes with the variation of VOLL.
- Specifically, we test the impacts of increasing the VOLL from the current value of **8000 €/MWh** to **16 000 €/MWh** and **24 000 €/MWh**, essentially doubling and tripling the current VOLL in line with the average and the high European VOLL estimates.
- The impact of a higher VOLL translates into the net welfare via higher security of supply (SoS) benefit, since **electricity consumers' willingness to pay for the avoided outage is greater.**
- In case of the strategic reserve (SR), **the net benefit turns positive for all years** (except 2045 in DE/EF with slightly negative value close to zero) **and both scenarios** (DE/EF and GA) by doubling the current VOLL from 8 000 €/MWh to 16 000 €/MWh.
- Naturally, the net benefit further increases when tripling the current VOLL and it is positive in all years and the two scenarios (DE/EF and GA).

Higher VOLL estimation could increase the CRM's net welfare benefits

DE/EF sensitivity to VOLL: Consumer welfare impact of the CRM, M€



GA/EP sensitivity to VOLL: Consumer welfare impact of the CRM, M€



- Similarly to the SR net benefits, we test the impacts of increasing the VOLL from the current value of **8000 €/MWh** to **16 000 €/MWh** and **24 000 €/MWh**, essentially doubling and tripling the current VOLL in line with the average and the high European VOLL estimates.
- The impact of a higher VOLL translates into the net welfare via higher security of supply (SoS) benefit, since **electricity consumers' willingness to pay for the avoided outage is greater.**
- In case of the CRM in DE/EF scenario, the **net welfare benefit with the higher VOLL turns positive for some years**, namely 2030 and 2045, i.e. years with higher LOLE and therefore higher SoS benefits but remains negative for 2035 and 2040.
- However, the increased VOLL has only **a limited impact on the net welfare of CRM in GA/EP scenario**, mainly because the number of LOLE hours the mechanism is addressing is relatively low (max 4h nationally), which **does not outweigh the associated costs.**

5.

Key findings

Key messages: comparison of adequacy issues across scenarios

Adequacy outlook in the Energy-Only Market

- The modelling suggests that an Energy-Only Market could induce some investment in decarbonised gas capacity (CCGT and OCGT) and DSR, driven by occasional peak prices, assuming no risk aversion of investors. But price differentials are not sufficient to make large-scale storage commercially viable.
- However, the investment potentially induced in the EOM is insufficient to reach the Swedish Reliability Standard of 1 h/y LOLE and the EOM results in the lower adequacy reaching 15 h/y. This general result is robust to variations on the assumptions of the price cap and the investment hurdle rate.
- Adequacy issues occur in all years 2030-2050 and are slightly more present in SE1 zone in which significant inflexible demand from electrolysers is expected.

Comparison across scenarios

- Comparison across model scenarios suggests that the adequacy issues under the EOM market design option depend on the evolution of the need for flexibility in the system and development of demand flexibility.
- Adequacy issues are the most acute in the DE/EF scenario (with average annual LOLE reaching 15 hours/year), which assumes a phase-out of nuclear capacity and a considerable development of onshore and off-shore wind capacity, while assuming limited implicit flexibility of demand.
- Adequacy issues are relatively minor (average annual LOLE reaching 5 hours/year) in the GA/EP scenario, in which nuclear capacity is increased, and less onshore and off-shore wind capacity is developed
- Finally, the DE/EF scenario combined with the assumptions of a more flexible load allows reaching the LOLE target of the Reliability Standard within the EOM market design option.

Conclusions

- It follows that a Capacity Mechanism may be needed to ensure that the Swedish Reliability Standard of 1 hour LOLE per year is met, particularly when factoring risk aversion and in scenarios with less development of flexible demand.
- In parallel to the development of a Capacity Mechanism, policies supporting the development of explicit and implicit demand flexibility should be considered.

Key messages: Impact assessment of a Strategic Reserve (SR)

Reliability Standard

- The SR could allow to contract DSR and Large-Scale Battery Storage but would require to keep these assets out of the market, as these could only be activated in case of adequacy issues, leading to dispatch inefficiencies.
- Such capacity contracted through the SR could be sufficient to reach the Reliability Standard of 1 LOLE hour/year.
- Our modelling assumes that SR activation would not distort the EOM prices and thus, the same energy prices and investment incentives would apply to capacity that does not participate in SR.

Capacity mix and prices effects

- Compared to the EOM, SR features additional DSR and storage capacity that allow to reach the Reliability Standard.
- The zonal nature of SR allows to potentially also address locational adequacy issues in specific zones, in particular, more SR is procured in SE1 and SE3.
- Capacity of procured SR is 1-3GW in the DE/EF scenario and 0.3-0.9GW in the GA/EP scenario.
- Assuming the SR activation does not distort the EOM prices, our modelling considers no additional effects of the SR on prices and dispatch.

Welfare impact

- The welfare analysis of SR includes two components: the SoS benefits and the SR procurement costs. Capacity not participating in the SR is assumed to operate in the same way as in the EOM with the identical market result, hence, with no other welfare impacts.
- The benefits of increased SoS with the SR outweigh the costs between 2030 and 2040, however the magnitude is different across scenarios. In 2030, SR brings net benefit of 40M€ in DE/EF scenario and 20M€ in GA/EP scenario. Both scenarios result in the net benefit close to zero in 2035. Finally, in 2040, GA/EP scenario suggests net benefit of 10€, while DE/EF scenarios results in a net loss of 40M€.
- From 2045 onwards, the cost of procurement of the SR outweighs the benefits from the SoS improvements in both scenarios.
- Note that these results are sensitive to the VOLL estimation and would result in a consistently positive net benefit in case of VOLL values > 16,000€/MWh

Key messages: Impact assessment of a market wide CRM

Reliability standard

- A market-wide CRM can support development of DSR and Large-Scale storage, as well as decarbonised CCGT and OCGT gas capacity, whilst allowing this capacity to operate in the energy and ancillary services markets without dispatch distortions.
- Such capacity procured through the CRM would be set to ensure reaching the Reliability Standard of 1 LOLE hour/year.
- The capacity procured through the CRM also contributes to addressing regional scarcity through cross border energy flows. As a result, a larger volume of capacity needs to be procured by CRM than by SR to reach the Reliability Standard (assuming SR is not activated for regional issues contrary to the CRM).

Capacity mix and price effects

- Compared to EOM, CRM induces higher capacity of peaking technologies, mainly DSR. In both DE/EF and GA/EP scenarios, most DSR capacity is attracted in SE1 and SE3. In both DE/EF and GA/EP scenarios, 4 to 5GW of additional DSR is procured by the CRM as compared to EOM.
- The higher peaking capacity induced by the CRM reduces price spikes and makes CCGTs and OCGTs slightly less profitable. However, with increasing demand in the long-term and DSR potential reaching its limits, price spikes remain and incentivize more peakers.
- As a result of the impact on the capacity mix that participates in the energy markets, the CRM reduces the energy prices and the net imports in Sweden.

Welfare impact

- The CRM creates significant welfare re-distribution resulting from its long-term impact on the dispatch and reduction in energy prices:
  - An increase of the consumer benefit from the reduction of the cost of energy accessed at the hourly wholesale price;
  - A reduction in the producer's benefits and congestion rents resulting from the reduction of the wholesale prices.
- Based on the assumed low VOLL, the SoS benefits remain lower than the CRM procurement cost. However, a higher estimate of VOLL could result in a positive net benefit, especially in the DE/EF scenario and assuming low capacity remuneration of the existing capacity.

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